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U.S. Department
of Transportation
**Federal Transit
Administration**

Clean Air Program

Compressed Natural Gas Safety in Transit Operations

U.S. Department of Transportation
Research and Special Programs Administration
John A. Volpe National Transportation Systems Center
Cambridge, MA 02142-1093

October 1995
Final Report

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This report examines the safety issues relating to the use of Compressed Natural Gas (CNG) in transit service. The safety issues were determined by on-site surveys performed by Battelle of Columbus, Ohio and Science Applications International Corporation (SAIC) of McLean, Virginia of seven transit agencies using CNG. The survey consisted of: 1) extensive interviews; 2) review of records, procedures, and plans relating to safety; 3) examination of facilities and equipment; 4) observation of operations including fueling, maintenance, morning start-up, and revenue service; and 5) measurement of methane concentrations in the air where the buses are being fueled or stored. Interviews included all job categories associated with management, operations, safety, maintenance, acquisition, and support. In general, operations at the sites observed are safe. Some safety deficiencies were noted and are given. The surveys also included an examination of the occupational hygiene aspects of CNG use. Survey results showed differences exist from transit agency to transit agency on hazard and consequence mitigation measures such as: 1) methane monitoring in the facilities including procedures and action upon the detection of methane; 2) control of strong ignition sources including maintenance and storage facility installation of explosionproof electrical systems; 3) number of air exchanges per hour for facilities which hold buses; 4) fueling/defueling practices; and 5) emergency preparedness both for incidents within facilities and for buses in service.

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ENGLISH TO METRIC

LENGTH (APPROXIMATE)

1 inch (in)	= 2.5 centimeters (cm)
1 foot (ft)	= 30 centimeters (cm)
1 yard (yd)	= 0.9 meter (m)
1 mile (mi)	= 1.6 kilometers (km)

AREA (APPROXIMATE)

1 square inch (sq in, in^2)	= 6.5 square centimeters (cm^2)
1 square foot (sq ft, ft^2)	= 0.09 square meter (m^2)
1 square yard (sq yd, yd^2)	= 0.8 square meter (m^2)
1 square mile (sq mi, mi^2)	= 2.6 square kilometers (km^2)
1 acre = 0.4 hectare (he)	= 4,000 square meters (m^2)

MASS - WEIGHT (APPROXIMATE)

1 ounce (oz)	= 28 grams (gm)
1 pound (lb)	= 0.45 kilogram (kg)
1 short ton = 2,000 pounds (lb)	= 0.9 tonne (t)

VOLUME (APPROXIMATE)

1 teaspoon (tsp)	= 5 milliliters (ml)
1 tablespoon (tbsp)	= 15 milliliters (ml)
1 fluid ounce (fl oz)	= 30 milliliters (ml)
1 cup (c)	= 0.24 liter (l)
1 pint (pt)	= 0.47 liter (l)
1 quart (qt)	= 0.96 liter (l)
1 gallon (gal)	= 3.8 liters (l)
1 cubic foot (cu ft, ft^3)	= 0.03 cubic meter (m^3)
1 cubic yard (cu yd, yd^3)	= 0.76 cubic meter (m^3)

TEMPERATURE (EXACT)

[(x-32)(5/9)] °F = y °C

METRIC TO ENGLISH

LENGTH (APPROXIMATE)

1 millimeter (mm)	= 0.04 inch (in)
1 centimeter (cm)	= 0.4 inch (in)
1 meter (m)	= 3.3 feet (ft)
1 meter (m)	= 1.1 yards (yd)
1 kilometer (k)	= 0.6 mile (mi)

AREA (APPROXIMATE)

1 square centimeter (cm^2)	= 0.16 square inch (sq in, in^2)
1 square meter (m^2)	= 1.2 square yards (sq yd, yd^2)
1 square kilometer (km^2)	= 0.4 square mile (sq mi, mi^2)
10,000 square meters (m^2)	= 1 hectare (he) = 2.5 acres

MASS - WEIGHT (APPROXIMATE)

1 gram (gm)	= 0.036 ounce (oz)
1 kilogram (kg)	= 2.2 pounds (lb)
1 tonne (t) = 1,000 kilograms (kg)	= 1.1 short tons

VOLUME (APPROXIMATE)

1 milliliter (ml)	= 0.03 fluid ounce (fl oz)
1 liter (l)	= 2.1 pints (pt)
1 liter (l)	= 1.06 quarts (qt)
1 liter (l)	= 0.26 gallon (gal)
1 cubic meter (m^3)	= 36 cubic feet (cu ft, ft^3)
1 cubic meter (m^3)	= 1.3 cubic yards (cu yd, yd^3)

TEMPERATURE (EXACT)

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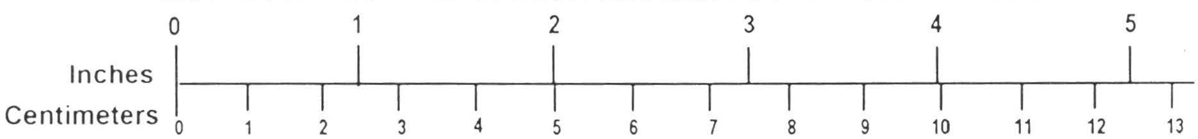

QUICK FAHRENHEIT - CELSIUS TEMPERATURE CONVERSION

°F	-40°	-22°	-4°	14°	32°	50°	68°	86°	104°	122°	140°	158°	176°	194°	212°
°C	-40°	-30°	-20°	-10°	0°	10°	20°	30°	40°	50°	60°	70°	80°	90°	100°

For more exact and or other conversion factors, see NBS Miscellaneous Publication 286, Units of Weights and Measures. Price $2.50 SD Catalog No. C13 10286

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PREFACE

In November 1992, the Volpe National Transportation Systems Center, in its support for the Federal Transit Administration's (FTA) Clean Air Program, initiated an industry survey of safety in transit agencies using Compressed Natural Gas (CNG) as an alternative fuel in bus operations. The results of that survey, presented in this report, examine the safety issues as determined from a survey of seven transit agencies using CNG. The on-site examinations were performed by Battelle of Columbus, Ohio and Science Applications International Corporation (SAIC) of McLean, Virginia. Each company visited different cities. Battelle surveyed four transit agencies and SAIC surveyed three agencies.

One of the conditions of this survey was that the individual transit agencies would not be individually identified in the final report. The survey was not intended as a safety investigation, but rather as an industry practices survey and determining problems at specific agencies was not the intent of the project. A parallel survey by the same contractors examined the use of Liquified Natural Gas (LNG) in transit service. The results of that survey are reported in a companion report.

Each contractor submitted summary reports to the Volpe Center which are reproduced in this document. Each contractor surveyed different agencies and presented their material somewhat differently, although many of the observations and conclusions are similar. Both reports are generally consistent in the hazards which they describe. However, readers should examine both as the two complement each other.

> **In both reports, Battelle and SAIC, along with observations and evaluations, present recommendations and conditions which they consider should be followed to provide safe use of CNG in transit operations. They both also note that local fire and other code officials have final approval authority. <u>The Federal Transit Administration has no facility regulatory authority.</u>**

Appreciation is given to the transit agencies which permitted their activities to be reviewed and to their personnel for the time and effort given in cooperating with the survey teams. In conducting the site visits, Battelle was assisted by Gannett Fleming of Harrisburg, PA, and Technology & Management Systems, Inc., of Burlington, MA. SAIC was assisted by STAR Environmental of Torrance, CA., and PAI, Inc. of Falls Church, VA. Providing program guidance were Vincent DeMarco and Steven Sill of the Federal Transit Administration. William Hathaway of the Volpe National Transportation Systems Center provided technical safety direction. Overall review of the project and preparation of this report was provided by David Knapton of the Volpe Center.

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EXECUTIVE SUMMARY

The Clean Air Program was established by the Federal Transit Administration (FTA) to support the national goals of reducing both vehicle emissions and petroleum imports. In its dual role of promoting transit and of encouraging safe operations, the FTA established an alternative fuel bus demonstration program and an industry survey of safety practices in transit agencies using alternative fuels. An earlier survey conducted in cooperation with the National Institute for Occupational Safety addressed the occupational health and safety of fueling, maintenance, and operation of methanol-powered transit buses[1]. The study reviewed in this report examines the safety issues of Compressed Natural Gas (CNG) buses as determined from a survey of seven transit agencies using CNG in revenue operations. The review was performed by Battelle of Columbus, Ohio and Science Applications International Corporation of McLean, Virginia. One of the conditions of this survey was that the individual transit agencies would not be individually identified in the final report. The survey was not intended as a safety investigation, but rather as an industry practices survey and determining problems at specific agencies was not the intent of the project. A parallel survey by the same contractors examined the use of Liquified Natural Gas (LNG) in transit activity. The results of that survey are reported in a companion report[2].

The individual surveys consisted first of an agreement with each agency to allow the FTA and its contractor to perform the survey. A survey plan was then designed and submitted to the agency. The site visit began with a briefing of objectives and discussion between the team and the transit agency. This allowed the scope of the survey to be understood by both parties, a schedule of specific interviews to be established, and an opportunity for determining the components of the system to be examined. The survey team consisted of one or two FTA representatives, the contractor with three investigators, and several subcontractor and consultant specialists selected by each contractor. Each on-site survey took three or four days. At the completion of each survey the contractor reported their observations to the transit agency. The survey itself consisted of: 1) extensive interviews; 2) review of records, procedures, and plans relating to safety; 3) examination of facilities and equipment; 4) observation of operations including fueling, maintenance, morning start-up, and revenue service; and 5) measurement of methane concentrations in the air where the buses are being fueled or stored. Interviews included all job categories associated with management, operations, safety, maintenance, acquisition, and support. The observations were submitted to each agency in the form of trip reports, allowing the agency to correct any factual errors and to suggest any differences in interpretations of safety practices.

At the present time there are over 700 CNG powered transit buses in operation in this country. CNG buses have performed well and have achieved acceptance by the public.

CNG is composed primarily of methane. The pipeline gas is supplied to the transit agency at 30-500 psi and is then compressed to 3500-4000 psi and stored in tanks for dispensing to the vehicle or is directly fueled into the CNG cylinders on the bus. CNG is available to most existing transit agencies in most major U.S. cities without large scale expansion of distribution systems.

CNG is not inherently more dangerous than conventual fuels. However, it is different and the differences can create hazards for personnel unfamiliar with its properties. It is a gas and under most conditions is lighter than air. Hence, it tends to rise although under some conditions CNG from high pressure leaks may be cooler than air and will sink to the lowest available surface. It is carried on buses under high pressure and creates the dangers of potential high pressure failures. Hazards relating to CNG are fire (a fully fueled bus contains 16,000 standard cubic feet of gas), asphyxiation by displacing oxygen from victims, and high pressure danger resulting from high pressure explosive failure. Ignition can come from contact with hot surfaces, open flames, and sparks, including static electricity.

Safety of the CNG activity at the sites was evaluated by comparing the survey team's observations with a combination of criteria, such as adherence to national codes and their interpretation, practices and lessons learned by the survey team from observations at other sites, and the combined experience of the team in transit and industrial safety and occupational health. In general, operations at the sites observed are safe. Transit authorities have made significant strides to build an infrastructure for safe operations with CNG. Some safety deficiencies, however, were observed and are noted in the report. Most workers involved with CNG are motivated and concerned about safety. The surveys also included an examination of the occupational hygiene aspects of the CNG use. With the exceptions of high CNG compressor noise levels at some agencies and of some unvented fueling nozzles, the work environment at the facilities was good.

No one site was found to be best in all safety aspects of CNG operations. Wide differences exist from transit agency to transit agency on hazard and consequence mitigation measures such as: 1) methane monitoring in the facilities including procedures and action upon the detection of methane; 2) control of strong ignition sources including maintenance and storage facility installation of explosion-proof electrical systems; 3) number of air exchanges per hour for facilities which hold buses; 4) fueling/defueling practices; and 5) emergency preparedness both for incidents within facilities and for buses in service. In general, a problem for the transit industry in converting to CNG operations is a lack of technical and procedural guidance. Each transit agency has had to learn from start of their CNG program and to profit from their own experience. Creation of a fire code to cover conditions not covered by existing codes is needed by the transit industry.

One of the most important resources in safe operations is a clear understanding by employees of the CNG hazards, knowing and following safe practices, and understanding and remembering proper emergency response procedures. More and better training is almost a universal need.

Unresolved issues that were identified during the survey that transit agencies should consider are: 1) code coverage and interpretation and building and equipment standards; 2) gas detection, including the location of detectors, reliability and calibration requirements, and response of remedial action; 3) the path, concentration, and duration of escaped gas, including the issue of density relative to air for all conditions; 4) the hazard of interior facility formaldehyde buildup with large fleets (formaldehyde was detected during the survey); and 5) actual risks associated with the hazards to more clearly identify the safety and costs associated with the hazard mitigation options that the industry faces.

1. "Industrial Hygiene Survey Report of Seattle Metro, Ryerson Base," Greg Piacitelli, National Institute for Occupational Safety and Health, Report Number 163.2.01, August 10, 1990.

2. "Liquefied Natural Gas Safety in Transit Operations," Report No. FTA-MA-90-7007-95-3, SAIC & Battelle, October 1995.

SECTION I

ALTERNATIVE FUELS IN TRANSIT OPERATIONS: COMPRESSED NATURAL GAS SITE SURVEYS

Battelle
Columbus, Ohio

1. INTRODUCTION

In recognition of the increasing need to more fully understand the modifications in transit facilities and transit operations required for the safe and effective use of alternative fuels, the Volpe National Transportation Systems Center (Volpe Center) has established a program for the Federal Transit Administration (FTA) that addresses such issues. With an increasing number of transit systems operating alternative fuel fleets in response to urban air quality issues, this program is intended to provide information needed for the safe and effective use of alternative fuels in transit.

This report is an account of surveys conducted at four sites using Compressed Natural Gas (CNG) as an alternative fuel for transit buses and other vehicles. CNG is natural gas that is stored on the vehicle in gaseous form at high pressure (up to 25 MPa, 3600 psi). The high fuel pressure requires special precautions for safe handling both in the vehicle and within transit bus storage, maintenance, and fueling facilities.

Natural gas is comprised principally of methane, with minor amounts of ethane, propane, butane, carbon dioxide, and nitrogen. Natural gas itself is colorless, odorless, and tasteless, but is required to be odorized so that a person can smell it at a concentration of 1/5 of the lower flammability limit. Natural gas at normal temperature and pressure has a density relative to air of only about 0.6, meaning that natural gas is considerably lighter than air. When mixed with air (at from 5 to 15 percent by volume) and exposed to an ignition source, the fuel will burn, and, if the mixture is fully or partially confined, an explosion will occur.

1.1 METHODOLOGY

The survey method included: site visits of several days; intensive interviews with transit personnel at various levels in each organization; observation of facilities and operational procedures for compressing, dispensing, and otherwise handling CNG in transit operations; and on-site measurements for ambient levels of CNG, formaldehyde, and noise. The survey team consisted of personnel from Battelle, Gannett Fleming, and Technology & Management Systems.

1.2 FINDINGS

The surveys revealed that, in general, CNG buses perform well and have achieved public acceptance. However, as an integral part of the site assessments, each aspect of the CNG operations at a given site were compared with the operation of other CNG transit sites, as well as with national standards and safety engineering practice.

No one site was found to be best in all aspects of CNG operations. For example, in some facilities, ignition sources were found near the ceiling or in areas where natural gas could be present. However, other facilities have successfully eliminated these ignition sources and/or implemented a strategy of methane sensor systems to warn of gas accumulation, along with electrical system controls to automatically disable ignition sources and ventilation exhaust to purge ceiling areas of fuel.

Workers involved with CNG operations generally appeared highly motivated and interested in safety, but the sites varied widely in the type of training provided, the amount of CNG safety information available on the shop floor, and the amount of objective knowledge attained. Although comprehensive information addressing all of the issues related to the processes of fueling, operating, maintaining, and responding to emergencies should be available in the work place, several cases were found where written procedures for certain CNG operations were not easily accessible. At other locations, redundant availability of written procedures for CNG fueling was standard, but emergency procedures for drivers and/or mechanics were not available. Sometimes comprehensive training and procedures manuals existed, but they were not fully appropriate to the intended audience.

The surveys also included an examination of the occupational hygiene aspects of CNG use. With a few exceptions, such as some high compressor noise levels and some unvented fueling nozzles, the work environment at the facilities was quite good.

1.3 REQUIREMENTS FOR SAFE CNG OPERATION

Based on surveys of the four sites, the following safety issues are of the greatest significance in planning and operating CNG transit systems:

- **Training of operating staff.** One of the most important resources in providing safe working conditions is the provision for a clear understanding by operating staff of the properties of CNG fuel and the proper procedures to follow when using or maintaining CNG vehicles and equipment. Both safety and operational information should be available in a form transit employees readily understand at accessible work place locations. Formal training updates should be given periodically and an institutional mechanism established for experienced personnel to share their CNG fuel experiences with less experienced staff.

- **Control of strong ignition sources.** Strong ignition sources should be removed from areas where CNG buses are stored, maintained, or fueled. Of primary concern are strong overhead ignition sources such as open flame gas heaters, motor starters on fans and door openers, and other spark-producing electrical equipment (electric bug zappers, etc.).

- **Alarms and other warning systems.** Warning systems consisting of combustible gas sensors and an alarm system should be installed in all CNG facilities. These systems can warn of potential hazards even when personnel cannot detect a fuel buildup or when personnel are not present. These warning systems can be configured to independently increase ventilation rates to more quickly remove any gas buildup and to disable potential ignition sources. Maintenance and testing programs for such alarm systems should be in place and implemented.

- **Facility ventilation.** Preventing gas buildups in CNG facilities is one of the primary methods of reducing potential fire hazards. Facility ventilation requirements are significantly different for CNG vehicles than for diesel- or gasoline-fueled vehicles, and ventilating ceilings and high areas is especially important.

1.4 REMAINING ISSUES AND TOPICS

Several relevant questions outside the scope of this study have yet to be fully resolved, including the complex issue of code coverage and interpretation, appropriate building and equipment standards, and the best methods for training and certifying transit employees in the use of CNG as a transit fuel. In addition, the following technical issues must be resolved as the results of additional safety research become available:

- More information is needed on the successful deployment and use of combustible gas detectors within transit facilities, including the number and location of detectors and periodic calibration requirements. Moreover, detector response time must be consistent with the time required to implement remedial actions.

- If tests being conducted by the FTA confirm that CNG releases can result in the formation of a dense gas plume, the findings will affect the basic philosophy of CNG bus facility design and operation, including the location of combustible gas detectors and the type of emergency response actions.

- Formaldehyde buildup with bus storage facilities during morning pull-out should be monitored as the CNG fleet size increases within a given facility.

- A system safety and hazard assessment analysis needs to be performed to more clearly identify the relative safety implications of the choice of fuel tank location on the bus (underfloor tanks versus roof-mounted tanks). This safety assessment should include the piping and valves associated with the fuel tanks.

1.5 REPORT FORMAT

This report presents an assessment of current practice and a summary of basic principles and general recommendations for the safe operation of CNG transit programs. The recommendations are based on information gathered and lessons learned from the transit sites surveyed, as well as on prevailing practices in industrial engineering, safety, and risk management. The report includes discussion and recommendations on CNG facility design, fueling, maintenance, vehicle storage, buses, operations, special concerns, emergency planning, management and safety awareness, and training.

2. TRANSIT SYSTEMS USING CNG

2.1 DEMONSTRATION PROGRAMS

The FTA has encouraged the transit industry to gain experience with alternative fuels by establishing the Clean Air Program (CAP) and the Alternative Fuels Initiative (AFI). Under this initiative, financial grants were provided to transit agencies to test a wide variety of alternative fuels. These grants were made to purchase alternative fuel buses and, when necessary, modify or install new fueling facilities, maintenance areas, and storage areas. CNG is one of the most popular alternative fuels with the transit agencies and currently receives a great deal of federal funding.

2.2 CONVERSION TO CNG

CNG buses are 1,000 to 3,000 pounds heavier (depending on length and number of fuel tanks) than diesel buses of the same length. Adding CNG buses to some routes, therefore, may be difficult due to weight restrictions on roads. However, new and lighter composite tanks may soon be approved and available for CNG buses.

As the transit industry (including suppliers of equipment and operators) gains experience in the use of CNG buses, the commitment to CNG as an alternative fuel becomes far less difficult. Early AFI programs faced the compound problems of newly developed engines and fuel systems (which affected vehicle reliability and availability), inadequate employee training materials, and facilities designed for traditional fuels. The CNG support industry has quickly matured, however. Currently, several major engineering equipment firms can supply the expertise and hardware necessary to convert a transit facility to CNG. The past experiences of these firms are important, and a transit agency considering converting to CNG should secure the services of companies skilled in this area.

2.3 CNG FUELING FACILITY

The major components of a CNG fueling and fuel storage facility are shown in Figure 1-1, which illustrates the way natural gas is received from the local distribution company, processed, filtered, dried, compressed, and dispensed to the fuel containers on transit buses. Although some time-fill (slow-fill) operations are also being conducted in the AFI, most transit agencies demonstrating CNG will utilize a fueling strategy similar to Figure 1-1 that can fast-fill a bus in approximately five minutes.

At a typical CNG fueling facility, natural gas is received from a local gas distribution company and goes through a pre-filter, an inlet dryer, and another set of low pressure filters before being compressed. Large reciprocating compressors are used to provide sufficient flow of compressed gas to fast-fill transit buses during the evening fueling shift. High-pressure cylinders (usually ASME pressure vessels) act as buffer storage to allow a more continuous operation of the compressors. The high pressure gas is fed through a fuel meter and dispenser and, finally, through a flexible hose to the fueling nozzle.

2.4 MAJOR OPTIONS AND DECISION POINTS FOR PLANNING A CNG TRANSIT SYSTEM

Any alternative fuel presents a safety challenge to the transit system interested in using it, as well as to local code officials. Building codes have not been rewritten to account for the range of alternative fuels now being used or considered for use by transit systems. This creates a dilemma for local fire marshals or local building code enforcement officials, who are the ultimate authorities for approving alternative fuel facility designs and operating plans. These officials should be involved as early in the facility planning and design process as possible to avoid unnecessary delays and the potential for misunderstanding. By involving local officials early, it is possible to provide education and documentation that addresses and reduces risks in facility planning and design, as well as to learn about local requirements and concerns.

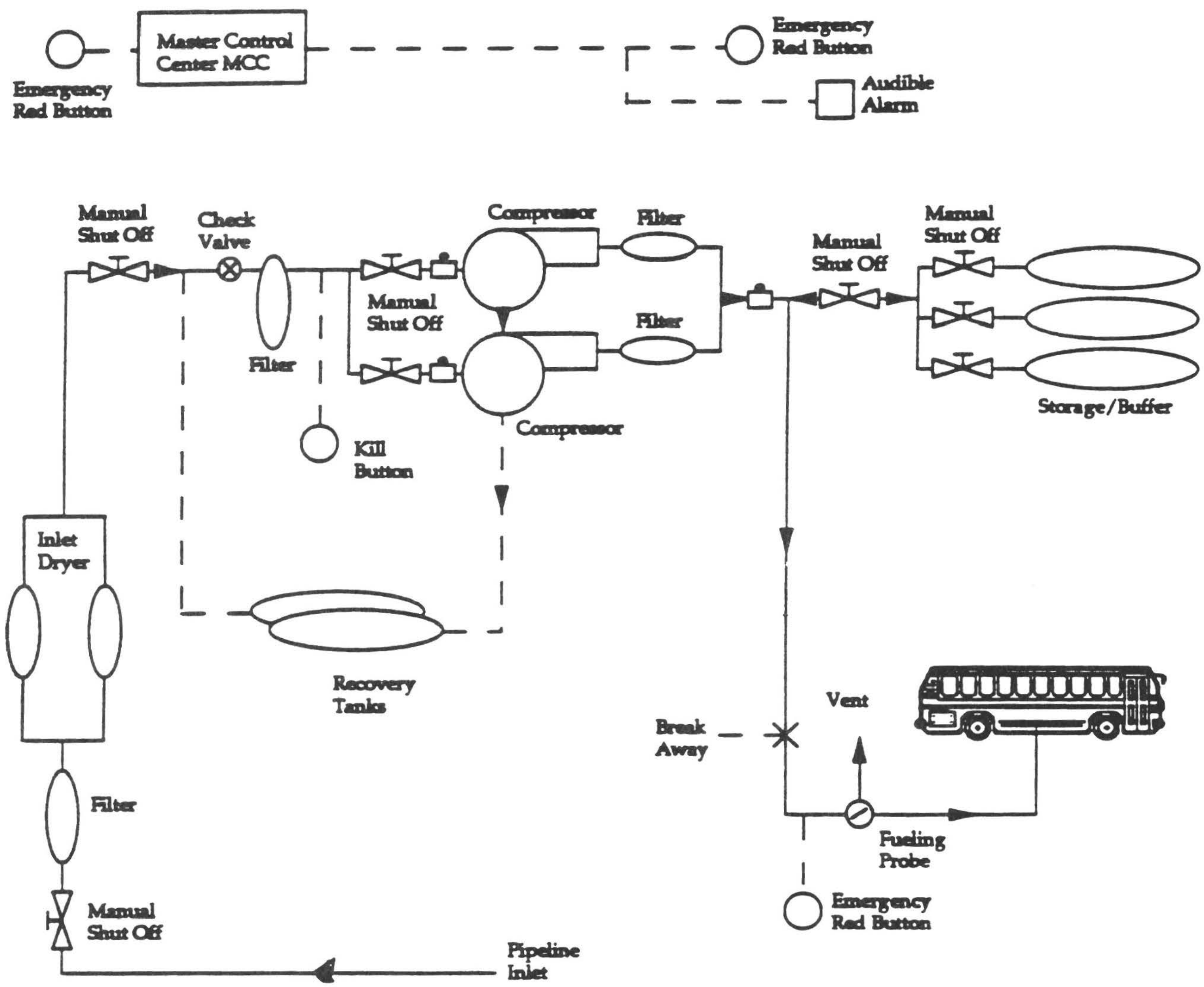

Figure 1-1. Schematic of CNG Fueling Facility

Principal contacts that should be made in determining how a CNG transit operation should be implemented include:

- A consultant skilled in analyzing both the needs of transit operations and all alternative fuels. A comparison of several options with current operation is often desirable.

- An architect and engineering firm with previous experience with CNG facilities, fueling operations, and a relationship with local codes and their enforcement.

- The local fire marshal.

- Fuel suppliers, which may include the local gas utility and wholesale producers.

Often a CNG program will include a demonstration or pilot phase where five or ten buses are operated for several years. If the pilot program is successful and/or if mandates require a switch to an alternative fuel, a phase-in strategy must then be formulated. The entire conversion could take more than 15 years and require conversion or modification of all facilities, replacement of all principal vehicles, and operation of a "mixed" fuel fleet for a number of years.

3. PROPERTIES OF COMPRESSED NATURAL GAS

3.1 PHYSICAL PROPERTIES

Natural gas is a mixture of several gases forming a fuel that can be used in homes for cooking and heating and can also be used to power most types of vehicles. As an example, one typical natural gas is composed of: 93 percent methane; 3.8 percent ethane; 1.5 percent propane; and smaller quantities of butane, pentane, hexane, CO_2, N_2, and water vapor. The water vapor is generally removed from the natural gas before compression because it can have a negative effect on fast-fill operations and fuel tank life.

3.2 DISPERSAL AND IGNITION

At normal ambient atmospheric temperature and pressure, natural gas is lighter than air and will rise to the ceiling if released indoors. This is quite unlike conventional liquid fuels such as gasoline, propane, and diesel whose vapors are heavier than air and fall to the floor. This unique physical property causes concern since it is not addressed by current facility building codes.

Moreover, the dispersion behavior of natural gas released from the high pressure inside a CNG cylinder may be quite different from natural gas that escapes from a building heating supply pipe at relative low pressure. The depressurization of the gas as it leaves the cylinder results in rapid gas expansion and cooling. Thus, the gas emanating from the cylinder will be very cold and may be more dense than air. Such dense gas will disperse close to ground level for a significant duration and distance from the release point. Experimental tests simulating realistic CNG releases from a bus fuel tank need to be performed to further explore the magnitude and extent of this effect. If the tests confirm that CNG releases can result in the formation of a dense gas plume, the findings will affect the basic philosophy of CNG bus facility design and operation including the location of combustible gas detectors and the type of emergency response actions.

Natural gas ignites only when the gas-to-air ratio is between 5 and 15 percent by volume. It has an ignition temperature of about 450 C, while gasoline ignites at about 300 C. The ignition energy of natural gas, like that of other hydrocarbons, is relatively low. For an optimum mixture and geometry, about 0.3 millijoules (milliwatt-seconds) of energy is required for ignition. Static discharges can easily generate several times this amount of energy.

4. CNG TRANSIT FACILITY DESIGN

As mentioned above, one of the factors used for assessing transit facility design was applicable codes and standards. At this time, no national, state, or local building codes exist that are specifically written for CNG transit fueling, maintenance, or storage facilities. The National Fire Protection Association (NFPA) 52 fire code covers CNG dispensing facilities, but does not cover vehicle maintenance or storage areas.

The most applicable codes are the fire safety codes promulgated by the NFPA. In addition, certifications of equipment by the American Gas Association (AGA) apply, but only with respect to gas dispensing equipment, fittings, etc. These codes are not specifically addressed because they are either part of equipment design or are incorporated by reference in the NFPA codes. Specific NFPA codes that may be at least partially applicable include:

- NFPA 30A - Automotive and Marine Service Station Code
- NFPA 52 - Compressed Natural Gas (CNG) Vehicular Fuel Systems
- NFPA 54 - National Fuel Gas Code
- NFPA 58 - LP - Gas Storage, Use
- NFPA 69 - Explosion Prevention Systems
- NFPA 70 - National Electrical Code
- NFPA 88A - Parking Structures
- NFPA 88B - Repair Garages
- NFPA 91 - Exhaust Systems for Air Conveying of Materials
- NFPA 497A - Classification of Class I Hazardous (Classified) Locations for Electrical Installations in Chemical Process Areas
- NFPA 497M - Classification of Gases, Vapors, Dusts for Electrical Equipment in Hazardous Locations.

Although several of the codes listed above may not directly apply, information provided in these codes can be valuable during the evaluation of design issues for which no specific code exists. They also support design decisions based on engineering judgment. Because of possible design liability, many A&E firms consider it prudent to evaluate facilities based upon *conservative* interpretations of the codes they consider relevant, particularly where extensive long-term implementation experience is lacking.

For transit CNG fueling facilities, the NFPA 52 fire code covers equipment used for the compression, storage, and dispensing of compressed natural gas. Most sites used and followed the provisions of NFPA 52 for the design of the natural gas compressing and fuel dispensing facility.

At this time no national, state, or local codes are specifically directed at CNG transit bus storage and maintenance facilities. Design engineers must interpret and apply such codes that do exist. NFPA 88A and 88B are two such existing codes that could be used as a starting point. The difficulty is that 88A and 88B are directed toward gasoline, which has vapor that is heavier than air, and do not consider vapors that are lighter than air, such as natural gas. NFPA 70, as well as the provisions and examples of NFPA 497A, are also helpful for determining proper electrical classification.

Because not enough transit facilities have used natural gas long enough to establish a long-term safety record for this fuel, a reasonable, responsible, and prudent philosophy should be used as the basis for a facility design that protects both life and property. Several design engineering strategies that are currently being used for facility modifications are reviewed in detail below.

4.1 DESIGN STRATEGIES

We have identified four distinct schools of thought on the application of the NFPA codes to CNG facilities. This range of options is particularly significant when addressing the modification of existing transit facilities to accept CNG-fueled vehicles. Although all four schools of thought have some validity, our surveys of CNG sites indicate that the fourth school now has the greatest currency. Our engineering analysis also indicates that this strategy has most relevance now when CNG vehicle technology is currently so young; the other approaches may be more appropriate as the technology becomes more mature and designers and code officials have available a demonstrated track record of successful implementation.

Complete Fuel Containment Approach

The first school of thought is based on an analogy to a comment in NFPA 58 code for propane, which says that propane-containing pipes and containers without valves, etc., do not require classified electrical systems. This school of thought assumes that the flammable gas (in this case CNG) is and always will be completely contained in pipes and tanks. Under this design strategy, conventional facilities would be adequate for both servicing and storing CNG buses. This strategy currently is being demonstrated at two major CNG transit agencies. No problems have been reported and no major CNG fuel releases have been encountered in these facilities. However, the total nationwide CNG bus experience to date indicates that numerous unanticipated accidental releases of natural gas have occurred in CNG transit fleets, many as the result of Pressure Relief Device (PRD) failures.

Omnipresent Ignition Sources Approach

The second school of thought holds that although releases of natural gas may occur, ignition sources are normally present in these areas as an inevitable part of the operations. Therefore, classified electrical and/or explosion-proof systems (heating equipment, switches, and motors) need not be used because there would be no point. That is, it would add nothing to safety. Again, several major transit agencies have opted for this strategy, with one incident reported - Sunline Transit, December 1994.

Strict Adherence to NFPA 70 Approach

The third school of thought is that a strict interpretation of NFPA 70 should be followed. NFPA 70 designates as Class 1, Division 2, areas where a flammable gas that is normally contained could be accidentally released. For reference and comparison, review and interpretation of NFPA 70 (the National Electrical Code), Articles 500 and 501, show the following:

- Article 500 of NFPA 70 defines atmospheres containing compressed natural gas as Class 1, Group D, areas.

- Properties, uses, and tasks typically taking place or reasonably expected to take place in vehicle storage and vehicle maintenance areas dictate that they are Class 1, Division 2, areas as defined in Article 500 of NFPA 70, and that they are subject to the requirements, recommendations, and standards set forth in Article 501. Since each CNG bus has several pressure relief devices, a CNG fleet has numerous possible discharges into the space.

- This interpretation is amplified in NFPA 497A, which states that classified electrical is required if any pressure relief valve discharges are located within the area. Since each CNG bus has several pressure relief devices, a CNG fleet has numerous such discharges into any space where CNG buses are parked.

Clearly this third approach is conservative, but may be justified if the frequency of natural gas releases is or is expected to be relatively high.

Modified NFPA 70 Approach

The fourth approach modifies the strict interpretation of the third school to take into account some of the technical information available about the ignition process for flammable gases. This approach would require that "strong" or continuous ignition sources always be removed whereas certain "weak" and incidental ignition sources may remain. This approach has appeal because:

- The issue of major fuel releases within the facility would be addressed by a responsible plan.

- It is believed that current combustible gas sensor technology has the capability and response time to provide shutdown of electrical equipment upon the accumulation of gas from minor leaks, provided the sensors are located strategically to sense methane vapors from a CNG leak in a timely manner.

- Expensive facility modifications, principally classified wiring and equipment, would be reserved to address items that are clearly ignition sources.

In this context, "strong" ignition sources are those that are sufficiently energetic to have a high probability to cause immediate ignition of a natural gas-air mixture. Examples would be open pilot lights, operating gas- and oil-fired open-flame heaters, and high wattage or inductive load electrical contacts.

On the other hand, "weak" ignition sources would include computers, telephones, exit lights, test equipment, and other low-wattage electrical devices.

The technical basis for this approach is the observation that though the minimum ignition energy for methane and other gases is quite low about 0.3 millijoules (milliwatt-seconds), the practical energy necessary for ignition in a less than optimum geometry is much higher. One study performed by Arthur D. Little for the Gas Research Institute* lists experimental results that show that only electrical contacts that carry a resistive load of 640 watts or more or activate motors 1/4 hp or greater will ignite natural gas clouds with a high probability, while lesser loads do not easily cause ignition in normal electrical contact geometries. As a practical matter, a factor of safety of two or three should be applied, leading to the conclusion that electrical contacts with a resistive load of less than 200 to 300 watts and motor-switching loads of less than 1/8 to 1/12 hp may be considered "weak" ignition sources.

Needless to say, this approach represents something of a compromise since there can be no guarantee that a weak ignition source cannot cause ignition unless that source has been certified as intrinsically safe. However, if this approach is coupled with a gas detection system and improved ventilation, the probability is high that a natural gas release will be safely vented before causing ignition.

Because this approach seems to be the one most frequently implemented and because of the desire to focus economic resources where the greatest safety benefit can be obtained, the discussion below of specific measures to take for CNG use generally follows this approach.

4.2 FUELING AREAS

General

Fueling areas should be subject to the requirements, recommendations, and standards set forth in Chapter 4 of NFPA 52 and NFPA 70, Article 514. In no way should this recommendation be interpreted to imply that these are the only codes applicable to specific installations.

* "Ignition Sources of LNG Vapor Clouds," D. J. Jeffreys, N. A. Moussa, R. N. Caron, and D. S. Allan, GRI report GRI-80/0108, January 1982.

During connection and disconnection of the bus fueling probe, unvented fueling nozzles can release fuel in the vicinity of the fueler (hostler). This can create an unsatisfactory and hazardous condition during disconnect. Only fueling hardware and equipment that prevents this from occurring should be utilized.

Lightning

CNG fueling areas should be protected from lightning, especially when located in an area with high lightning risk. Grounding and bonding must be employed on all CNG equipment and fuel storage containers. NFPA 180 describes the specific measures required for proper lightning protection.

Noise Control

Compressor noise should be adequately contained within the compressor shelter. Noise levels at CNG fueling areas should comply with Occupational Safety and Health Administration (OSHA) and American Conference of Governmental Industrial Hygienists (ACGIH) guidelines, both from a worker safety viewpoint and to facilitate communication among employees. The control of noise through engineering modifications is preferred to the use of personal protective gear.

4.3 BUS STORAGE AND MAINTENANCE AREAS

Ventilation

Adequate ventilation should be provided for CNG facilities. All CNG fueling areas should be ventilated and should be capable of providing five to six air changes per hour (NFPA 52 guidance is being followed here) if a gas leak is detected. Ventilation systems should be integrated with facility gas detection systems.

In both storage and maintenance areas, outdoor exhaust fans or fans with explosion-proof motors should be located near the buses. The system should be designed to prevent leaking gas from being carried deeper into the garage and becoming trapped in the roof system or migrating to other parts of the building.

Heating Systems

Gas fired make-up and heating units with open flames should be removed. Even though these units utilize nearly 100 percent outdoor air, the negative pressure on the intake to the unit could draw in gas if there are any holes or cracks into the ducts.

Surface temperatures of all heating equipment should be less than 450 C to eliminate hot-surface ignition problems. Exterior mounted and reverbrative/radiation type heating equipment may have to be "re-tuned" to a lower firing rate to provide lower surface temperatures on indoor parts. Direct-fired heaters should be replaced with indirect-fired units (hot water, steam, etc.) that do not create an ignition source.

Electrical Systems and Other Potential Ignition Sources

No strong or continuous ignition sources should be located near the ceiling or in close proximity to CNG vehicles. Motors or switches installed near the ceiling and used to open doors or start fans should either be moved to the exterior of the building or be made explosion-proof. Special procedures may be needed for the use of overhead cranes because such use of necessity involves overhead sliding electrical contacts.

Leak Detection Equipment

Combustible gas detectors should be installed at the fueling station and in maintenance and storage buildings. These detectors should be tied into an annunciation system that is continuously monitored on site, such as a vehicle dispatching area that is always staffed. An electric power control strategy may be part of the safety system, removing all potential electrical system-based ignition sources if a gas release is noted by the detectors.

4.4 OPERATIONAL ISSUES

Fuel system leaks are inevitable in a transit operation involving large numbers of vehicles in revenue service. While CNG buses may be designed to a higher safety factor or currently receive more management attention than diesel buses, many aspects of CNG vehicle design have not yet gone through a full vehicle life cycle. Fluid dynamic studies performed for FTA have shown that all but the smallest compressed natural gas leaks form flammable plumes of significant dimensions.

If a CNG leak does occur, it is essential that the leaking gas not contact an ignition source. While a combination of combustible gas detectors and increased ventilation can help keep flammable layers from lingering, these systems require time to respond and operate. In the presence of an ignition source, a flammable mixture ignites in only milliseconds. Therefore, if an ignition source is present directly over a CNG leak, and a plume of natural gas reaches the ignition source, the natural gas *will* ignite.

The only way to prevent such ignition is to remove ignition sources. This philosophy is consistent with the philosophy long applied to fuels with heavier-than-air vapors, which prohibits ignition sources at a level lower than the level of probable fuel vapor release. This same strategy would be followed in applying the "removal of strong ignition sources" school of thought to interpretation of NFPA codes.

It is not believed reasonable to expect that mechanics will make all such repairs outdoors far from tools and parts, particularly at night or during inclement weather. Therefore, it is not adequate to address the issue of fuel release during fuel system maintenance or repairs by establishing a procedure requiring that all such repairs be performed outdoors.

Also, "No Smoking" signs should be located and enforced in the maintenance and fueling facilities, particularly in the pits where service operations may be conducted on the fuel system, as well as where CNG fueling is performed.

5. FUELING

NFPA 52 specifies design criteria and equipment qualifications for compression, storage, and dispensing systems for CNG fuel. Although the code allows flexibility in equipment and dispensing locations, all but one of the sites visited used outdoor fueling. All the fueling station designs followed NFPA 52 recommendations. The following important features were observed:

- Sound attenuating enclosures are effective in controlling compressor noise and providing weather protection for the equipment as long as ventilation and gas leak detection requirements of NFPA 52 are met.

- Fast-fill CNG fueling stations usually come in two types, buffer or cascade. The buffer type system uses large capacity compressors and a small amount of high-pressure storage. The cascade type system uses smaller capacity compressors and a large amount of high-pressure storage. Both systems are described below.

- As required by NFPA 52, combustible gas alarms should be used to annunciate gas leaks and shut down the fueling operation when the compression station is considered indoors (e.g., in an enclosure).

- Fuelers should be aware of the small but hazardous combustible gas plume created during operation of an unvented fueling nozzle. If the fueling nozzle is vented, it must be vented at a safe distance from the fueler and fueling station.

Other fairly typical features are discussed below.

5.1 CENTRAL FUELING FACILITY EQUIPMENT

CNG fueling stations can be time-fill (slow-fill) and fast-fill. Time-fill stations consist of one or more small-capacity compressors and possibly a cascade storage system. Vehicles are filled in 30 or more minutes with one or more vehicles being filled at the same time. The more vehicles being filled at the same time, the longer it takes. Time-fill stations were not considered in this study because it was assumed that only fast-fill stations could meet the requirements of large transit fleet fueling operation. Once transit systems start operating a CNG bus fleet larger than 10 heavy-duty vehicles, a time-fill system will not be adequate to refill the buses before morning pullout.

All but one site reviewed in this study used fast-fill systems to fuel their CNG buses. A typical fast-fill CNG fueling station is shown in Figure 1-1 and is described in the following discussion. CNG fuel is provided by mechanical compression of natural gas directly from a lower pressure pipeline. Natural gas is supplied from a pipeline from the local gas utility, usually at 16 to 300 psi to the compressors. The gas piping, on-site storage, and compressor system should be confined (e.g., fenced-in) and protected from vehicles by a barrier. The natural gas inlet station should be separated from the fueling station area and protected from vehicles by a barrier.

A desiccant dryer should be considered either on the inlet (low-pressure) or after the compression stage (high-pressure). Pipeline quality natural gas is specified to have a water vapor content of 7 or lower lbs/MMscf. To assure that no water or ice crystals form inside the storage tanks, either at the fueling station or on the bus, the natural gas should probably have a water content less than 1 lbs/MMscf. Water in the high-pressure storage tanks or on-board fuel tanks could cause corrosion and stress corrosion cracking. Ice crystal formation is detrimental to the components of the fueling nozzle because during a fast-fill operation, the natural gas is being loaded onto the bus at a high rate or velocity. If that high-velocity natural gas stream were to contain ice crystals (or any particles), the parts within the fueling nozzle would be eroded and possibly destroyed by the ice particles. Some CNG operators are using a high-pressure filter to catch particles before reaching the fueling nozzle, however, prevention of those particles is recommended as well. Ice formation can also impede and eventually stop the fueling process by blocking passage of the fuel.

ASME containers are used for high-pressure storage of natural gas. As mentioned above, storage can be either as a buffer or as a cascade. A typical storage buffer has a CNG capacity of 31,000 scf (three ASME containers). The buffer allows continuous compressor operation while the buses are switched at the fueling island. The buffer is then directed into the next bus before the compressor "tops-off" the bus to full operating pressure. A typical storage cascade could have three to six times the amount of on-site high-pressure storage as a buffer. In this case, fueling is accomplished by filling the bus from the high-pressure cascade with the compressor(s) replenishing the supply of compressed natural gas to the cascade. Many times, the cascade fueling process includes using only a few of the ASME containers at a time. In this way, there would be several ASME containers with high-pressure natural gas available at the end of the fueling process to "top-off" the bus tanks.

The compression of the pipeline natural gas to the buffer or cascade should be accomplished by at least two parallel mechanical compressors. Two compressors are required to ensure that, if one compressor goes down, the second can continue the fueling process. The size of the compressors is determined by the type of fueling preferred, cascade or buffer, by the transit agency or the architect and engineering consulting firm used by the transit agency. The compressors and recovery tanks should be mounted within a noise reducing enclosure with proper ventilation (defined in NFPA 52). This enclosure protects the equipment from the weather and reduces noise exposure of the fuelers or nearby public. If the compressors are to be placed outside, it is strongly suggested that qualified acoustic engineering surveys are made and proper noise barriers are used. Noise concerns are further discussed in Chapter 10 of this section.

The high pressure gas is piped to the fueling dispenser, which physically resembles a gasoline pump at a local gas station. This dispenser measures and displays the quantity of CNG dispensed. The fueling nozzle should be of an appropriate design to provide the flow rate required to fill the buses in the time required. Also, the fueling nozzle should have a return line that is vented away from the fueling area at a safe distance. Venting is strongly suggested since an unvented nozzle will release natural gas at the end of the fill, near the fueler's face. This plume of natural gas is small, but of a sufficient size to be in the flammable range while the plume is close to the fueler's face at fuel hose disconnect. Should a static discharge be present at the time of disconnect, the fueler would be at risk of injury.

The fueling station should have a natural gas recovery system to capture the blow-down of the compressors. When the compressors shut down, a certain amount of natural gas is in the various stages of the compression and should be moved to a low-pressure recovery tank. At the next startup of the compressors, this natural gas would be fed back to the compressors. Also, the vented fueling nozzle should be vented to the low-pressure recovery system.

5.2 HAZARDS

Several hazards could be present at the fueling area. NFPA 52 and other codes suggest several ways to mitigate these hazards. Some hazard mitigation methods are discussed on the following pages, including a combustible gas detection system, lightning protection, breakaway cages for fueling hoses, fuel hose vent lines, fueling area surveillance, classified electrical systems, telephone and kill switches at a safe distance from the fuel dispensing area, and static discharge mitigation.

A combustible gas detector system (including combustible gas and infrared detectors) recommended by NFPA 52 should be mounted in the compressor enclosure and connected to an alarm system. If the compressors are outside, they should be protected by a canopy of some kind and there should be a combustible gas detection system. Most sites utilize a two-level alarm that annunciates visually and audibly the leak severity, disables equipment, and activates additional ventilation. This alarm should automatically turn off the compressors and all electrical power to the fueling area at the higher alarm level {no more than 40 percent Lower Flammability Limit (LFL)}, requiring manual restart. Often this alarm is also used to activate purge fans and notify station personnel that a gas leak has been detected at the compressor facility. Such alarms should be tested and calibrated regularly to ensure proper operation.

Everything within an enclosed fueling area should be classified and explosion-proof, including incandescent light fixtures, conduits, motors, etc., within the proper area around the compression and dispensing equipment (as suggested by NFPA 52). Several "kill" switches should be located on the compressor enclosure and near the fueling dispensers that completely shut down the fueling area. The details of this design are all suggested in NFPA 52. At least one kill switch and a telephone should be located nearby. However, this kill switch should be located at a safe distance from the fuel dispensing area to allow safe shut down. This remote switch should not be in an area where the person pushing the switch would be at immediate risk. In addition to having a kill switch, the area should be under surveillance by security or the dispatcher (on a 24-hour a day basis or at least during normal fueling times).

For drive-away protection, the fueling hoses should be passed through breakaway cages containing a check valve. If the bus should pull away during the fueling process, the connection is intended to automatically disconnect and close the check valve, shutting off the natural gas supply. Only a minimal amount of gas should be able to escape. Most newer CNG vehicles have an ignition interlock system which will not allow the vehicle to start with the fuel door open. The vehicle should be off during fueling as specified by most states.

The fueling area and the fueling station itself should be adequately grounded and protected from lightning. At disconnect, the fueling nozzle should be vented away from the fueler possibly into the compressor blow-down recovery system. Also, some form of static discharge protection should be used for the fueling hose, possibly including a grounding strap before fueling.

5.3 EMERGENCY EQUIPMENT AND PROCEDURES

Adequate emergency equipment and procedures should be available to personnel in the fueling areas. Some items include:

- The CNG compressor enclosure or area should have emergency warning placards posted in several locations, with emergency telephone numbers written or etched on them.

- A telephone should be permanently mounted near the fueling station or within line-of-sight, with emergency contact numbers posted nearby.

- Employees should be able to shut down gas compressors in an emergency from a remote location (the emergency shutoff switch should be readily accessible to personnel), possibly near the telephone.

- Fueling operations should be observable from a remote location (e.g., from the maintenance manager's office) via remote TV cameras.

- A short list of emergency instructions should be posted near the fuel dispensers and kill switches.

Detailed and specific written procedures and training materials should be available near the fueling hose to indicate what the fueler has to do to operate the equipment properly, as well as what to do in the case of an emergency. Documentation should list the types of emergencies that could occur, how the fueler should diagnose each situation, what response the fueler should initiate, and where and when the fueler should turn for help. This documentation should be readily available to all personnel.

There may be incidents that will not allow the fueler (hostler) to reach the kill button. Also, panic and unfamiliarity can be a problem in an emergency. For this reason, very complete instructions associated with specific hypothetical incidents are essential to help the individual diagnose and respond to an emergency. Frequent periodic refresher training is also helpful.

5.4 FUELING ON THE ROAD VIA SERVICE VEHICLES

Because of the reduced range of some CNG transit buses, several transit authorities have investigated methods of refueling a CNG bus on the street. The transit authorities generally believe that such a service truck might be considered to be transporting hazardous materials (CNG) and would then need to carry placards, while the driver would need a Commercial Driver's License (CDL) with hazardous goods riders.

To address this concern, one of the transit authorities has purchased and upfitted their roadcall truck to run on CNG. This roadcall truck is equipped with hoses and a fuel nozzle connection for CNG vehicles, and can easily transfer fuel from its primary fuel tank to a disabled bus. This allows the vehicle that is out of fuel to obtain CNG from the service truck and return to the fueling station under its own power. The program is working well at that agency. However, there has been no verification of any regulation that would require placarding or using a CDL for a quantity of hazardous material that is less than 1,000 pounds unless that material is specially listed. Natural gas is not on these lists.

6. MAINTENANCE

6.1 MAINTENANCE FACILITIES

Maintenance facility design must include systems for sensing natural gas leaks. Several designs for maintenance areas are being evaluated by transit agencies. These methods differ principally in the amount of equipment that is shut down during a sensor alarm. A second difference is the treatment of existing overhead ignition sources.

A common method used to sense natural gas leaks in a maintenance facility is to use a combustible gas detector system that provides only a warning in case of a major fuel leak. Usually, a number of gas detectors are used in maintenance areas. They are often centered over individual maintenance pits or centered in a maintenance bay, typically 1 to 2 feet below the ceiling.

In other facilities, a two-level alarm system is actuated by detectors, depending on the concentration of combustible vapor detected. A low-level alarm is actuated at 20 percent of the LFL of methane in air. The alarm activates a red strobe, shuts down all overhead and shop floor ignition sources (such as overhead heaters), turns on exhaust fans, and opens overhead doors (if they are closed). An audible and visual alarm is also sounded in the maintenance manager's office. A high-level alarm is actuated at 40 percent LFL. In addition to all annunciations associated with a low-level alarm, an alarm horn also sounds in the maintenance area.

In the preferred facility design, in addition to actuating alarms, sensors disable all shop floor power and overhead lighting. Ventilation is increased by starting exhaust fans or opening overhead doors that are external to the building or explosion proof and overhead ignition sources are shut off. In such facilities, there are no overhead gas heaters in the maintenance area. Instead, the area is heated indirectly by hot water or forced air from gas heaters located elsewhere. All obvious overhead ignition sources are either omitted during facility construction or removed during refit of the facility.

The fundamental features of the preferred design make it more desirable over the long term. A transit agency that deploys such as system should also consider the following factors related to equipment.

6.2 MAINTENANCE EQUIPMENT

The CNG maintenance area should be isolated from areas where ignition sources (such as welding operations, grinding, and machining) are present. This isolation will help prevent a major gas leak from reaching possible sources of ignition. Electrical panels located within CNG maintenance areas should be in a special enclosure equipped with a purged air system.

Leak detection systems should be installed in CNG vehicle maintenance areas. Gas detection is considered by many to be a prudent safeguard in potentially hazardous areas and is one of the approaches that could be interpreted by "the authority having jurisdiction" as a way to declassify the area. Specifically, an on-line, real-time, multistage alarm with electrical shutoffs can provide such a system.

High-level ventilation and exhaust systems should also be used to prevent gas from accumulating at the high point of a sloped roof. Adequate ventilation with continuous backup may also provide advantages. Ventilation in maintenance pits and lift areas should be sufficient to ensure that a fuel system leak will not result in pockets of gas under the bus skirt of higher than LFL concentration.

Electric motors used to actuate ventilators that are located close to the roof should be prevented from acting as ignition sources if they are opened to provide better ventilation in the event of a gas release within the building.

6.3 MAINTENANCE PROCEDURES

All personnel in the maintenance department should be familiar with the CNG bus maintenance procedures. Documentation on safe handling methods for CNG in the maintenance area should be readily available.

CNG buses brought indoors for service on the fuel system, under certain conditions, should have their fuel tanks purged. Written procedures or guidelines should be developed describing when it is safe to bring a CNG bus into the shop and the circumstances when fuel tanks do or do not need to be purged prior to beginning repair work. For example, one area of uncertainty is the policy that should be followed if open torch welding is to be performed on a non-fuel system item located close to the engine compartment or fuel tanks.

CNG maintenance personnel should be trained on the use of high pressure valves, pipe fittings, and Swagelok (compression) fittings. A Swagelok fitting consists of a body, two ferrules, and a nut that joins tubing to tubing or tubing to pipe thread. These fittings are unique to each other once they have been tightened. A used fitting that was originally tightened on one fitting body may leak if tightened against another fitting body. Fittings and body pairs should be numbered on disassembly so that they can be reassembled properly. This will not assure a leak-free system, but it has the best chance for success.

Written emergency notification and action procedures should be available to the maintenance crew. These procedures should be made known to personnel through concerted management policies.

6.4 HAZARDS

Ventilation should be provided in the pits or under the buses for dispersing potential gas leaks. Shop fans or table fans used to ventilate the undercarriage of a bus should conform to the NFPA code requirements for electrical equipment usage around combustible gases, as should all electrical equipment used in bus maintenance areas.

Annunciators, posters, and warning signs or lights in the maintenance shop should be in place to alert other personnel in the vicinity that a CNG bus is being serviced. Signs should remind workers to take precautions with flammable materials, ignition sources, and electrical equipment (for example, incandescent bulbs). When maintenance is performed on the CNG fuel system, smoking should be prohibited in or near the bus. Signs should be posted throughout the maintenance area.

Reliable and accurate pressure gauges should be installed on the bus fuel tanks. These gauges, combined with appropriate procedures, will help ensure that a fuel line or tank is really empty before repair work on the bus is initiated. A partially empty fuel line or tank can pose significant risks to the maintenance crew.

7. VEHICLE STORAGE

7.1 VEHICLE STORAGE FACILITIES

At many transit agencies, indoor storage is not an issue since all buses, including the CNG buses, are stored outside in designated areas. This is typical for transit systems located in Southern states.

In one indoor bus storage garage visited, special lanes are dedicated to CNG bus parking. Increased ventilation for the CNG bus lane area is provided by roof-mounted fans and electrically operated doors at both ends of the storage building. Combustible gas detectors are suspended above each of the lanes about two feet below the garage ceiling. Each sensor is positioned over a lane and protects an area of about 625 square feet per sensor.

CNG detectors typically trigger a three-level alarm system, depending on the concentration of methane detected. At 20 percent LFL, the doors at either end of the lanes are opened, exhaust fans are turned on, a red strobe light is turned on, and an audible and visual alarm is annunciated at the control panel in the maintenance manager's office. At 25 percent LFL, the natural gas to the ceiling mounted heaters is shut off. At 40 percent LFL, a loud horn is typically sounded.

In the preferred facility design, strong overhead ignition sources (open flame heaters, switches, electric motors and relays) are also removed. Combustible gas detectors are used to sense CNG fuel spillage or releases and subsequently deactivate any minor remaining ignition sources. Only indirect heating systems are used. A storage facility design that includes both an alarm system and removal of strong overhead ignition sources is recommended.

Indoor storage of CNG transit buses should assure that the sudden release of the entire fuel load (failure of a pressure relief device) would not jeopardize the safety of the facility or any of the transit employees. Removing open flame natural gas burner heaters and other strong overhead ignition sources is the safest way to design indoor storage facilities. While a 25 percent LFL detection may result in burner shutdown, methane vapor could move along the ceiling without being detected in time to prevent ignition. This could occur where deep interbeam spaces exist in the roof structure and because the sensors have a finite reaction time. The preferred facility design discussed above should be implemented with the following additional guidance.

7.2 STORAGE FACILITIES EQUIPMENT

CNG buses that are parked indoors should be parked only in storage lanes that have been initially designed or upgraded to accommodate them. Specific written guidelines or standard operating procedures should be available to instruct the dispatchers on the requirement for parking CNG buses in designated lanes only. In many instances, parking areas that are suitable for diesel buses would be unsuitable for CNG buses.

Any overhead garage door operating motors, exhaust fan motors, and switches or relays either should be moved from the ceiling space (typically outside on the roof) or made explosion-proof. Open flame heaters should be removed from service, and only indirect heating systems should be allowed in the vehicle storage area.

Gas detection and alarm systems should allow the person monitoring the system to easily associate an alarm situation at the panel with a location at the storage facility. A map of where each sensor is located in the facility should be placed on the outside of the control panel.

In most facilities, particularly in the North where freezing temperatures regularly occur, the entire storage area is sprinkled utilizing both wet and dry systems. Dry systems are often located in the vicinity of exterior doors, while the rest of the facility is protected by a wet system.

Combustible gas sensors should be installed as close to the roof/ceiling as possible. The location should keep to a minimum the volume of space near the ceiling where methane can accumulate without being detected by sensors. Simulation of a CNG fuel spill has suggested that the resulting flammable plume will pass a roof mounted sensor at a high rate of speed. A response time window (the period of time between 20 percent and 100 percent LFL) is less than one second when the leak is directly below the sensor or potential ignition source.

Even if the ceiling-mounted sensor/ignition source has a horizontal displacement of 183 feet from a large fuel release (e.g., a PRD failure), a response time window of only 15 seconds is available to detect the plume and activate any control strategy. Current sensor technology being deployed in CNG facilities does not provide sufficient speed to provide protection from major fuel releases.

7.3 STORAGE PROCEDURES

Written standard operating procedures should be available to dispatchers, showing them how to handle different types of emergencies that could arise in the bus storage area.

Also, emergency pull stations should be available in work areas so that if there is a natural gas release in the shop (e.g., odor detection), any employee can signal the alarm and turn on the ventilation system without delay or waiting for sensor activation.

8. CNG BUSES

8.1 FUEL TANKS

CNG fuel tanks are mounted on the roofs of the buses, as shown in Figure 1-2, or below the floor, as shown in Figure 1-3.

The fuel storage tanks currently used on CNG transit buses are thick-walled, fiberglass-reinforced aluminum or steel. All DOT, FRP-1, and FRP-2 fuel containers are manufactured in compliance with DOT regulations and, as required by law, must be removed and tested (recertified) every 3 years. New ANSI/NGV2 CNG storage tanks are becoming available that utilize plastic liners with carbon fiber reinforcement. They weigh significantly less than the current metal-lined tanks and require only visual inspection to recertify.

The BIA buses currently in service are 40-foot buses. Each bus has 8 or 12 roof-mounted CNG cylinders (seamless aluminum with carbon fiber reinforcement), each of which has a 145-liter water volume, and a 37.5-standard cubic meter (1,324-scf) capacity at 3,000 psi.

The 35-foot Flxible bus in service at many transit agencies is configured with four (4) floor-mounted CNG fuel tanks. These tanks are also seamless aluminum liners but have a fiberglass-fiber reinforcement. Each tank has a 250-liter water volume and a 75.5-standard cubic meter (2,666-scf) capacity at 3,600 psi. A 40-foot Flxible CNG bus uses six (6) of these fuel containers and has proportionally more fuel storage.

8.2 FUEL TANK CAPACITY

Whereas a 40-foot Flxible CNG bus has six fuel tanks, the 30-foot bus design allows for only two fuel tanks and, thus, has a very short range. The problem of the short range of 30-foot CNG buses is compounded by unreliable fuel pressure gauges on some CNG buses. A modest increase in range can be effected by replacing the air start with an electric start and replacing the air tank with two small fuel tanks (about 6 equivalent diesel gallons).

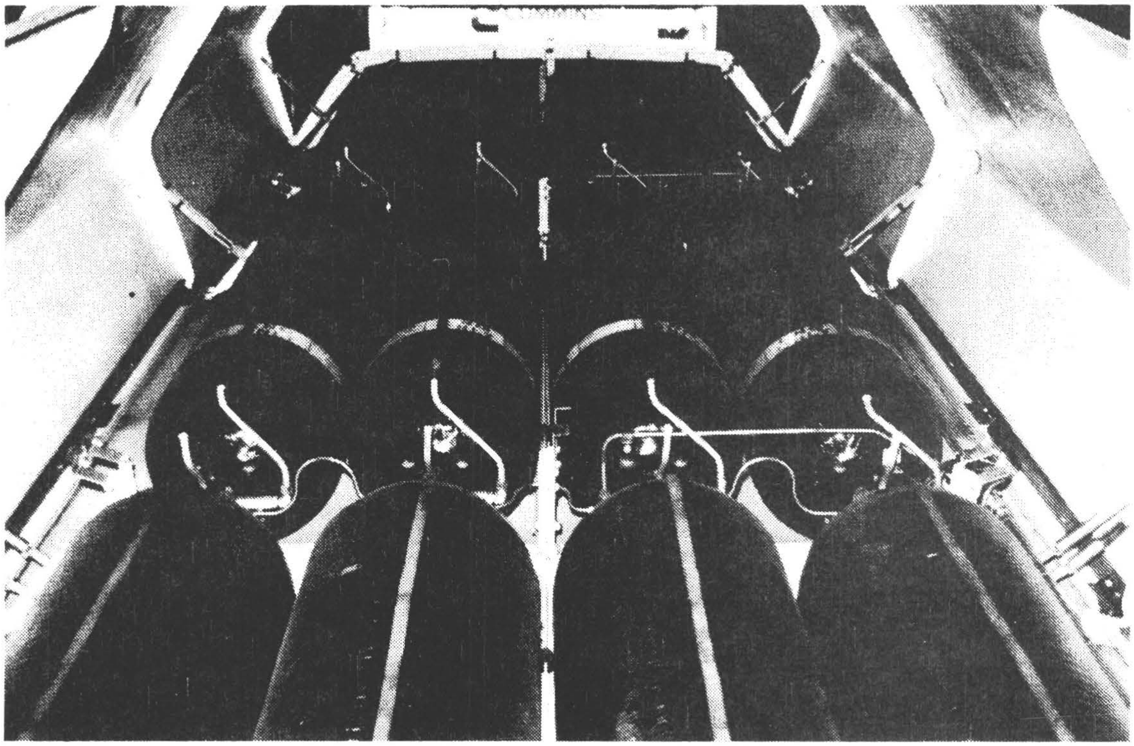

Figure 1-2. CNG Fuel Tanks Mounted on Roofs of Buses

Figure 1-3. CNG Fuel Tanks Mounted Below the Floor

Several ways to improve the range of the 30-foot buses have been investigated. For example, fuel tanks could be topped off in the morning after the bus engines have been warmed up, but before pullout to make sure a full fuel load is delivered to the bus. This practice would also indicate leaks in the fuel system if a large amount of CNG was required to top off the tanks.

8.3 FUEL TANK STORAGE PRESSURE

The storage cylinders used on Natural Gas Vehicles (NGVs) are 1/2 to 3/4 inch thick and withstand impacts better than gasoline tanks made of thin sheet metal. Standard storage pressure of CNG used in transit operations is either 3,000 or 3,600 psi. Unlike propane, natural gas is always in gaseous form and compression alone will not liquefy it. During fast fill of the bus fuel tank, both higher pressures and fill temperatures well above ambient are anticipated.

The new ANSI/NGV2 standard allows pressures at 125 percent of nominal service pressure to fully fill the fuel tanks. The fueling nozzle manufacturers are upgrading their nozzles to accommodate this. However, many of the fuel tanks currently used on CNG buses were not designed, tested, or rated to be used at this high pressure. Cyclic pressure tests are an essential part of a fuel container's design qualification tests. In the various cylinder design standards, these cyclic pressure tests test the cyclic fatigue capability of the container to a lifetime of refuelings. The number of cycles selected is based on the intended use and nominal service pressure of the container.

Because the pressure cyclic tests for the DOT FRP-1 or FRP-2 containers are conducted at only nominal service pressure, and because the total cycles are not representative of a 15-year life container, these containers *should not be routinely filled* to 125 percent of nominal service pressure. ANSI/NGV2 fuel containers *are* qualified with a cyclic pressure test in which a portion of the fatigue cycles are 125 percent of normal service pressure. These NGV2 cylinders are capable of withstanding the higher fill pressures.

8.4 SAFETY FEATURES

CNG buses have been designed with a number of safety enhancing features, which can include:

- Infrared (IR) sensors within the engine compartment, which will detect incipient engine fires due to methane leaks and then activate a dry chemical fire extinguishing system (also provided inside the engine compartment).

- A fuel input receptacle and a quarter-turn shut-off valve located on the curb side of the bus toward the back end, about 5 feet above ground. These are protected by an angle beam, which serves as a crash protection bar. This location, at a considerable height above ground, protects against side impact from automobiles and other small vehicles and prevents damage to CNG plumbing.

- Tubing delivering CNG to the engine made of stainless steel and coiled within the engine compartment to relieve thermal expansion loads on fittings.

- An engine compartment fire suppression system emergency "Manual Actuator" just behind the driver's seat for rapid action.

- A cut off switch on the fuel receptacle door, which prevents starting the bus engine during fueling.

9. TRANSIT BUS OPERATIONS

9.1 PUBLIC ACCEPTANCE

An important aspect of bus operations is to assure public acceptance of the transit authority's programs and practices. To assure that correct agency plans are given to the public, it behooves transit management to properly inform and train the point of contact with the public (i.e., the bus operator) in any new and perhaps controversial subjects. To achieve the desired results for use of an alternative bus fuel, a continuing education and training program for the bus operators is needed.

CNG buses in general have performed well and have achieved driver as well as public acceptance. One demonstration site is aggressively pursuing CNG fleet conversion and has placed an order for 32 additional 35-foot buses.

9.2 DRIVER TRAINING NEEDS

Current practice is to schedule periodic training sessions for bus operators to review correct procedures for CNG buses. These CNG procedures are usually contained in a manageable handout that addresses such things as bus accidents with and without leakage of CNG and what to do in case of a fire on a CNG bus. Although full CNG orientation and more detailed training for CNG bus operators is needed (to achieve both awareness of the fuel and a public acceptance of CNG as a safe and needed diesel replacement), the efforts currently underway are having meaningful results.

Bus operators should know correct emergency procedures and be tested accordingly. Detailed instruction should be available to the bus operator while on the bus and cover what to do in all on-board emergencies.

Additional training would expose CNG bus operators to a working knowledge of the buses' CNG systems. This knowledge would assist in correctly answering questions that could be asked by passengers. For harmonious relations and public acceptance of CNG, it is essential to correctly answer any questions and concerns that may be voiced by interested passengers.

Often these questions can be anticipated and a meaningful reply formulated by the transit staff and management.

10. OCCUPATIONAL HYGIENE ISSUES

One focus of this study was to address possible implications for transit worker safety and hygiene in the work place if CNG were the principal engine fuel for transit operations. Since little has been published on the subject to date, one of the program objectives was to increase the amount of data available to the transit community on the levels of:

- Natural gas in the work environment and its effects on staff safety.
- Formaldehyde in the work environment and potential health problems that may be caused by formaldehyde exposure.
- Noise affiliated with the operation of CNG-fueled buses and associated CNG equipment.

10.1 NATURAL GAS LEVELS

Objective

The objective of the natural gas concentration measurements was to determine if natural gas levels associated with the fueling, maintenance, storage, and operation of compressed natural gas buses posed a fire hazard, a health hazard, or represented a significant release of fuel into the environment.

Method

The natural gas concentration measurements were made using a MIRAN 1B portable gas analyzer. The analyzer contains a calibrated infrared spectrometer as well as a sample handling pump. The MIRAN is capable of measuring methane concentrations from 2 to 5000 ppm by volume over several ranges. The calibration of the methane scales on the MIRAN was verified using a cylinder of certified standard calibration gas (containing both methane and ethane in air) prepared by Matheson.

Applicable Standards

The apparent Threshold Limit Value (TLV) for natural gas is 10,000 to 15,000 ppm depending on the quantity of higher hydrocarbons in the gas. The Lower Flammability Limit (LFL) for natural gas is about 5 percent or 50,000 ppm. Below the LFL mixtures of air and gas are too lean to burn and will not ignite, and above the higher flammability limit of 15 percent the mixture is too rich to burn.

Results

No natural gas concentration values were measured which even approached either of the TLV or the LFL. The methane concentration data show that in the absence of leaks or abnormal conditions, the natural gas concentrations associated with the use of CNG buses are generally quite low.

However, the following conditions were noted:

- At two sites the concentration of natural gas was higher in the vicinity of parked CNG buses than diesel buses.
- At one site the concentration of natural gas was relatively high in the vicinity of the fueler's head during unvented fueling nozzle disconnect.
- At one site the exhaust air from the CNG compressor enclosure contained a relatively high concentration of natural gas, amounting to a loss of about 1 kg of fuel for each bus fueled.

10.2 FORMALDEHYDE LEVELS

Objective

The objective of the formaldehyde sampling was to determine whether the formaldehyde levels associated with the use of compressed natural gas fueled buses were significantly greater than those associated with diesel fuel buses and also whether the formaldehyde levels posed any occupational health concerns. Formaldehyde levels were measured at three sites.

Method

A wet chemistry technique was utilized to determine concentrations in the field in near real time. A portable, battery-operated sample pump was used to draw a known volume of air through an impinger containing a known quantity of distilled water. The concentration of formaldehyde in the distilled water was then determined using the MBTH reagent, which combines with formaldehyde to produce a blue color. A spectrophotometer was then used to measure the color intensity.

The spectrophotometer readings were then compared to a calibration curve developed from diluted certified formaldehyde standard solutions. A correction factor of 1.11 was applied to account for an assumed impinger efficiency of 90 percent.

Applicable Standards

In "Threshold Limit Values and Biological Exposure Indices for 1992-93,"* the ACGIH has set a ceiling value of 0.3 ppm for formaldehyde. A ceiling value is a limit which may not be exceeded. Formerly, the ACGIH set a Time Weighted Average (TWA) of 1 ppm and a Short-Term Exposure Limit (STEL) of 2 ppm for formaldehyde.

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* ACGIH "1992-1993 Threshold Limit Values for Chemical Substances and Physical Agents and Biological Exposure Indices," American Conference of Governmental Industrial Hygienists. p. 113.

Results

At one site, all formaldehyde concentrations observed were well within ACGIH limits. The highest measured value, from a sampler on-board an idling CNG bus in a group of four idling CNG buses, was 1/3 of the ACGIH limit.

At another site, formaldehyde concentrations in vehicle storage area exceeds ACGIH limits during pull-out and was higher than the level in a diesel-only section of the building.

At a third site, because CNG bus storage, start-up, and pull-out all occurred outdoors, and because of the brisk breeze during the time the measurements were made, no significant formaldehyde concentrations were expected. However, an increased formaldehyde concentration was still observed as compared to diesel operations. Although not conclusive, the data suggest the possibility that formaldehyde concentrations for a large CNG fleet could be significant during calm wind conditions or within buildings. Such potential is difficult to access.

Figure 1-4 shows formaldehyde levels during morning pull-out at two transit agencies that use indoor storage. Note that in both cases the formaldehyde levels associated with natural gas vehicles were higher than those for comparable diesel vehicles. A comparison with the ACGIH recommended ceiling limit and the OSHA action level is also shown. Although the OSHA 8-hour exposure limit is higher, 0.75 ppm, concentrations at the action level trigger several requirements including medical monitoring and detailed record keeping.

A naive extrapolation would predict that, as the fraction of CNG buses in the total fleet increases, the formaldehyde concentration would increase in like fashion. However, diesel buses also produce some formaldehyde, so not all of the measured formaldehyde can be attributed to the use of CNG. Also, as the number of CNG buses increases the fleet would receive the benefit of more of the existing ventilation capacity, due to the greater area the CNG fleet would occupy in the garage.

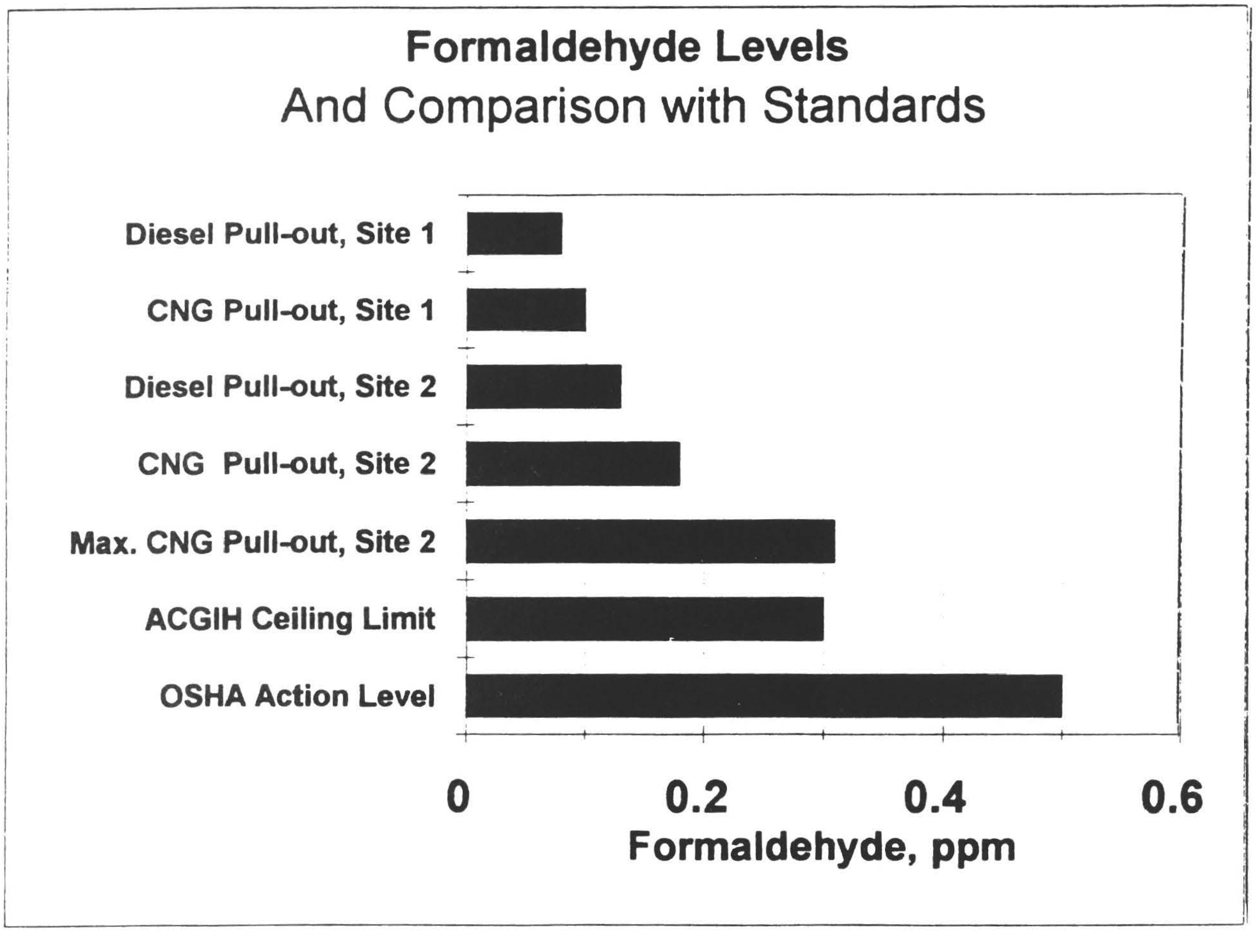

Figure 1-4. Formaldehyde Levels and Comparison with Standards

Even considering these factors, transition to an all CNG fleet would be likely to increase the existing formaldehyde concentration within bus storage facilities. The level of this exhaust product should be monitored as CNG bus fleets expand. Greater ventilation rates or different bus operating strategies may have to be considered if concentrations exceed recommended levels.

10.3 NOISE LEVELS

Objective

The objective of the compressor noise measurements was to determine if the noise associated with CNG compressor operation presented a hazard to hearing acuity or the safe conduct of transit vehicle operations.

Method

Noise levels were measured using one of two models of noise survey meters. Both meters had available scales for both "A" and "C" response curves. Both meters were calibrated with a sound pressure standard at a range of frequencies and found to be accurate within $\pm$ 2 dB. Most errors were 1 dB or less.

Applicable Standards

The OSHA standards for noise exposure are listed in Table 1-1. A noise dose of 50 percent of the durations listed in Table 1-1 or an 8-hour average noise level of 85 dB constitutes an OSHA "action level." For example, an exposure of 4 hours at 90 dBA would constitute an action level. At this level of exposure, employers must implement a hearing conservation program, including baseline audiometric testing of new employees, noise monitoring, regular audiometric testing, hearing protection, employee training, and record keeping.

Observance of the OSHA standards may still result in significant hearing loss. OSHA standards protect most workers against hearing handicap, where a hearing handicap is defined as a hearing loss of more than 25 dB in the middle (speech) frequencies. Even so, at a 90 dBA noise level approximately one eighth of the population of exposed persons will still develop such a hearing handicap over a 20-year work exposure (Beranek, 1971)*.

Moreover, noise levels that comply with OSHA standards can result in a significant hearing loss at other frequencies. These issues are explored in greater depth in *Noise and Vibration Control* (Beranek, 1971)**. Many noise control experts feel that noise limits must protect a higher fraction of the exposed population and that many workers would object to any job-related loss of hearing, even if hearing at speech frequencies remained largely intact.

For these reasons, other noise control policies and standards suggest that noise limits 5 or even 10 dB below the OSHA limits are appropriate. The ACGIH Threshold Limit Values for Noise (ACGIH 1993) are also listed in Table 1-1. These noise levels are 5 dB less than the OSHA permissible noise levels. The U.S. Air Force hearing conservation program is based on a criterion of 84 dB at the 8-hour daily exposure with a 4 dB trade-off for a halving of exposure time (Beranek and Ver, 1992)***.

Comments on Noise Control Strategy

Application of such engineering controls should precede the application of ear muffs, ear plugs, or other personal protective gear. OSHA regulations on noise exposure state:

> *"When employees are subjected to sound exceeding [permissible limits], feasible administrative or engineering controls shall be utilized. If such controls fail to reduce sound levels to within [permissible] levels, personal protective equipment shall be provided and used to reduce sound levels..." 29 CFR 1910.95 (b)(1).*

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* Beranek, Leo L., ed. *Noise and Vibration Control*, McGraw Hill, 1971. See discussion on "Damage-Risk Criteria for Hearing," pp. 541.

** Beranek, Leo L., ed. *Noise and Vibration Control*, McGraw Hill, 1971. See discussion on "Damage-Risk Criteria for Hearing," pp. 537ff.

*** Beranek, Leo L. and Istvan L. Ver, eds. *Noise and Vibration Control Engineering*, Wiley-Interscience, 1992. p. 591.

Table 1-1. Permissible Noise Exposures for Various Noise Durations

Noise Duration per day, hr	OSHA Permissible Noise level, dBA	ACGIH TLVs for Noise, dBA	USAF Allowable, dBA
8	90	85	84
4	95	90	88
2	100	95	92
1	105	100	96
1/2	110	105	100

The use of engineering controls would also reduce the possibility of community complaints of excessive noise from CNG bus operations.

Results

At one site, the measured noise levels were lower than the OSHA limit for noise with the exception of the area directly in front of the open door to the compressor enclosure. Subjectively, conversation was not unduly hampered by compressor noise. At this location, a sound attenuating compressor enclosure was provided and proved very effective as a method of noise control. Figure 1-5 shows both a typical natural gas compressor noise spectrum and the sound attenuation provided by a partial enclosure.

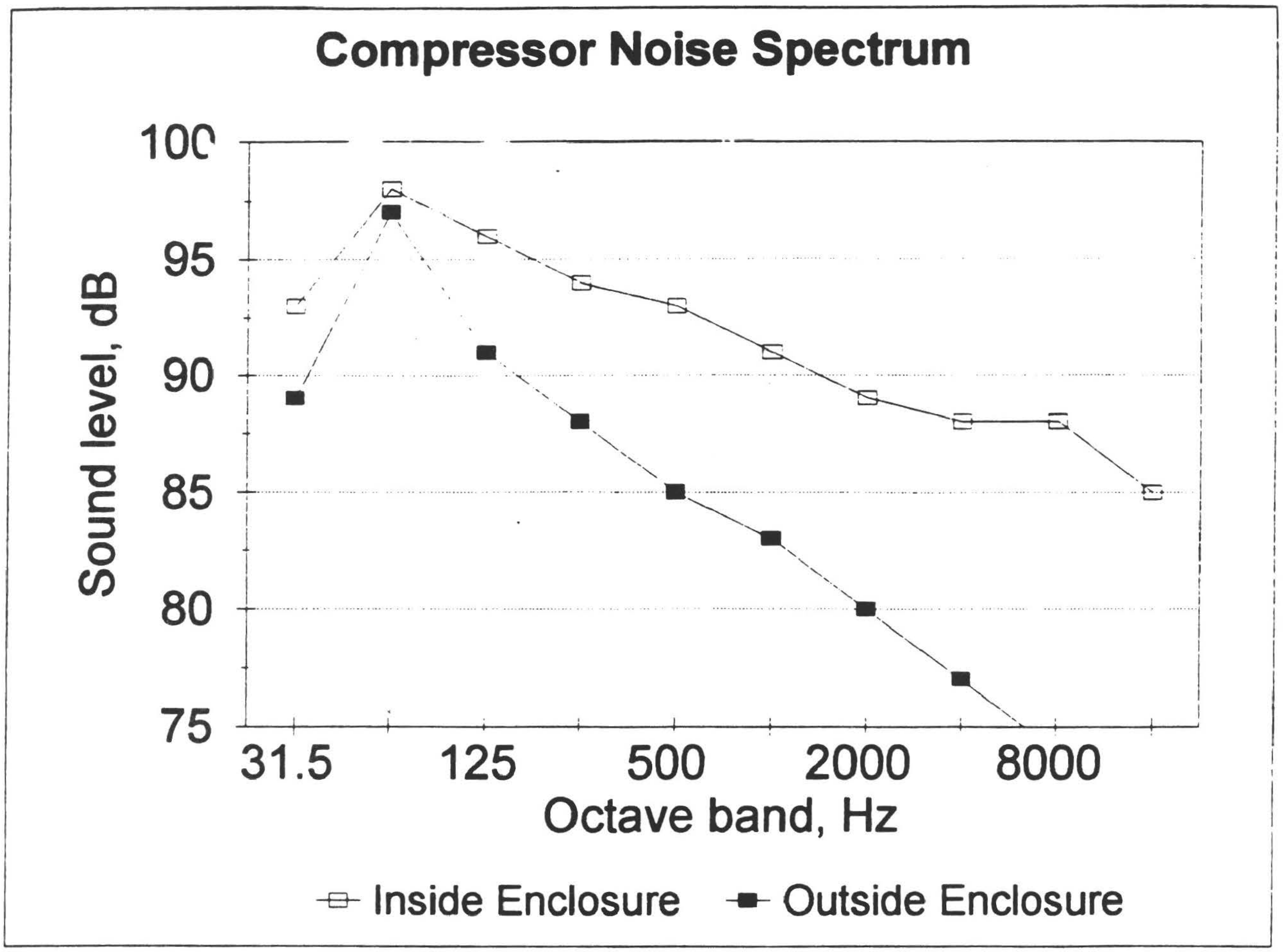

Figure 1-5. Compressor Noise Spectrum

At another site, the noise exposure at the CNG fueling island was clearly in excess of OSHA permissible limits and also ACGIH TLVs. Noise abatement is recommended to prevent possible hearing damage to employees working in this area.

Another problem with high ambient noise levels in the vicinity of the CNG compressor station at this site was the inability of transit employees to hear verbal communications, the approach of moving vehicles, or even vehicle horns. Such a situation can present a safety hazard in an area where vehicle movements are frequent.

11. EMERGENCY PLANNING

As part of an overall facility system safety plan, a transit agency that is operating with alternative fuels should consider aspects of an emergency plan. The plan must be site-specific and relate to physical characteristics and capabilities of the responding agencies (fire, EMS, police). Other issues to be addressed include response time, capability of staff to address the emergency, and other issues that are discussed below.

11.1 PLANNING, ESTABLISHING, AND DOCUMENTING EMERGENCY PROCEDURES

Easily accessible written documents should be provided to dispatchers to initiate emergency response procedures for gas releases that are detected inside the bus storage area. Written documents on emergency response procedures should also be in place for the fueling facility, maintenance shop, and bus storage area. For example, these lists of "do's and don'ts" should indicate who is responsible, when to take action, and who is to be notified.

The gas detection system annunciators in the maintenance manager's office or some other staffed area should indicate graphically the location of fuel releases, and individual sensing units should either be labeled with the same legend as in the annunciator panel or show through a warning light that they have been activated.

A plan for recording safety incidents, accidents, or alarms from the gas detection system should be enforced. A written record should be kept for tracking fuel leak incidents and similar events.

11.2 COORDINATION WITH LOCAL EMERGENCY MANAGEMENT AGENCIES

At one site, before any CNG activities commenced, transit officials from several departments coordinated their planning with local fire departments, local codes officials, and the local natural gas utility. In the interest of safety, all participants agreed to all procedures and facility modifications before the CNG demonstration began. Transit personnel indicated that discussions have taken place with the local fire department on emergency response protocol for dealing with CNG bus emergencies.

Specific written agreements, arrangement documents, formal understandings, or a coordination protocol should be developed between the transit authority and local emergency officials. The terms of authority, in an emergency, between the transit operator and local/municipal emergency response agencies should be made clear.

Local fire department personnel should be familiar with the CNG bus layout and storage and maintenance facilities. Officials from every local community through which CNG buses operate should also be included in emergency response planning.

11.3 STAFF DRILLS AND TRAINING IN EMERGENCY PREPAREDNESS

Tabletop exercises or, preferably, emergency drills should be conducted with the fire department or police department to educate these emergency response agencies on the details of the CNG bus and safe handling procedures.

In a large metropolitan area, a number of different political jurisdictions may provide their own emergency services. All emergency management personnel in these areas should be familiar with the details of CNG buses and be provided with remedial training by the transit agency.

One specific area of concern is bus engine fires. For example one large transit operator experiences approximately one engine fire per year due to grease and oil build-up. Transit staff should be trained and prepared for such an incident involving a CNG bus.

12. MANAGEMENT AND SAFETY AWARENESS

12.1 MANAGEMENT COMMITMENT TO SAFETY AWARENESS

Transit management should be conscious of CNG safety and committed to improving procedures and guidelines that will ensure safe operations.

Management also should encourage employees to learn about all aspects of CNG bus operations. Also, a direct and formal involvement by senior management promotes worker safety. Operations should be based on written procedures, not merely "word of mouth." Corporate policy should foster gathering, formalizing, and disseminating CNG safety knowledge, including the details of safety incidents, to the degree that such details are instructive in prevention. A formal hazard analysis for CNG vehicles and facilities should be completed for every transit site.

12.2 SAFETY AWARENESS RECOMMENDATIONS

Responsibilities

One individual in the transit organization should be specifically charged with improving safety in CNG operations. This person should be aware of CNG safety issues and corresponding worker training, system enhancement, and technical product improvement issues, and should proactively work to improve safety. Responsibilities among the different departments should be clear, as should the appropriate delegation of authority.

All CNG activities should be coordinated among different departments within a transit agency. Because of the novelty of alternative fuels, it is common that a champion of the technology will reside within the maintenance operation. If so, effective transfer of knowledge to the drivers and fuelers may require special provisions for information transfer within the organizational divisions. The responsibilities of each department should be clear, as should appropriate delegations of authority.

Communications

Material provided to staff should be adequate to ensure safety compliance in all operations. Ready access should be provided to the workers in the field for quick reference in an emergency. Documents should be available at the locations of work (in the fueling area, maintenance bays, storage area, or on-board an operating bus) for ready reference to execute proper emergency procedures. Tests or other methods should be in place to determine if the personnel trained indeed understand the features and issues associated with handling and operating a CNG bus or the facility. Formal feedback mechanisms should be available for an operator or a shop worker to provide responses, based on his or her experience in the field, to either modify the training content or enhance it.

A program for exchange of safety information with other transit administrations using the same fuel should be established and maintained.

13. TRAINING

Training of key employees who must interact with the new CNG fuel is essential in assuring the overall safety and operation of the facility. All transit agencies have employee training programs available for their staff. This training effort must be extended to include any changes that are made in the normal operations by the use of CNG bus fuel. When possible, the local gas distribution company should provide training and technical assistance in CNG handling. A formal training program should include the following major items:

- Fueler (hostler) instruction;
- Driver's program;
- External agencies; and
- Mechanics training.

13.1 TRAINING PHILOSOPHY

Training of transit employees for alternative fuel use should adhere to the following principles:

- Easily accessible written procedures should be provided at key locations throughout the CNG facility. These procedures should be available for any staff with responsibility for CNG buses or their operation.

- The principal objective of the training materials should be to provide employees with the information needed to perform their jobs. Thus, training materials should only secondarily be aimed at marketing alternative fuels.

- The content of the training materials should be technically accurate.

- The training materials should be understandable by the intended audience.

- To the extent possible, training materials should explain "why" as well as "how to."

- Training materials should provide information on both routine activities and procedures and on emergency procedures. Emergency procedures should be duplicated in an easily accessible form or location.

- Testing or certification should be provided to ascertain the level of knowledge actually attained.

- There should be a formal mechanism for updating and transferring new information and experiences to the existing staff.

- Periodic retraining or review should occur.

13.2 FUELER INSTRUCTION

Fuelers (or hostlers) should be required to meet a CNG certification as part of their training. The test should demonstrate that trainees understand the various aspects of the fueling process and the safety issues and more importantly what needs to be done (and in what order) in the event of a natural gas release.

Such training would include both classroom and hands-on training. The latter involves the normal fueling operations and the emergency shut-down procedures. During the classroom training, video films on safety and normal fueling procedures are shown and discussed in a later wrap-up session. A one-page handout on CNG bus fueling given to the students can provide a reminder for later use.

The curriculum for formal training of staff offered/conducted by one transit authority is shown in the following list. All curriculum items focus on CNG-specific issues.

- Fueling Station Familiarization
- Fueling Station Preventive Maintenance
- Fuel Nozzle Training (Fueling Station)
- Coach Orientation
- Coach Emergency Training
- CNG Orientation for Municipal Emergency Response Personnel

13.3 DRIVER'S PROGRAM

Bus operators should also be tested and certified in the basics of operating a CNG bus and in responses required of the operator in an emergency. A system should be developed for tracking the training program. Managers should be able to assess whether all staff have been to all training classes and/or understand all aspects of the CNG training provided.

A typical driver training session would familiarize the trainee with the CNG coach features, operability on a road, turning radius, etc. The course would include topics on alternative fuels, the construction features of CNG coaches, fuel cylinders, and any changes in the road maneuverability of the vehicle.

As part of this course, the drivers would be trained to read the fuel pressure gauge, become aware of the fuel gauge light on the dashboard panel, and initiate very minimal emergency response procedures such as operating the shut-off valve (quarter turn valve), recognizing a gas leak from smell, and the procedure for contacting the dispatcher to indicate CNG-related problems. In addition, the bus operator is often shown a CNG safety film that includes the types of accidents that may lead to fires and explosions.

Written instructions for operator actions should be posted in the bus in case of emergencies involving a CNG release. Detailed training should be provided to the bus operators in the following areas:

- CNG Familiarization for Transit Personnel
- CNG Coach Orientation
- Coach Emergency Training for CNG
- CNG Orientation for Municipal Emergency Response Personnel.

13.4 MECHANICS TRAINING

A program of certification and periodic recertification for mechanics would allow only fully trained personnel to repair CNG buses. A program with "hands on training" with CNG buses is most valuable. The specific emphasis of this training is to educate the staff on the following:

- CNG Coach Orientation
- CNG Familiarization for Transit Personnel
- CNG Orientation for Municipal Emergency Response Personnel
- Overall CNG system and its components in a bus
- Safe procedures with high pressure gases
- Leak detection for CNG assuring vehicles are regularly inspected with portable gas detectors.
- CNG Engine Familiarization and proper engine tuning.
- Ignition System and Engine Controls
- Carburetion System
- Coach Air Conditioning & Heating Systems
- Swagelok Safety Seminar (Fuel Supply Lines).

Specific points that should be covered by the training include:

- What to do in case of a fuel system leak, especially the locations of shut-off valves.
- The need and procedures for fuel system inspections for leaks and damage from road debris. These inspections should include, but not be limited to, the CNG fuel tanks.

13.5 EXTERNAL AGENCIES

The training department personnel or designates should develop a "road show" with a CNG bus that is taken to various fire departments in the local metropolitan area to demonstrate its features to fire department personnel. The purpose of this "road show" is to educate the fire departments on the details of the CNG bus, the locations of emergency shut-off valves, battery disconnects, fuel line features, details of pressure and make of fuel tanks, etc. Each fire department visited should be provided copies of printed documentation compiled by the transit operator's training department.

With such exposure, the fire department would be aware of the protocol in a CNG bus emergency. The fire department should be invited to bring fireman trainees to the CNG facility. Transit personnel should show the trainees the fueling station, its operations, and CNG bus details (such as shut-off valves on each CNG tank, the quarter turn cut-off valve, the battery cut-out switch, etc.). The training can be supplemented with two videotapes (one from the American Gas Association, and the other from CNG Cylinder Corporation) that provide basic information on CNG properties and details of tanks used in buses.

14. CONCLUSIONS

14.1 SUMMARY OF RECOMMENDATIONS FOR SUCCESSFUL CNG OPERATIONS

Based on the four industrial surveys, the following issues are of the greatest significance in planning and safely operating CNG transit systems:

- **Training of operating staff.** One of the most important resources in providing safe working conditions is the provision for a clear understanding by operating staff of the properties of CNG fuel and the proper procedures to follow when using or maintaining CNG vehicles and equipment. Both safety and operational information should be available in a form transit employees readily understand at appropriate work place locations. Formal training updates should be given periodically and an institutional mechanism established for experienced personnel to share their CNG fuel experiences with less experienced staff.

- **Control of strong ignition sources.** Strong ignition sources should be removed from areas where CNG buses are stored, maintained, or fueled. Of primary concern are strong overhead ignition sources such as open flame gas heaters, motor starters on fans and door openers, and other spark-producing electrical equipment (electric bug zappers, etc.).

- **Alarms and other warning systems.** Warning systems consisting of combustible gas sensors and an alarm system should be installed in all CNG facilities. These systems can warn of potential hazards even when personnel cannot detect a fuel buildup or when personnel are not present. These warning systems can be configured to independently increase ventilation rates to more quickly remove any gas buildup and to disable potential ignition sources. Maintenance and testing programs for such alarm systems should be in place and implemented.

- **Facility ventilation.** Preventing gas buildups in CNG facilities is one of the primary methods of reducing potential fire hazards. Facility ventilation requirements are significantly different for CNG vehicles than for diesel- or gasoline-fueled vehicles, and ventilating ceilings and high areas is especially important.

14.2 REMAINING ISSUES AND TOPICS

Several relevant questions outside the scope of this study have yet to be resolved, including the complex issue of code coverage and interpretation, appropriate building and equipment standards, and the best methods for training and certifying transit employees in the use of CNG as a transit fuel. In addition, the following issues must be resolved:

- More information is needed on the successful deployment and use of combustible gas detectors within transit facilities, including the number and location of detectors, and periodic calibration requirements. Moreover, detector response time must be consistent with the time required to implement remedial actions.

- If tests being conducted by Battelle for the FTA confirm that CNG releases can result in the formation of a dense gas plume, the findings will affect the basic philosophy of CNG bus facility design and operation, including the location of combustible gas detectors and the type of emergency response actions.

- Formaldehyde buildup with bus storage facilities during morning pull-out should be monitored as the CNG fleet size increases within a given facility.

- A system safety and hazard assessment analysis needs to be performed to more clearly identify the relative safety implications of the choice of fuel tank location on the bus (underfloor tanks versus roof-mounted tanks). This safety assessment should include the piping and valve associated with the fuel tanks.

Physical movement of a CNG fuel cloud from a large gas release is not well understood. The technical issue not resolved is the dispersion behavior of natural gas released from the high pressure inside a CNG cylinder. This depressurization of the gas in the cylinder results in rapid gas expansion and cooling. Thus, the gas emanating from the cylinder will be very cold and may be more dense than air. Such gas could disperse close to ground level for a significant duration and distance from the release point.

Since any change in current lighter-than-air assumptions about such gas movements would impact facility design and bus operations and maintenance, suggestions presented in this document may need altering to reflect new information.

SECTION II

STATUS OF CNG SAFETY IN TRANSIT APPLICATIONS

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1. INTRODUCTION

The FTA has been sponsoring a national demonstration program titled the Alternative Fuels Initiative (AFI) since 1988. Under this program, various alternative-fueled transit vehicles (primarily transit buses) are introduced into regular transit service. While not charged with any major regulatory responsibility over public transit, FTA does have limited safety oversight and reporting responsibility. Consistent with this authority, the FTA, through the Volpe Center, engaged Science Applications International Corporation (SAIC) and its subcontractors to conduct a safety assessment based on surveying a sample of transit bus operations using CNG and LNG. The results and experiences gained from these surveys form the basis for this report on CNG and its companion report on LNG.

1.1 OBJECTIVE

The objective of this report is to provide a safety assessment of selected transit bus systems using CNG buses. A companion report provides a similar assessment of transit bus systems using LNG buses. Taken together, the specific objectives are to:

- Provide an assessment of the safety and operational characteristics of CNG- and LNG-fueled transit buses and their attendant fueling and other support systems, based on a limited survey of actual, introductory operations of these vehicles; and

- Establish an initial safety information database for the use and benefit of the FTA and the transit agencies, to assist them in their future decisions with respect to the selection of alternative-fueled buses and, in general, to learn from the initial experiences of their peers.

1.2 BACKGROUND

Federal actions such as the Clean Air Act Amendments of 1990, the Energy Policy Act of 1992, and Executive Order 12759 mandating the acquisition of alternative-fueled vehicles by Federal agencies, established an ambitious schedule for introducing AFVs, including buses. In addition, several states have introduced their own fleet and fuel requirements.

Fuel supply distribution and infrastructure requirements make large fleets of centrally-fueled vehicles ideal candidates for AFV use. Transit buses, which number more than 60,000 nationally, are among the vehicles whose operational and fueling characteristics make them relatively well suited for AFV use, including CNG and LNG use.

Many of the transit agencies who participated in the early introduction of one or more types of AFV buses were essentially writing the rules as they went. The absence of formal or central rules or regulations on CNG or LNG bus use creates a need to capture the lessons learned thus far and pass them along to others. This requirement holds for performance at all levels, training, maintenance, operations, acquisition, and so forth. One of the greatest needs, given the role of transit buses in society, is for information on safety.

Wide differences exist from transit agency to transit agency on hazard and consequence mitigation measures, such as methane monitoring, maintenance facility air exchanges, fueling/defueling practices, and emergency preparedness. Similarly, wide differences in bus design, particularly tank placement and venting arrangements, are common. There are no standards for emergency response, passenger evacuation, system shutdown, staff training and other safety factors.

Transit agencies may view their ATF programs as experimental, full commercial, or something in between. This perspective explains certain decisions over capital investments and training programs. It does not, however, ensure safe operations. To address this situation, the FTA is attempting to develop usable information and guidance on safety issues. As an assistance-oriented agency, the FTA's role is to provide such information to the transit agencies, bus suppliers, user organizations, localities, and others.

1.3 APPROACH

The approach to the present task included in-depth on-site interviews and investigations at three CNG bus operations, reviews of bus and LNG/CNG safety literature, and comparison of CNG safety findings with similar findings from the investigations at two LNG bus operations. The Gas Research Institute report, Introduction to LNG Vehicle Safety, was particularly important in developing the present report. Excerpts were liberally used in areas covering non-cryogenic properties of natural gas and natural gas safety.

The safety assessments included vehicle safety, maintenance facilities and techniques, operations, fueling equipment and operations, storage (parking) facilities and practices, program safety effectiveness, and emergency preparedness.

Actual site visits began with a briefing of objectives and a discussion of the proposed methods. The role of the survey team and the meaning of a safety assessment was discussed. This was followed by a site walk-through and records review. The majority of site activities included extensive interviews in all job categories associated with bus operations, safety, management, maintenance, acquisition, support, etc. Safety and operating procedures and policy changes were of particular interest.

In addition to the interview process, fugitive vapor emissions were measured at each site. The measurement activities covered: 1) area measurements and vapor concentration mapping; 2) instantaneous measurements in the breathing zones of fueling activities; 3) quantification of fugitive vapors from nozzles; and 4) time-weighted measurements in specified areas.

The material in the present report is a safety assessment. A safety assessment identifies hazards and hazardous activities, practices, designs, etc. In the case of CNG buses (or, more generally, CNG systems), these hazards are fire, high-energy gas jets or fragmentation, and asphyxiation. Hazardous activities include indoor maintenance on buses with CNG in the fuel tanks and the use of open flame heaters in maintenance facilities. Non-CNG hazards from buses are not discussed.

A safety assessment does not quantify risks or consequences or recommend modifications to practices, equipment, structures, etc. Thus, there is no discussion of the likelihood or the consequences of a fire initiated by an open flame heater in an indoor maintenance facility. There is only the recognition of the hazard.

A natural follow-on to a safety assessment would be a risk assessment. A safety assessment identifies practices and procedures, and describes the safety-related events that have occurred at transit facilities. Issues are identified, and often corrective actions to problems are observed, identified and presented. However, the safety assessment cannot be used to prioritize actions. Decisions regarding the resolution of identified hazards should be based on assessment of the risk involved. A risk assessment can look at the possibility (or, if quantitative, the probability) of an event or mishap, and couple that with consequences to determine if that scenario should be dealt with.

Risk assessment takes into account hazard or mishap possibility, which ranges from frequent to improbable, and resultant consequences, which range from catastrophic to negligible. An example of a frequent event with negligible consequences is the puff release of gas when disconnecting the refueling nozzle. Less probable but higher consequence events entail the release of gas coupled with the existence of a source of ignition. The events span a range of possible consequences from moderate (i.e., equipment damaging fire) to catastrophic explosion (devastating the entire facility). Risk analysis is a structure that allows the evaluation of event/consequence pairs. The evaluation can take into account decisions or acts to mitigate the event frequency (i.e., design margins in pipes, low relief valve failure rates) or to reduce consequences (minimizing the amount of fuel onboard a bus parked indoors). The FTA may wish to consider additional research in these areas to evaluate risks and consequences.

1.4 CAVEATS

In reviewing this report, please note the following:

- In both the LNG and CNG reports, the safety issues are not identified with particular facilities. The objective of this report is to summarize safety at the industry level, not to report on issues by site. Separate site-specific summaries were provided to the FTA and informally shared with the transit agencies.

- The site investigations took place in early to late 1993. Practices and facilities may have changed since that time.

- An unrelated contractor team (led by Battelle) conducted similar assessments to the ones described by the SAIC team. Their assessments have been documented in the preceding section.

- The project should be characterized as information collection and reduction, not as an engineering review. Technical information was obtained from the personnel and records of the facilities, but was not independently measured, examined or calculated.

2. GENERAL DESCRIPTION OF CNG TRANSIT SYSTEMS

2.1 COMPRESSED NATURAL GAS (CNG)

High quality pipeline gas is available to most existing transit facilities in most major U.S. cities without large-scale expansion of distribution systems. It is composed primarily of methane (CH_4) and has similar physical-chemical properties to methane. For safety purposes, the gas is odorized with a chemical that is distinctly detectable when the natural gas concentration in the air is below its flammability range. The pipeline gas, supplied at 30-500 psi by the local gas distribution company, is compressed to 3500-4000 psi and stored in tanks for dispensing to the vehicles or is directly injected into the CNG cylinders on the buses. Generally, the higher the methane content of the CNG the more desirable it is for vehicle use. CNG presents fire hazards, asphyxiation hazards, and hazards associated with highly pressurized gas and fragmentation of high-pressure components.

2.2 CNG BUS OPERATIONS

While in revenue service, a CNG bus can be distinguished from a diesel bus by a small DOT-required placard labeled "CNG," the absence of the visible smoke and smell associated with the exhaust of a diesel engine, and the existence of a structure above the bus, if the CNG is stored on the bus roof.

CNG buses are serviced like diesel buses. Buses enter the facility in the mid to late evening after completing their routes. They are then marked or lined up for service. The operators leave the buses to the service personnel who fuel, service, and wash the buses. Most CNG facilities fuel buses outdoors before bringing them into a canopy area for servicing. Others fuel buses from dispensers adjacent to the diesel fuel dispensers and other serving apparatus located under the canopies. The fueled and serviced buses are then washed and parked for the next day's operation. Preventive maintenance is performed on the fully fueled buses.

Two of the three transit agencies reviewed report that CNG buses are 'essentially' equal to or more reliable than comparable diesel buses. The third transit agency, which is using pre-production CNG buses with experimental modifications, reports significantly poorer reliability.

2.3 CNG BUS CHARACTERISTICS

The most significant modification required to convert a standard diesel bus design to accommodate CNG is the installation of the high-pressure fuel storage and delivery systems. CNG is stored in 6 to 12-inch diameter high-pressure cylinders mounted on the top or the bottom of the bus. The additional weight is similar for either mounting scheme, and the effects on cornering are slight. Structural modifications are necessary for either mounting arrangement. In the fuel system, high-pressure gas traverses to the engine through a high-pressure regulator and a low-pressure regulator that is part of the engine control system. The buses use turbocharged engines, a natural gas carburetor and control system, and spark ignition. The buses are heavier than diesel buses, and have poorer acceleration and braking. The acceleration loss may be partially offset by an optimized transmission.

2.4 CNG BUS FUELING

Each transit facility uses a fast-fill system based on high-capacity compressors coupled with buffer or cascade storage. The fueler locks a fueling nozzle into a nozzle-activated receptacle on the bus to initiate fuel flow. Fueling is controlled by a computer, which measures tank pressure and ambient temperature, and calculates the necessary fill volume. Fueling takes 4-10 minutes per bus (depending on the station capacity and the number being fueled at a time), compared to 3-5 minutes for a similar sized diesel bus (even if several buses are fueled at the same time).

2.5 CNG BUS MAINTENANCE

The design and operation of the CNG bus maintenance facilities vary. The three facilities visited each began with an existing diesel facility containing a series of service bays with rising doors and a combination of recirculation and fresh air ventilation. Two of the three sites use gas-fired space heaters. The approach to the CNG bus maintenance facility at the three facilities visited can be summarized as:

- One facility allowed no indoor maintenance on CNG vehicles;

- One facility spent several million dollars on modifications to allow indoor maintenance (but continues to use open flame gas-fired space heaters); and

- One facility made no facility or procedural modifications and allows all maintenance to be performed indoors.

The maintenance requirements for CNG vehicles are fundamentally the same as for other internal combustion engines. Maintenance on the CNG components is comparable to that required for the fuel-related components on a diesel bus. The most notable additional maintenance requirement on a CNG bus is that the fuel cylinders must be periodically removed and tested.

2.6 CNG BUS STORAGE AND START-UP

At the facilities visited, CNG buses are stored next to diesel buses in outdoor lots. Start-up procedures are identical. Warm-up characteristics are limited by the pneumatic system, which is the same for diesel buses.

3. THE FUEL -- COMPRESSED NATURAL GAS

3.1 CNG COMPOSITION AND PROPERTIES

CNG is composed primarily of methane (CH_4) and has similar physical-chemical properties to methane. Pipeline-quality natural gas typically contains 85-99% methane. It also contains heavier hydrocarbons, including ethane (C_2H_6), propane (C_3H_8), some butanes (C_4H_{10}), and trace amounts of five-carbon (pentane) and higher species. Nitrogen, carbon dioxide, water, and trace amounts of helium and hydrogen sulfide are also present. At least one engine manufacturer requires 92-95% methane in the CNG.

According to Chapter 2-2 of NFPA-52 (Compressed Natural Gas Vehicular Fuel Systems), gas quality shall comply with the following:

H_2S and soluble sulfides partial pressure	0.05 psi, max
Water vapor	7.0 lb/MMCF, max
CO_2 partial pressure	7 psi, max
O_2	0.5 vol. %, max

Natural gas introduced into any system covered by the standard shall have a distinctive odor potent enough for its presence to be detected down to concentration in air of not over 1/5 of the lower limit of flammability.

Natural gas composition varies from site-to-site and seasonally at some sites. Personnel at each site are concerned that large amounts of non-methane hydrocarbons will enrich the fuel mixture, reduce the octane number, lead to increased hydrocarbon emissions, and increase the potential for engine knock. Additionally, they are concerned about the potential for increased corrosion of components and cylinders in the system. One site reported that it regularly monitors gas composition for non-methane hydrocarbons and for moisture. The other sites irregularly monitored their supply. No site reported serious problems with gas quality.

Important properties of CNG with safety implications are summarized below:

- Autoignition Temperature: Autoignition temperature is the lowest temperature at which a gas will ignite after a lag time (i.e., several minutes). This temperature depends on factors such as the air-fuel mixture and pressure. The average autoignition temperature for pure (100%) methane at atmospheric pressure is 1202°F (650°C). As the concentration of heavier hydrocarbons in CNG is increased, the autoignition temperature is lowered.

- Ignition Energy: The minimum spark ignition energy required to ignite the most flammable mixture of methane in air is 0.29 mJ (millijoule). Practically speaking, most sparks have enough energy to ignite a flammable mixture of methane in air.

- Flammability Limits: Flammability limits express the amount of a fuel that must be present in air for the fuel to burn (assuming air contains 21% oxygen). The lower and upper flammability limits for methane in air are 5% and 15% by volume, respectively.

- Density and Specific Gravity at Standard Temperature (60°F): Density is the mass of a substance per unit-volume. Specific gravity is the density of a substance compared to the density of a standard substance, usually water or air, depending on whether the comparison is with a liquid or a gas. The density of methane at atmospheric pressure and standard temperature (60°F, or 16°C) is 0.0424 lb/ft. The specific gravity of methane under the same conditions is about 0.55.[*] At standard temperature, methane rises in air.

- Density and Specific Gravity at Low Temperatures: The density of methane increases as temperatures decrease. This behavior affects the dispersion of a cold vapor cloud. At temperatures below −160°F (−107°C) the density of methane is greater than that of air at 60°F. During high-pressure leaks, the CNG jet may cool down enough to behave like a heavier-than-air vapor, i.e., like LNG vapor. This is an area of increasing interest at the FTA since it carries important implications

[*] A gas with a specific gravity greater than 1.00 is heavier than air (i.e., it will tend to stay near the ground and will not easily disperse into the air). Conversely, a gas with a specific gravity less than 1.00 is lighter than air and will easily disperse in well-vented areas.

for tank and methane sensor placement. Cold CNG vapor accumulates in low areas until it warms.

3.2 CNG SOURCES

CNG for transit operations is usually obtained from the existing distribution infrastructure. CNG is typically distributed through 2-inch diameter city mains at 25-50 psi, which would not be adequate for a transit facility. However, a 6-inch or larger main, which probably would be adequate for a transit facility, is normally located within a few blocks of any point in a city. One facility tapped into a city main that operates in these pressure ranges, and has found the supply to be adequate for a 50 bus fleet.

Ideally, a transit facility will be located near a higher-pressure gas line, such as those used for long distance transmission or to supply a natural gas-fueled power station. These lines, which operate at 300-500 psi, significantly reduce the cost of compression and localized pressure fluctuations in the CNG distribution system. Two of the sites visited had access to these types of gas lines. One facility was unable to find a gas dryer that could operate at these elevated line pressures, and had to reduce the pressure to 150 psi for drying prior to compression.

Natural gas enters the property of the transit facility in an underground header. Shortly after crossing the property line, the header rises to an above-ground metering station that typically includes redundant flow meters, manual shut-off valves, and pressure reducers for low-pressure uses. The equipment at the metering station is the property of the local gas company. After the metering station, the piping, which is the property of the transit facility, goes back underground and travels to the compressor station. Filters remove water and particulate. The gas is compressed and stored in high-pressure tanks. Since storage is only adequate for a few buses, the compressors run nearly constantly during bus refueling.

3.3 CNG HAZARDS

The use of CNG presents hazards in three areas: fire and explosion*; high-pressure gas jets or fragmentation; and asphyxiation.

- Fire hazards -- Fire and explosion hazards faced by personnel include thermal radiation (heat) burns from fire and contact with hot surfaces, inhalation of combustion products, and physiological effects of a pressure wave from an explosion or associated fragments and projectiles. In a CNG fire, materials such as wood, rubber, most plastics, and fabric will ignite, and metals will soften and may melt. CNG fire and explosion conditions are summarized below:

  Natural gas is flammable in air (which contains 21% oxygen) at concentrations of 5% to 15%. In well-ventilated areas, this concentration range may be reached in a small region near the leak source. In enclosed areas, flammable concentrations are more easily reached over a large area.

  For methane to explode, it must be confined (as in a closed room or a very dense field of obstructions). Flame speeds are too slow to produce the pressure front needed for an explosion in unconfined areas. However, in partial confinement a flame front can accelerate, generating turbulence and, ultimately, a dangerous pressure front. The density and extent of obstructions, therefore, can directly affect the severity of an explosion. Cold, heavier-than-air CNG from a high-pressure leak may flow into confined spaces and may explode if ignited.

- High-pressure gas or fragmentation -- The stored energy associated with any gas compressed to 3000 psi can inflict mortal injuries at close range (several feet). Serious or fatal injuries can be received by jet impingement, impingement of surface dust or pebbles (especially to eyes) or by fragmentation of some part of the high-pressure system.

- Asphyxia -- CNG vapor is not toxic but it can cause asphyxiation. Lung damage may occur from prolonged exposure. Asphyxia occurs where there is prolonged

*"Explosion" refers to the formal term "deflagration," not "detonation."

breathing of air that contains less than about 10% oxygen, or about half the volume of oxygen in air. Under most leak scenarios, asphyxia is not likely because of the strong odorant in CNG.

4. CNG BUS OPERATIONS

Two of the three facilities integrate CNG buses with other buses. The buses run the same routes as similarly equipped diesel buses, are subject to the same preventive maintenance schedule, are fueled and serviced at the same time in the same lanes, and are driven by the same operators. A third facility kept the CNG buses separate, had several dedicated routes, used selected drivers, and had a separate maintenance staff.

The only CNG-related equipment that is under the control of the operator is the fire suppression system. The operator also needs to be aware of two additional CNG-specific components: the fuel gauge (tank pressure), and the shutoff valve. The engine compartment fire suppression system used in the buses is simple, and the operators interviewed were confident that they were adequately trained to use the system if needed. Operators have found the dashboard-mounted fuel pressure meter to be unreliable and, when working, not particularly useful. Operators were not trained on the location of the fuel shut-off valve, or when to use the valve. In some buses, the fuel shut-off valves are not readily accessible to the operator or the access doors are screwed shut.

An operational issue associated with the fuel shut-off valve is the conditions or scenarios in which a bus operator should shut the valve. The use of this valve was discussed with operators, safety and training personnel at each site. Many of those interviewed believed that the bus operators should not be trained to operate the manual shut-off valve. Each bus type has an automatic shut-off valve within several feet of the manual valve, thus the manual valve only protects a few feet of pipe. The risks of being close to a bus with a CNG leak may outweigh the potential benefits of shutting the valve.

At one facility, experimental CNG buses are being used in regular transit operations. Although the buses are nominally as safe as diesel buses, several operators reported that problems with reliability, acceleration, power, braking, stalling, and other factors have become so severe that the buses are a safety problem.

4.1 OPERATIONS HAZARDS

A CNG-fueled bus presents different on-road and on-facility hazards than traditional diesel buses. Several operational events of particular safety significance have been discussed with transit agencies.

- Overpressure relief valve failure -- A tank overpressure valve spuriously lifted on a bus in the fueling lane, but not actually fueling. The failure caused an emergency-shutdown (ESD) actuation, shutting down all fueling activities. The CNG tanks vented quickly and the evacuation went smoothly, the natural gas smell did not linger and the refueling activities were resumed within 45 minutes.

  The transit personnel were disappointed that the valve manufacturer had not yet provided a post-failure analysis. The transit authority did not have any documented incident reports available from these events. The corrective action was to remove the mechanical overpressure relief valves from the tanks. The only protection for the tanks is two redundant thermal relief valves. This is inconsistent with Chapter 2 of NFPA 52, which requires overpressure protection whether a tank is certified to DOT or ASME standards.

- High-temperature relief valve failure -- A temperature relief valve spuriously lifted on a tank pressurized to 400 psi. The tank was in a section of the maintenance shop reserved for body work and paint preparation. The failure did not result in any automatic protective action, since the paint preparation shop does not have gas detectors. The transit agency does not believe that the paint preparation shop needs a gas sensor since it is designed to electrical Class 1, Division 2 standards.

- The release occurred shortly after a worker completed using a small torch to apply a decal to this bus (he did not heat the area of the relief valve). Transit personnel believe that if the relief valve had opened several seconds earlier, the results would have been catastrophic. As with the first event, the valve manufacturer had not yet provided a post-failure analysis.

- CNG Bus Stalling on Railroad Tracks -- An experimental CNG bus with reliability problems, carrying an unknown number of passengers, stalled on a railroad crossing and the passengers were evacuated.

  After several minutes the bus was re-started and moved to a safe location. This incident was frequently cited by operators as evidence that the CNG program was not successful. The incident was well-known to the mechanics and operators but the safety department was unaware of it. There was no follow-up action or written reports, other than ongoing work to deal with the stalling problems.

- Repeated Spurious Lifting of Relief Valves -- One transit agency reported repeated spurious lifting of thermal relief valves (approximately 30) while buses were stored in the lot. The problem was corrected by a vendor replacing all the relief valves.

4.2 CONTINUING ISSUES

The following operations-related issues were being dealt with at the transit agencies:

- Acceleration -- At each transit agency, operators reported that the acceleration of CNG buses was poorer than for similar diesel buses. At the two transit agencies with large CNG programs, the operators reported that the lack of acceleration was not a safety problem. They stated that it merely required some minor adjustments to driving habits. At one agency, several operators reported that the poor acceleration was a safety problem.

- Braking -- Operators reported that the heavier CNG buses required earlier application of breaks than similar diesel buses when approaching stops. This is most likely to be a problem for an operator that switches back and forth between the two bus types.

- Bus weight -- Many CNG buses are at or slightly over the maximum allowable weight for a two-axle, six-tire vehicle.

Two of the three sites had enough experience to perform meaningful evaluations of CNG bus reliability. The CNG buses have recently arrived at the third site, so no statistically significant data was available. Data provided at the first site visited allowed three relevant measurements on data taken from a study group consisting of diesel buses, 9-tank CNG buses and 12-tank CNG buses.

- Average monthly miles -- The 9-tank CNG buses averaged 3000 miles per month, the 12-tank CNG buses averaged 4500 miles per month while the diesel buses were averaging about 5000 miles per month. The differences were attributed to the CNG buses being selected for shorter runs.

- Miles between road calls -- The 9-tank CNG buses averaged about 5500 miles between road calls, the 12-tank buses averaged 6500 miles between road calls and diesel buses averaged 7000 miles between road calls. The differences were attributed to the out-of-fuel road calls for the CNG buses.

- Road calls by major subsystem -- Figure 2-1 shows the road calls broken down by major bus subsystem for two types of diesel buses and CNG buses (not broken into tank configurations). Note that the distribution of road calls is similar with the exception of the out of fuel system road calls for the CNG buses.

Modifications to the fuel gauge, driver training, route planning, and the conversion to an all 12-tank fleet are reportably reducing the number of out-of-fuel road calls at this transit organization. Bus availability data was available in different forms at the other transit facility with data. The road call information could not be broken out to directly compare the diesel buses to the CNG buses. However, based on a log maintained by the CNG mechanics, the CNG bus availability for service on a daily basis was 56%. The diesel bus availability was well over 80% based on their proven ability to meet road call, which requires 80% of the fleet, on a daily basis. A reason for the poor performance is that these vehicles were designed to be proof of concept vehicles, containing experimental engines, engine electronics, sub-engine components, CNG cylinders, fuel systems, etc. In addition, the non-CNG equipment on the vehicles utilizes a number of one-of-a-kind, proof of concept system configurations including the braking system, the suspension, the transmission, and parts of the electrical wiring. The use of experimental components and proof of concept system configurations, placed into a fully operational environment, resulted in extremely challenging maintenance requirements. The impact of these maintenance-related issues

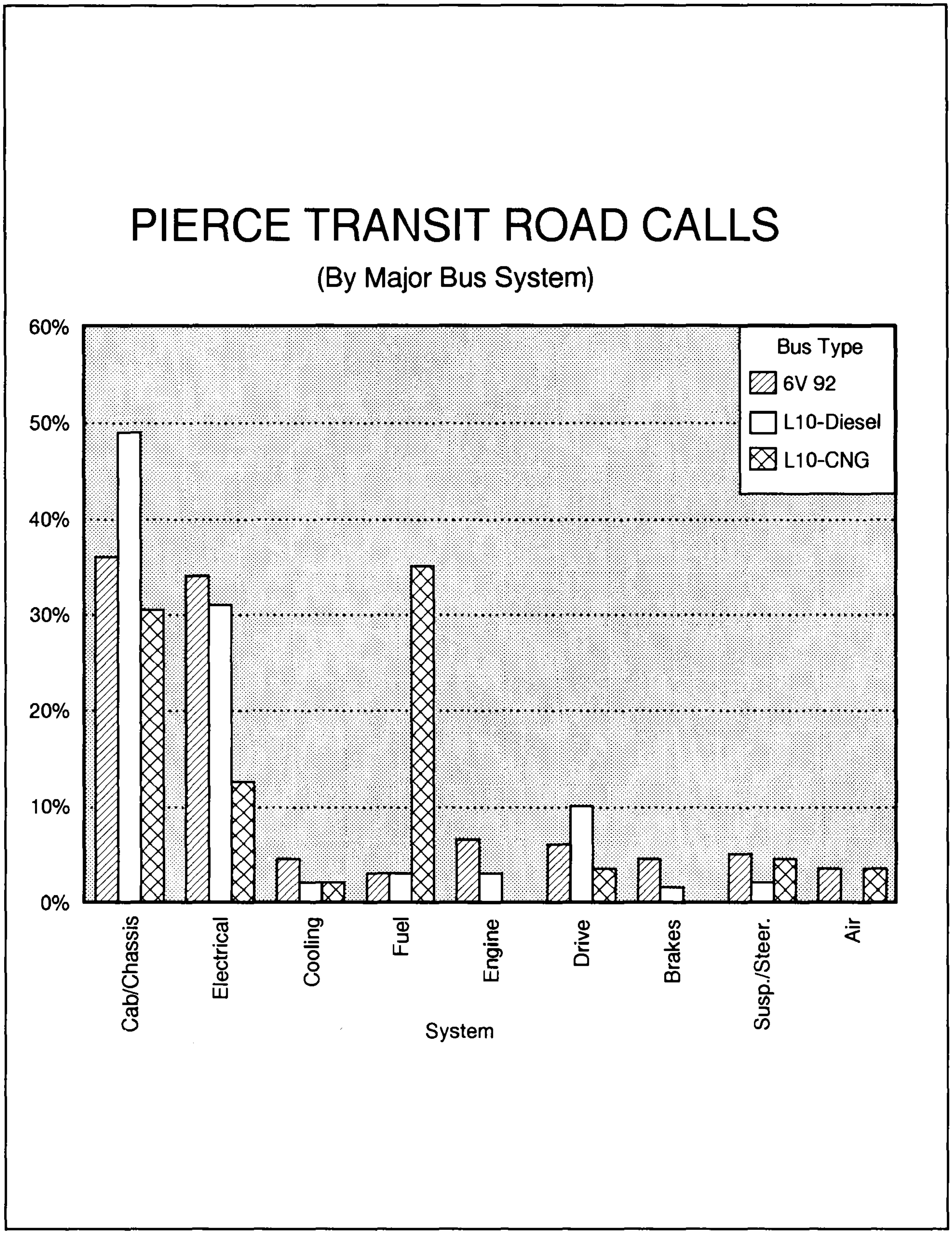

Figure 2-1. Road Calls by Major Bus System

(financial limitations, organizational issues, experimental components, and proof of concept system configurations) is clear from the very low bus availability -- 56% versus greater than 80% for diesel buses.

5. CNG BUS CHARACTERISTICS

5.1 CODES

Chapter 3 of NFPA 52 provides recommended requirements for an on-board fuel system. Major sections include information on component qualifications, fuel supply containers, pipes, valves and other systems. The high-pressure fuel tanks used on the CNG buses require re-certification on a three-year basis as prescribed in the Code of Federal Regulations 49 CFR 173.34(e).

5.2 EQUIPMENT

Two types of CNG buses were observed. Buses built by the Flxible Corporation have the fuel tanks below the bus. Buses built by Orion have the tanks above the bus. The obvious advantage of the top-mounted tanks is safety-related, in that they are ordinarily less prone to direct hits by other vehicles during accidents and, if damaged in a collision in which the bus remains upright, would leak or vent upwards away from passengers. (As discussed earlier, high-pressure CNG leaks may be heavier-than-air for a period of time and thus not immediately rise. This issue in under review.) Undercarriage mounting provides better structural support from the bus chassis and nominally better balance. Figures 2-2 and 2-3 show the arrangement and features of the fuel systems.

Operators reported no instance of a bus with top-mounted tanks making a bus feel top-heavy. There are no known instances of a bus with top-mounted fuel tanks rolling over. The bottom-mounted tanks are protected by a support skirt and located below the frame and between the front and rear axles. Although CNG piping has been damaged in side impact collisions, there have been no serious injuries as a result of a collision with a CNG bus.

The volume of the fuel required to travel the standard 400-mile operating range between refuelings is approximately 16,000 standard feet^3 of natural gas (at standard temperature and pressure). To get this volume of gas into the tanks, the gas is compressed to 3000-3600 psi. In the bottom-mounted buses, the gas is compressed to 54 feet^3, and contained in six DOT-certified high-pressure cylinders. Each cylinder has a water capacity of approximately 9 feet^3 or 67 gallons. Orion buses originally had 9 cylinders on the roof. The common arrangement is now

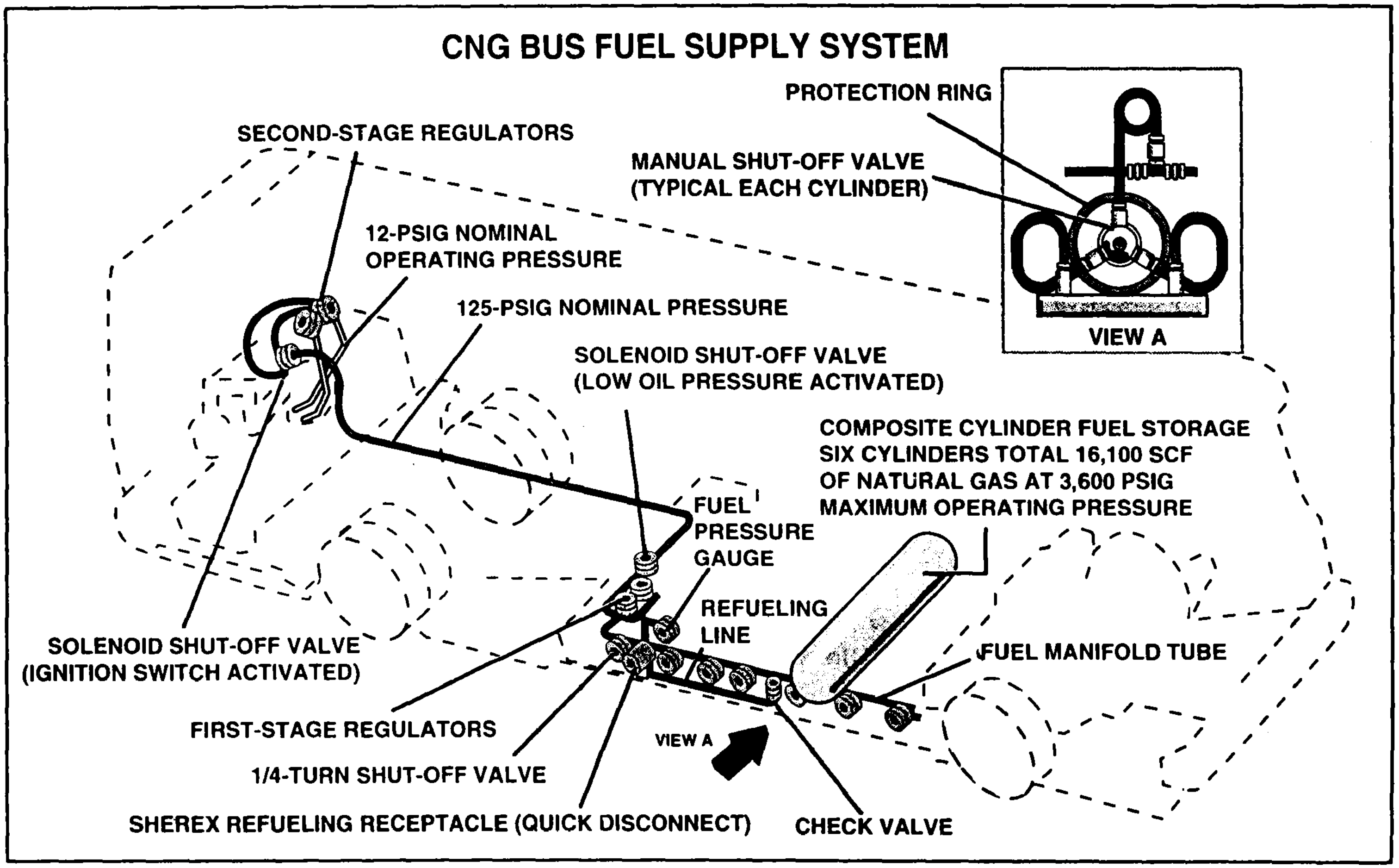

Figure 2-2. Flxible Corporation Bus Fuel System Arrangement

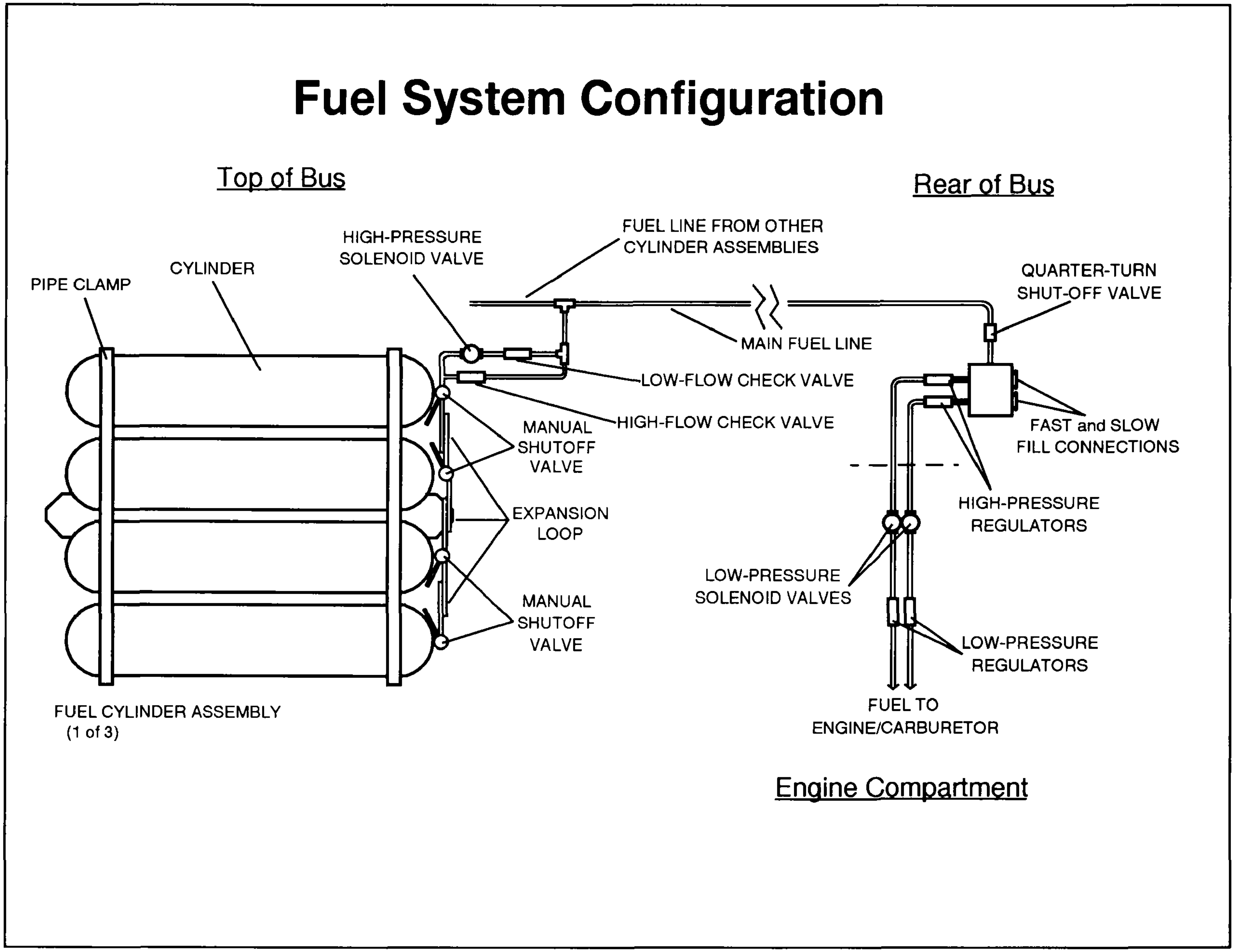

Figure 2-3. Orion Bus Fuel System Configuration

12 cylinders. Pressure transducers coupled with dashboard-mounted gauges provide the bus operator with a rough indication of on-board fuel available.

The fuel cylinders are made of spun aluminum wrapped with Fiber Reinforced Plastic (FRP). Each tank has two thermal relief valves designed to vent at 100° C (212° F). Two mechanical (rupture disks and spring-loaded) pressure relief valves are also fitted to each tank. One transit agency removed the mechanical relief valves and will order future buses without them. Another transit agency experienced frequent ruptures of the thermal relief valves. The relief valves suffered from failures due to the soft eutectic material being extruded from the housing.

Relief valves are manifolded together. The bottom-mounted tanks vent to a common header that runs toward the rear of the bus from the undercarriage. It rises up and around the engine compartment into the air-conditioner's air-intake compartment. The header makes a right-angle turn rearward and exhausts at the upper right corner at the rear of the bus away from the bus doors and windows but within the air conditioner's air-intake grate. The top-mounted cylinders are equipped with individual relief valve ports that direct the gas upward through holes in the protective cover.

A shut-off valve is installed in each tank, located on the right side (curb side) of the Flxible buses and in the roof compartment of the Orion buses. The purpose of these valves is to isolate each tank from the rest of the fuel system. Stainless steel tubing and compression fittings are used throughout the high-pressure side of the fuel system. The entire fuel storage system is isolated from the engine fuel delivery system by a 1/4-turn shut-off valve. The Orion quarter-turn valve is located behind a door in the rear corner of the bus, about 6 feet above the ground. The valve on the Flxible bus is located underneath the skirt.

Fueling is accomplished using Sherex CC-5000 couplings. A check valve was installed in the high-pressure manifold as a redundant safety feature. Failures in the check valves were due to debris in the refueling system.

An oil-filled bourdon tube pressure gauge is used to indicate pressure in the fuel system. The fuel door is equipped with a magnetic switch that prevents the bus from starting and driving off with the fuel nozzle still attached. However, it does not prevent a bus from continuing to run if it was already running when the fuel door was opened.

The high-pressure gas is reduced from the service pressure of 3600 psi through water-heated regulators located near the fuel tanks. Engine coolant circulates through the regulators to eliminate freezing as the gas goes from high to low pressure. The lower-pressure gas is fed to secondary regulators located in the engine compartment where its pressure is reduced further. A CNG engine uses the same block and major mechanical components as a diesel engine but different controls. In a CNG engine, the low pressure gas is mixed 1:26 with the combustion air from the turbocharger. The mixture flows through a throttle valve assembly to the cylinders. This function is accomplished by the injectors in a diesel engine.

Compression is a maximum of 10.5 to 1, which is below NG's autoignition point. Ignition is by spark. In comparison, a diesel engine compresses pure air 17:1 and then receives an injection of fuel, which causes immediate combustion via autoignition.

Several other unique features of a CNG engine include:

- High-pressure CNG regulators that must be warmed with engine coolant to prevent icing.
- Low-pressure regulators that control the pressure of the gas to the mixer.
- Increased turbocharger cooling requirements because exhaust temperatures are higher.
- An electronic or electromechanical governor to control engine speed.

5.3 EMERGENCY EQUIPMENT

The Flxible buses have a fire sensor in the engine compartment connected to a chemical extinguisher. The Orion buses have a dry chemical system that can be manually operated from the driver's seat or automatically activated at a temperature of 275°F in the engine compartment. Additionally, the operator can manually actuate the system from a device near the driver's seat. In any case, the system fires a nitrogen squib from a small tank near the driver that traverses a metal pipe to the engine compartment. The pressure spike from the nitrogen activates the system.

5.4 CONTINUING ISSUES

On Flxible buses, the on-board CNG tank relief valves lift into a header that traverses from the tanks toward the rear of the bus, then up through the engine compartment to the upper rear grating. This same grating area serves as the intake for the bus air conditioning air. The gas released should generally go outside of the vehicle structure. However, the possibility of gas, either from a spurious relief valve lifting or from a valve seat leakage, being sucked into non-spark free equipment and, ultimately, into the passenger area of the bus is of concern.

NFPA 52 Chapter 3-6.2 requires "... a manual shut-off valve shall be installed in an accessible location that will permit the isolation of the containers from the remainder of the system." All buses have manual shut-off valves, but the valves are difficult to find on the Flxible buses. The valves' location is not marked in accordance with NFPA 52, Chapter 3-6.2.2 because of a concern about them being maliciously shut by pedestrians. On some Orion buses, the valve doors can only be opened by a special wrench that is not carried on-board. An evaluation (i.e., HAZOP) should be conducted to determine if these valves should be positioned for immediate access by drivers and on-site transit personnel.

CNG buses are somewhat heavier and have slightly lower horsepower than their diesel counterparts. Adjustments to the transmission (i.e., lowering shift points) have mitigated acceleration problems sufficiently to satisfy most operators. The extra weight has also affected braking performance and brake life. Transit authorities and bus manufacturers should carefully monitor brake performance to determine proper maintenance schedules.

No buses have on-board (passenger compartment, engine compartment, or fuel tank area) methane detectors. Since CNG is odorized, leaks that penetrate the passenger compartment during bus operations will be detected before flammability levels in the compartment are reached. However, other leaks that do not penetrate the passenger compartment may go undetected while the bus is in operation.

6. FUELING

6.1 EQUIPMENT

Figure 2-4 shows a typical fueling station at a transit facility. Fueling station specifications should be based on: 1) the average daily transfer rate per bus, at a pre-determined delivery pressure (3000-3600 psi); and 2) the rate at which buses are expected to arrive. For example, one four-dispenser system was required to initially fill four buses in one ten-minute period followed by one bus every ten minutes thereafter. These specifications were chosen to match as closely as possible the fueling times of diesel buses.

The compressors and the high-pressure storage tanks are either in a fenced area, a lockable protective shed, or both. High, protective metal guard posts set into concrete are spaced around the perimeter of the compressor area for protection from vehicular traffic.

The main components of the compressor stations are:

- Dryer -- The dryer removes moisture from the incoming gas. Typically, dryers have desiccant-filled chambers, microcomputer control panels, and externally-heated blowers for regeneration.

- Station Control Panel -- Controller for the compressors designed to control the filling of buses and storage vessels.

- Compressors -- Electric-powered, 3- or 4-stage compressors rated to 4000 psi are normally used. Compressors in warm, dry climates are outdoors. Compressors in cooler climates are in sheds.

- Storage Banks -- Each site used multiple vessels grouped into banks. Each vessel has a valve for isolating it for maintenance and a pressure relief device for safety. Cascade and buffer storage banks are used. Cascade storage fills the buses from the lowest pressure tank first. The compressor simultaneously fills the tanks. Buffer storage allows the compressor to fill either the tank or the bus, and allows the tanks to empty into the bus while filling.

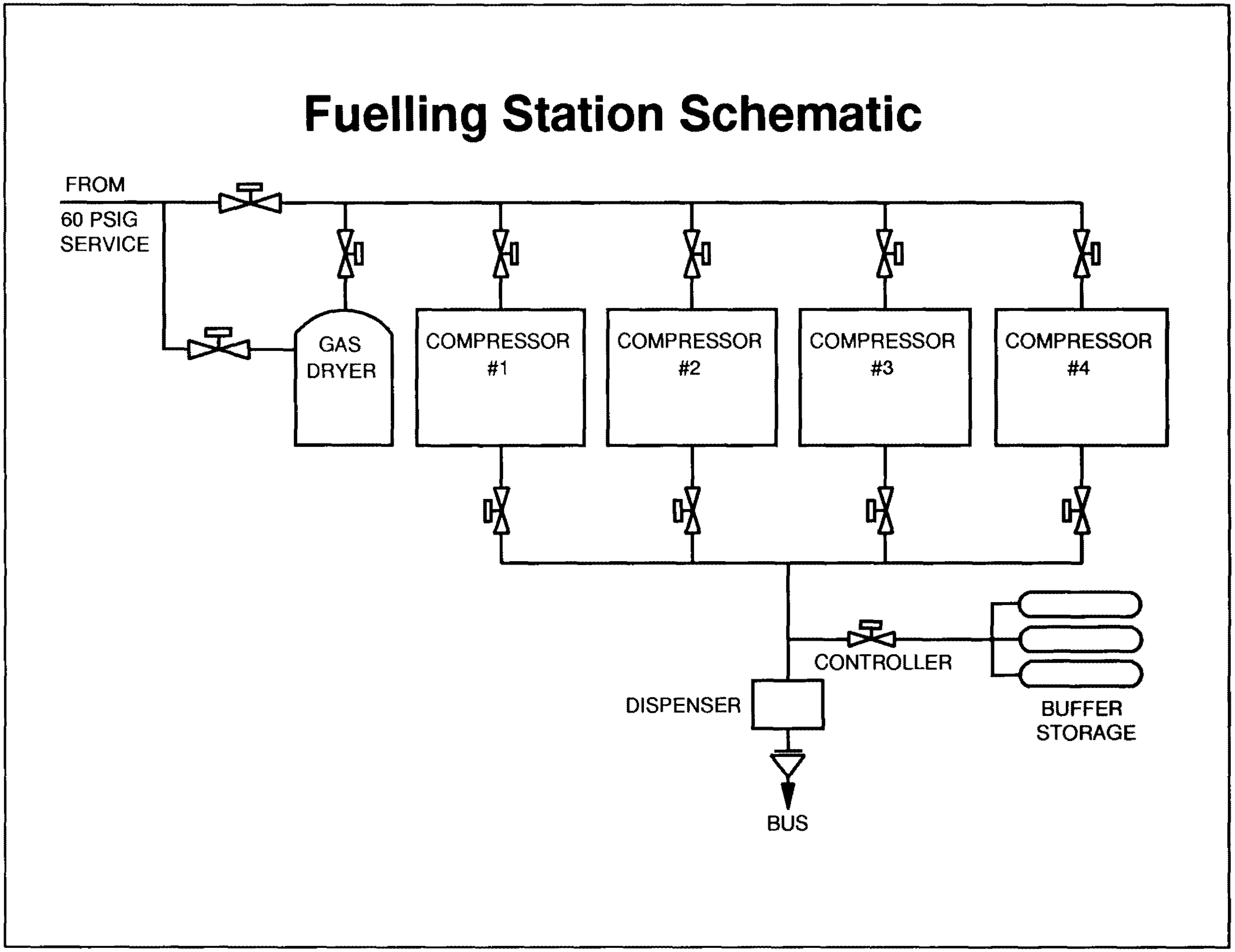

Figure 2-4. Typical Fueling Station Schematic

- Fill Posts -- Each site has multiple fill posts at the fuel island, which is separated from the compressor area. Each fill post is equipped with a Sherex CC-5000 nozzle, breakaway connection for safety, shut-off valves, pressure gauge, nozzle relief valve for venting (to allow removal of the nozzle from the vehicle if seized), and an electrically-operated solenoid valve that closes when a ceiling-mounted gas monitor detects natural gas. A micron filter was added to several units to capture dirt and welding slag.

- Gas Monitoring Equipment -- The facilities with covered fueling areas had gas monitoring equipment connected to emergency shutdown equipment. Facilities were not consistent in determining the need for monitoring equipment in the area of the compressors.

- Dispenser Control -- Using the initial tank pressure and ambient temperature, a computer controller calculates the mass of CNG to be supplied to a bus. The dispenser is shown in Figure 2-5.

Some of the fuel supply stations are equipped with a valve that shuts upon excessive flow, as would be experienced following an on-site line break. The manual valves located near the meter could be shut during an on-site problem, but no site had such action in its emergency procedures or training plan.

6.2 CODES

The codes and standards used in the design of a fueling station are:

- National Fire Protection Association (NFPA) Standard #52, CNG Vehicular Fuel Systems

- City Building Code

- City Fire Department Requirements

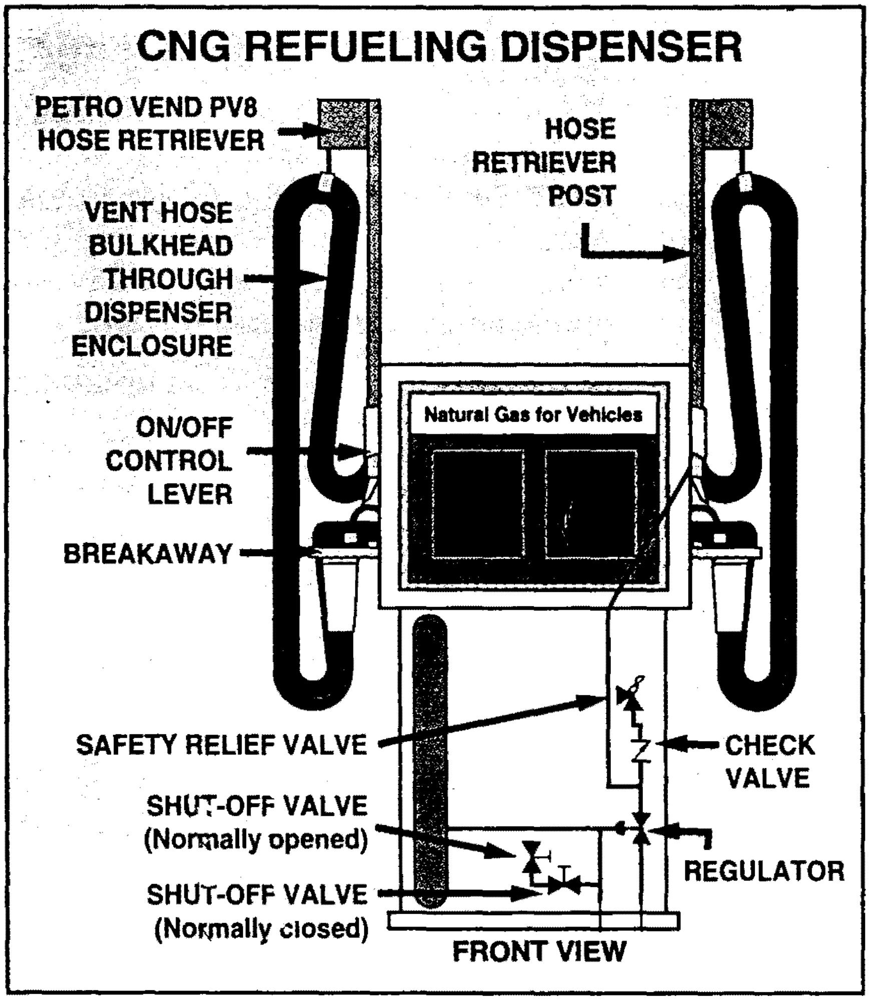

Figure 2-5. Typical CNG Dispenser

- Local Gas Company Standards
- NFPA Standard #70, National Electrical Code
- American Society of Mechanical Engineers (ASME) Code Section VIII, Unfired Pressure Vessels
- Underwriters Laboratory (UL)
- American National Standards Institute (ANSI) Code for Pressure Piping, B31.3
- Uniform Building Code, 1988 edition

There is some controversy in the industry on the electrical rating requirements for the compressors and associated equipment. Local fire marshals reviewed each installation and, although no specific guidance is provided in national codes, determined that equipment within the compressor enclosures should be Class 1, Division 1. Other equipment that could be exposed to explosive environments should be Class 1, Division 2. The 1992 version of NFPA 52, which was published after the agencies visited had completed their initial installation, gives clarified guidance in Chapter 4.

6.3 HAZARDS

A lengthy list of hazards and potential hazards associated with fuel supply equipment and refueling were identified during this survey. These are grouped according to design, equipment, procedures, and leaks.

<u>Design</u>

- The vents for some fueling islands empty under a canopy, creating the potential for gas build-up. An engineer stated that this was done to provide the operator with an audible verification of venting. The canopy is open on three sides and equipped with gas detectors. Since the most commonly used refueling island vents above the roof, there is no experience to indicate whether gas build-up is a problem. Plans to have all vents empty above the roof line are being made.

- In some cases, the stations are poorly protected from internal traffic (buses and other support vehicles) and from external traffic threats, which vary with the local traffic patterns. The facilities typically use 3-to 4-foot hardened stanchions spaced less than the width of vehicles to protect the stations.

- There is no immediate access to emergency communication system (phone, intercom, etc.) at fueling and compressor stations.

- Poor ergonomics exist in several fueling areas. No instructions or procedures are posted or available at the work site, valve handles are placed in awkward locations, and gauges are not easily visible from fueling area. The CNG dispensers have been back-fit into very close proximity (less than 5 feet) of the older diesel dispensers. Despite the large expense in designing and installing the CNG facilities, the gauges, fill, and vent valves are mounted on shop-created structures and labeled by hand with a marker.

- One enclosed fueling station has sparking equipment located about 16 feet from the fueling point. More research is needed to determine if 16 feet is adequate (or excessive) separation from a 3600 psi CNG tank.

- One facility located the CNG dispensers on an island separate from the other fueling and servicing equipment. The other facilities integrated CNG dispensers into their regular service lanes and basically established spark-free zones in the area of the fueling. All the electronic fuel control terminals adjacent to the fill posts were relocated away from the Class 1, Division 2 hazardous location as defined by NFPA 52.

- One fuel island has a pitched roof, thus ventilation had to be added at the highest point of the roof to exhaust the natural gas.

Equipment

- Multiple nozzle leaks on dispensers were noted at some fueling stations report.

- Breakaway systems at the refueling stations are not foolproof. At one facility, a bus drove away with the hose attached, and the breakaway mechanism failed to function.

- Several transit agencies had to back-fit additional filters to trap particles left in the system during construction.

- Fuel dispenser valve handles failed during evening refueling. The partially operable valve continued to be used throughout the night. Although apparently not a safety problem, the fuelers seemed accustomed to operating with degraded equipment at one facility.

Procedures

- According to procedures, the fueling hose should be vented after each use. The review team checked the hoses during a period of very low activity and found several hoses pressurized. This could have been caused by poor material condition (leaking valve) or poor procedural compliance.

- Fueling operators, the safety manager, and a fueling manager did not know where the manual shut-off valve was located on the bus.

- Diesel buses are not regularly shut off while CNG buses are refueled in an adjacent lane.

- At one site, the compressor system and controls are unlocked, unguarded, and within unguarded gates. A malicious individual with a standard wrench could initiate a high-pressure gas leak at any of these facilities. At other sites, the equipment was inside the perimeter fence.

- Regular maintenance was performed by isolating sections of the system from other portions of the system that continued to operate at high power. None of the facilities used red or danger tag procedures such as those required by OSHA regulations in 10 CFR 29 Section 1910.147.

- No warning signs, such as "No Smoking" or "CNG" are present at the large compressor and storage station at one site.

- Contractual complexities and the unavailability of parts and service from a vendor caused a transit authority to operate under less than desirable (but not necessarily unsafe) conditions.

- Refueling operations are not fully attended (could not detect leaks while refueling, could not notice equipment malfunctions, etc.).

Leaks

- Natural gas could migrate through holes in the ceiling above an enclosed fueling lane and accumulate in a dead space between the ceiling and roof.

- Leaking gas from compressor and fueling areas coupled with the lack of gas detection or alarm equipment at one site increased site risk.

6.4 EMERGENCY EQUIPMENT

At least one local (near compressors) and one remote (near fueling station) push-button to shut down the compressors was installed at each site. One site that fuels under a canopy open on three sides installed one detector per lane that shuts down CNG flow to the entire fuel island.

One site installed an elaborate facility-wide ESD system to protect the CNG station, the fueling lanes, and the two major areas of the bus shop. Each area has an independent system consisting of rotating red and yellow beacons, an alarm horn, one or more gas detection sensors and transducers, egress lighting, and emergency stations at the three most likely shop exits. The ESD system runs off a circuit independent from the main breaker in the switchgear.

When a 20% Lower Explosive Limit (LEL) is detected by a sensor, the yellow beacon, alarm horn, and mechanical ventilation in that area are activated. If 50% LEL is detected or the system is manually activated, red beacons and alarm horns are activated, and main power to the facility is cut off. All workers are trained to evacuate to a point across the street from the facility. The ESD system also includes rooftop beacons to inform evacuated personnel of the status of the event.

The CNG fueling facility is equipped with ESD valves in the inlet gas line to the compressors, at each compressor, at each buffer vessel, and in every line that feeds the dispensers. In addition to an ESD signal, the following conditions cause these valves to shut:

- loss of electrical power;
- loss of instrument air;
- physical damage to a dispenser (i.e., struck by a bus); and
- low pressure sensed at the vessels.

All equipment energized by the ESD circuit that is within 16 feet of a normal bus parking area (based on a postulated rupture) or within 18 inches of the ceiling in the shops (based on vapor filling this area) is electrical Class 1, Division 2.

Other emergency equipment includes:

- breakaway protection that stops natural gas flow in a bus pull-away accident;
- valves that fail shut upon loss of power;

- manual isolation valves that can be shut to isolate major sections of the system; and

- grounding devices to prevent ignition from static or stray currents.

6.5 CONTINUING ISSUES

The acceptability of fueling in an enclosed or semi-enclosed area needs to be evaluated. Fueling in an enclosed area will be accompanied by the flurry of activity associated with servicing buses, which increases the likelihood of human errors and the possibility of sparks. Two facilities fueled CNG from dispensers adjacent to the diesel fuel pumps. This was more efficient from a queuing standpoint. One facility fueled outdoors, just before entering the service lane. This adds an extra discrete step to the servicing while lowering the risk of CNG accumulation under an enclosure. This extra step reduces the capacity of the service lanes, which may be a problem for other facilities. Neither operation appeared to introduce unacceptable levels of risk or operational delays, but continued evaluation is warranted.

7. MAINTENANCE

Three distinct approaches to maintenance facilities were observed. One transit authority, located in a warm, dry climate, performs essentially all maintenance outdoors. One lane of one facility (the dynamometer shop) was made spark-free, but since it is required for general use, CNG buses cannot be parked in this area for long periods.

Another facility determined that no modifications to the maintenance facility were necessary to support CNG maintenance. Buses are maintained in the same bays as diesel buses with no additional ventilation and no gas detection.

At a third facility, extensive modifications were made to the existing maintenance garages at the same time as the fueling facility was being constructed:

- The area within 18 inches of the ceiling deck was defined to require Class I Division 2 electrical equipment. Existing non-classified equipment in this area was either relocated to a non-classified area or replaced with Class I Division 2 equipment.

- Improved natural ventilation was provided by replacing the clerestory windows with screens and louvers to allow natural ventilation.

- Class I Division 2 mechanical ventilation systems capable of an air flow rate of 5 air changes per hour were installed.

- A Gas Detection System was installed at the ceiling. At 20% LEL, this system turns on the active ventilation and sounds an alarm. At 50% LEL, the system shuts off all non-classified electrical devices located above the buses by de-energizing the circuit at the main breakers.

- Manual activation of the 50% LEL actions is provided at key locations.

- Eight gravity hoods were installed. These hoods are louvered devices installed in the roof, designed to open and release the lighter-than-air natural gas vapors at the slightest overpressure.

7.1 CODES

NFPA 52, Chapter 3 provides significant guidance on the maintenance, inspection, and testing of on-board CNG components. Specific guidance is provided in installation of system components such as fuel containers, piping, valves, and connections. Maintenance and parts replacement must be conducted to ensure that only CNG-qualified components are used.

Section 3-12.2 of NFPA 52 states that "Before use, every connection shall be checked with a non-ammonia soap solution or a leak detector instrument after the equipment is connected and pressurized to its service pressure." This requirement is not followed in the field.

NFPA-52 exempts CNG mounted in vehicles from the maximum indoor storage requirement. However, it does give ventilation, detection system, and ignition source prohibitions that are applicable to storage facilities. If buses are parked inside a maintenance facility, it seems reasonable to conclude that it be considered a storage facility. Since it is operating on an exemption on the total volume of gas allowed, extra care in preventing problems is warranted.

Transit authorities have been unable to identify codes or provide detailed requirements for building or modifying maintenance facilities. Some authorities have patterned their approach after that of other authorities. However, there is no consistent or accepted approach.

7.2 MAINTENANCE LEVELS

Two of the three sites have noticed no significant increase in the amount of maintenance (preventive or corrective) for CNG buses compared to diesel buses. This was confirmed by an independent review of the maintenance records at one site with several years of experience. The other site did not have enough experience to make a valid assessment.

At the third site, managers expressed significant concerns about the operational availability of CNG buses. The number of road calls and operational availability were concerns. The mechanics' logs showed that average operational availability for CNG buses was 56%. This is far below the FTA fleet average requirement for 80% availability for roll-out. Since this facility has "never" failed to meet the roll-out requirement, diesel availability must be well above 80%.

On a per bus analysis, the CNG buses were less than a factor of 2 worse than the diesel buses but the CNG buses spent considerably less time on the road than the diesel buses. Reasons for the reduced road time include:

- The CNG buses operate weekday-only runs.

- Operators choose non-CNG buses when possible.

7.3 SPECIFIC HAZARDS

Work is conducted on the 3000-3600 psi CNG systems without procedural controls. Workers are aware that the system is hazardous but not uniformly aware of the potential consequences. The following are examples of safety issues raised at various sites:

- No CNG-specific safety program or safety manual. A one-page draft guide was constructed during our visit.

- Individual mechanics find it difficult to disseminate information about preferred safety procedures.

- Not all indoor staff are able to handle simple emergency response procedures (locate main shut-off valve on the bus or locate and access open flame heater shut-off switches).

- No application of lock out / tag out procedures when breaking the integrity of the high-pressure gas system, either on the vehicles or at the refueling station. (Investigate OSHA standard 10 CFR 29 Section 1910.147).

- No emergency action procedures or training are provided. Immediate action following a 3000 psi line rupture could prevent a catastrophic incident.

- Lack of uniform and uniformly disseminated information about the CNG vehicle maintenance practices.

- No manuals, no instructions, limited training, no contractor/supplier support, lack of spare parts and special tools (i.e., engine analyzer, drop light) at one facility.

- Limited trained manpower to work on CNG vehicles. Maintenance personnel stated that untrained personnel will not work on even the non-CNG portions of CNG vehicles because of fear of the unknown.

- At one site with a small number of early buses, non-standard design of electrical systems, engines, and other bus systems caused logistical problems.

- Inconsistency between training manual and as-built configuration of buses.

- CNG buses are not allowed into the regular maintenance or tire shop, making them undesirable to work on. Several mechanics (CNG-trained, but not CNG specialists) resented having to work outdoors. This requirement increases the unavailability of the CNG fleet.

7.4 CONTINUING ISSUES

Transit maintenance facilities typically use natural gas-fired space heaters. Space heat is necessary because central heating is virtually impossible in buildings where large doors are continually opened and closed. Space heaters are used whenever exterior temperatures dip to about 50 degrees Fahrenheit. Most engine work cannot be performed with heavy, warm gloves or excessively cold hands.

Space heaters are an ignition source since they are normally above the work area. If the facility has no detection equipment or improperly placed detection equipment, a fire could occur before the leak was detected and corrective action taken. In the event of a faster leak, which could be detected by sound or smell, it is unlikely that maintenance personnel could secure and cool the space heaters rapidly enough to prevent ignition.

The overall problem is the lack of clear guidance, standards or criteria for a CNG vehicle maintenance facility. One facility determined that the best solution is to not allow its buses into the normal maintenance shop. Few climates in the United States are warm enough and dry enough for this policy to work. Even in good weather, maintenance technicians do not like to work outdoors because of the requirements for mobile lifts, carrying tools, rougher ground, and general inconvenience. The requirement to perform maintenance outdoors contributed to an unsupportive and sometimes antagonistic attitude toward the CNG program.

Therefore, maintenance safety should be treated with an additional degree of care and formality, much like that required at industrial facilities (i.e., refineries, nuclear reactors) or in the military (i.e., ships, aircraft). The types of activities that should be incorporated into this program are:

- Formal training or certification before work on high pressure systems. Maintenance personnel continuously expressed the need for additional training from equipment vendors. Two of the sites had significant problems with the lack of vendor support for compressors and related equipment. Vendors did not leave adequate technical manuals, did not provide detailed hands on training, and were often unavailable for consultation.

- Standard safety procedures for every CNG job, with requirements for venting tanks in some specific cases, double valve isolation, etc.

- Use of red tags so that valves and breakers are not inadvertently actuated.

- Work area safety procedures that carefully control the ignition sources around the shop to keep them away from the CNG work.

- Safety procedures and training for potential incidents in maintenance shops.

8. CNG BUS STORAGE -- PARKING

Each facility stores all buses outdoors. None reported considering indoor storage. Although not analyzed in detail, the capital cost of such a facility makes conversion to indoor storage expensive. Since indoor storage increases the likelihood of a rare but extremely high consequence fire or explosion for a single bus, and significantly increases the conditional probability of an event spreading to multiple buses, it is not recommended. If other requirements necessitate indoor storage, the area should be well-ventilated and supplied with gas detectors. Indoor storage does, however, increase the life of the bus's body by protecting it from the elements and of the engine by not requiring starts when the oil is very cold. Additionally, indoor starts and storage improve driver morale and comfort.

The buses are fueled in the evening after the day's operation, thus they are stored for the night at full tank pressure. Since two of the facilities have had relief valve failures, there is a continuing concern for leaks in the storage yard. Transit agencies are quite noisy if any buses are operating, thus a significant leak may not be heard by the few people in the area.

The two hazards associated with storing CNG buses are rapid and slow CNG leaks. The most likely cause of a rapid leak is a failure of a high-pressure relief valve attached to a tank. Two transit facilities reported problems with spurious lifting of relief valves. One had to replace all relief valves, and the other removed them. These actions have significantly reduced spurious lifting problems. As the relief valves age, however, the likelihood of failure increases.

Slow leaks are less likely to be detected when a bus is stored outdoors since slowly leaking natural gas disperses quickly. (Rapidly leaking gas may not disperse as rapidly because of the cooling and density issues discussed earlier.) Slow leaks are not likely to be a significant flammability hazard if gas is not allowed to accumulate.

One facility stores CNG and diesel buses in a paved area under a highway overpass. A long-lasting fire or an explosion could cause minor damage to the highway, and necessitate closing it to traffic. It is unlikely that an event in the bus lot could injure anyone traveling the highway. It is difficult to imagine a credible scenario in which a highway incident would create a serious incident in the bus storage yard.

9. SPECIAL CONCERNS

Various measurements were taken at the CNG facilities to try to determine the occupational exposure and safety hazards associated with the operation of CNG buses. Bag samples were taken from the atmosphere inside the maintenance facility and in the area of the refueling activity. Aldehyde samples were taken inside the maintenance facility. Total hydrocarbon measurements were taken throughout the entire facility, indoors and out. The leakage from fueling connections was measured by building an enclosure around the bus fueling connection and the Sherex 5000 nozzles.

The bag samples and aldehyde measurements indicated measurable levels of hydrocarbons and formaldehyde, respectively. However, the source could not be traced to CNG buses, diesel buses, or other activities in the maintenance building. The formaldehyde levels varied from 0.0022 to 0.0065 ppm.

Hydrocarbon measurement indicated low levels of hydrocarbons everywhere but in the immediate vicinity of the compressors and, to a much lesser degree, the dispensers. This was attributed to the large number of CNG fittings under pressure and the vibration of the compressors.

Accurate measurements of the amount of CNG lost during the fueling process were difficult to obtain, but it appears that a small amount is lost during normal refueling connections. It appears that leakage from the Sherex 5000 nozzles is consistently less than 5 cc per refueling. The gas disperses quickly and the occupational and ignition risks are minimal.

10. SAFETY PROGRAMS

According to personnel interviewed, CNG transit programs need two distinct emergency plans. They need a focused plan for on-site emergencies and a broad plan for on-road (i.e., off-site) emergencies. Two of the three sites had little or no emergency plans for on-site emergencies and essentially no on-road emergency plans.

One site had considered an emergency plan starting with the design phase of facility modifications. As part of this plan, an ESD system is installed to protect the CNG station, the fueling lanes, and the two major areas of the bus shop. Each area has an independent system consisting of rotating red and yellow beacons, an alarm horn, one or more gas detection sensors and transducers, egress lighting and emergency stations at the three most likely shop exits.

This transit agency is also the only agency visited that conducts on-road emergency training. Two CNG buses were received several months prior to the rest of the fleet. The transit agency visited each fire department likely to respond to an on-road emergency and gave fire fighters a detailed tour of the vehicle. Additionally, they presented a briefing on the characteristics of the bus and of high-pressure CNG in general.

The involvement of safety professionals in all the aspects of the CNG program varies from site-to-site. In situations and portions of programs in which safety professionals were involved, more standards were followed and safety-related ideas were implemented. At one facility, safety professionals were heavily involved in the design of the fueling facility, but not involved in the buses or day-to-day operations. Based on discussion with the staff at that facility, there is significant concern about the safety of day-to-day CNG operations and maintenance other than fueling buses. Although there are unresolved safety issues at the fueling facility, the personnel seemed confident that the facility is safe. Similar situations were observed at other facilities.

11. MANAGEMENT AND SAFETY AWARENESS

CNG has significantly different hazards than those associated with diesel fuel. Many of the workers interviewed were very interested and knowledgeable about how company management and safety officials were involved in the implementation of the CNG programs. The acceptance of the CNG programs appears to be directly related to involvement of the safety programs in all stages of the program.

11.1 INTEGRATION

The integration of a developing CNG program requires significant input from management and safety personnel. No site specifically assigned a dedicated, full-time individual to CNG safety or program management. Programs with accessible managers and safety personnel are significantly more successful than programs without such managers. Off-site safety managers or CNG program managers are generally regarded as faceless corporate entities.

Transit facilities have taken various approaches to integrating CNG buses with existing diesel fleets. At one extreme, CNG buses are treated as a separate sub-fleet. Operations and maintenance are CNG-specific. This approach makes it easier to keep the high-pressure gas away from ignition sources. It is impractical for most transit agencies because of the way that buses must be purchased and the capital cost of a new facility.

The other extreme is to completely integrate the buses. This approach is chosen by most transit agencies.

Complete integration appears to be the more successful approach to operations. However, it needs to be performed with attention to CNG safety. Small, experimental or pilot fleets are not recommended. At the facility with the experimental fleet, many problems were found:

- Operators -- most indicated that the training was poor, was not CNG-performance specific, developed little understanding or appreciation for the system, and provided poor understanding of emergency procedures.

- Refuelers -- felt uncomfortable with the system and had difficulty operating the system.

- On-Road Response Technicians -- felt confident but had a poor knowledge of CNG and the CNG bus (could not locate safety shut-off valve).

- Vehicle Maintenance Staff -- the most knowledgeable mechanic was self-trained; some transfer of knowledge took place informally but no formal training was provided.

- Compressor and Refueling System Maintenance Staff -- received no training, felt uncomfortable with the system, and felt abandoned by the manufacturer.

- Management, Including Safety Officials -- site managers have no dislike for CNG but did not think it was introduced the correct way. The organizational setup allows them no control over the vehicles but makes them responsible for service. The dissatisfaction with this arrangement causes resentment and frustration.

- Operator Trainers -- seem to have little familiarity with CNG and have limited teaching materials. They lack enthusiasm for CNG and sympathize with the operators.

11.2 CNG PROGRAM DEFINITION

A CNG program can either be carried out as an experimental program or as a fully operational portion of a transit system. An experimental program is characterized by a few buses (<10), special routes, reduced operational requirements, increased management and safety attention on a per bus basis, and some degree of separation from the normal line operations. In a fully operational program, the CNG buses are integrated into the fleet. The buses would be expected to perform regular duties and routes. The line managers responsible for normal operations would be responsible for the operations and maintenance of these buses.

11.3 PROGRAM DESIGN

At two facilities, the safety manager was involved in all aspects of the design. He was also the person tasked with training the personnel on the technical aspects of the modifications. The safety features of the equipment were clearly understood by the safety manager, who could respond to even the most technical question.

An analysis of requirements and an analysis of hazards should be performed prior to embarking on a CNG program. From these assessments, the hazards can be systematically mitigated by design modifications and procedural steps. One facility used an extensive formal hazard operations assessment for evaluating the hazards.

11.4 OPERATIONS AND TRAINING

The personnel involved with the operations and maintenance of CNG equipment need to be well-trained and regularly retrained. The involvement of management, and its willingness to devote small sums of money (relative to the capital requirements of a CNG program) to these activities, has had a significant affect on the attitude of individuals.

Procedures should be based on hazards and requirements. Procedures should include operational procedures for the equipment, safety procedures that are robust enough to cover CNG, and emergency procedures that involve local fire, rescue, and police personnel. Transit agencies need to actively seek out these officials and stress the importance of training.

12. TRAINING

Operating CNG buses throughout a metropolitan area necessitates training a variety of transit and non-transit employees. Based on interviews and observations, the following persons and/or organizations should be trained in CNG vehicle safety:

- Police;
- Fire/rescue;
- Operators;
- Road mechanics/wrecker operators;
- Dispatchers; and
- Supervisors.

Training should include:

- Fundamentals of CNG;
- Locations of major CNG equipment on the bus; and
- Evacuation.

12.1 TRAINING NEEDS

Each agency trained large numbers of its employees, including those not directly involved with CNG, in the general properties of this gas. Each agency used a film prepared by natural gas companies as the primary training aid. The film left an impression with most who saw it, since it contained dramatic scenes such as shooting a CNG canister with large caliber weapons. However, it did not teach steps to avoid CNG-related accidents, or steps to take during an actual

CNG problem. The film viewers appear to overestimate the degree of safety associated with CNG and gained little or no practical knowledge.

Federal and state OSHA regulations require regular training of employees on hazardous materials in the work place [i.e., Material Safety Data Sheet (MSDS) training]. In the case of transit facilities, this involves solvents and other petroleum products. CNG is not listed as a hazardous material and, therefore, MSDS training is not specifically required. However, CNG safety is voluntarily included in MSDS training at two of the sites.

Personnel at all levels, at all sites visited, are concerned about receiving refresher training on CNG-related matters, even though they were recently trained. Personnel not actively involved with CNG do not feel that they are retaining the training.

12.2 IDENTIFICATION OF PERSONNEL TO BE TRAINED

Each site visited was gradually expanding its training plans and tailoring it to the needs of the CNG program. The level of training varied from basic familiarization for administrative personnel to detailed, component-by-component training for mechanics. Personnel generally believed that everybody should receive at least the basic training course, even if his or her job does not deal with CNG. Table 2-1 summarizes the maximum training given and expected by personnel interviewed.

Table 2-1. Personnel Training

	General CNG Properties	Detailed CNG Properties	Basic Bus Systems	Detailed Bus Systems	Emergency Procedures	
					On road	On site
Operators	x		x		x	
Operator Trainer	x		x	x	x	
Fuelers	x	x	x			x
Dispatcher	x	x	x	x	x	
Bus Mechanic	x	x	x	x		x
Site Maintenance	x	*				x
Fire/Rescue	x		x		x	x
Police	x		x		x	
Supervisors	x		x			x

* - Site maintenance workers responsible for the fueling system should receive this training.

Bus mechanics need additional equipment-specific training, usually from vendors. Every mechanic does not need to be formally trained in every piece of equipment, but several mechanics should be trained on each piece of equipment. Ideally, a transit agency should plan this technical training based on the number of buses on site, expected frequency and duration of maintenance of each piece of equipment, and complexity of equipment. Realistically, this amount of training is not available. Some sites select the lowest bid or do not specify training as part of the project and therefore receive none.

The site maintenance workers responsible for the fueling system need additional training. Special training is necessary for compressor maintenance.

12.3 TRAINING CLASSES/MATERIALS/LECTURERS

Training is generally conducted in small groups during normal working hours. Training usually consists of a hands-on approach and is often conducted at or around the affected equipment. Each transit facility has independently developed lesson plans and training materials. The quality varies but, in general, the material is not professionally prepared.

Bus operators typically receive a basic short class on CNG properties and the CNG systems shortly after the buses arrive on site. Prior to driving a CNG bus they will be checked out individually by an operator trainer on that particular bus type. The transit facilities do not have firm schedules for refresher training. Operators have stated that refresher training is necessary, especially for those who normally drive diesel buses.

All mechanics at the sites received the same or a similar basic course on CNG and CNG systems as the operators. At two of the sites, one bus mechanic has received all available CNG-related training. He has been designated as the key CNG mechanic. Other senior mechanics received smaller amounts of training. Junior mechanics only got the basic training. At these sites, the lead CNG mechanic performs most of the work on CNG systems, and supervises the small amount of work that he doesn't actually perform. The key CNG mechanic provides hands-on and classroom training for junior mechanics and, in some cases, for non-mechanics. At these sites, CNG buses often sit unrepaired when the key CNG mechanic is unavailable.

The training also varies among equipment vendors. At one site, the engine vendor retained responsibility for the CNG engines for a year, working nearly full time on site.

Vendor training programs on the fueling system were inadequate at two of the sites visited. The third site is still relying on the vendor to maintain the buses and the refueling system. Each site is considering establishing a permanent contractual arrangement for compressor station maintenance. However, it should be noted that one transit facility has been having problems because it is under a maintenance contract (of sorts) with an out-of-town vendor. Because of a number of minor problems, such as leaking fittings, more consistent support is needed.

12.4 CERTIFICATION

None of the facilities are using an aggressive certification program. Some of the mechanics stated that a certification-type program may be appropriate. This certification could deal with the safety and quality of work requirements unique to CNG.

12.5 REFRESHER SCHEDULE

The bus operators and the trainers received some CNG related training which consisted of viewing CNG videos on safety and a bus walk-down. For most of the operators, the training was received one to two years ago with no subsequent refresher courses. In many cases, the operator training occurred six months to one year prior to operating a CNG bus. Although refresher courses are available, drivers and operators consider them inadequate. Maintenance personnel seem to be less concerned about refresher training since they seem to learn on the job.

12.6 EXTERNAL EMERGENCY RESPONSE PERSONNEL

The transit authority that has aggressively trained fire departments seems to be in a far better position to deal with an off-site emergency. Unfortunately, there are no requirements to conduct such training. The absence of this requirement may create problems in cities with hundreds of individual fire stations, none of which will be qualified for emergency responses to CNG hazards.

12.7 CONTINUING ISSUES

The following shortcomings were noted in operations-related training:

- Evacuation of handicapped people is dealt with inadequately. The passenger lift requires sparking equipment to operate, which may not be a good idea. The drivers are not trained on alternative methods of evacuation. There may be situations when outside assistance (i.e., ambulance crews) is required to evacuate disabled persons. Alternatively, further evaluation may determine that the likelihood of a CNG leak into the passenger compartment of a bus with top-mounted cylinders is so low that the event does not need to be emphasized in training and procedures.

- Films on safety showing activities such as shooting CNG tanks with high caliber weapons can lead to complacency unless they are followed by realistic safety training.

- Retraining, especially on the basic properties of CNG, is necessary. Several employees who had been to training had significant misconceptions about the behavior of CNG.

- The trainers need to be better trained. Many of those responsible for training operators did not feel that they had adequate knowledge of CNG.

13. MEASURED LEVELS OF HYDROCARBONS AND FORMALDEHYDE

This chapter describes emissions measurements conducted by Star Environmental at refueling facilities for compressed natural gas transit buses.

13.1 EQUIPMENT AND GENERAL APPROACH

Hydrocarbon (HC) measurements were made with a Foxboro Model 108 portable Organic Vapor Analyzer (OVA). The instrument has a full-scale range of 10,000 parts per million (ppM), corresponding to approximately 20% of the lower explosive limit (LEL) for natural gas. HC concentrations were mapped throughout each facility. Representative values are shown in the data tables presented in the following subsections for each facility. Methane and total gaseous non-methane hydrocarbon (NMHC) were measured by time-weighted bag collection and subsequent laboratory analysis by gas chromatography. Typically, two bag samples were collected over approximately eight hours: one in the area of heaviest activity, and one upwind of the operations. Aldehyde samples were collected in the areas most likely to have elevated concentrations. Aldehyde samples were collected on DNPH-impregnated filter cartridges and analyzed for formaldehyde by high-performance liquid chromatography. All measurements for worker exposure were conducted at breathing zone height and distance.

At two facilities, gas releases during refueling connection-disconnection were estimated in a plastic containment apparatus. The containment apparatus was constructed from a plastic bag that was attached to the refueling hose and bus receptacle area using a thermal sealing device. HC concentrations in the containment apparatus were measured with the OVA. Bag volume was determined after the experiment by recreating the amount of bag inflation during the test and deflating the bag through a pump and calibrated flowmeter. Precision using this technique is limited by the ability to repeatedly re-inflate the bag to the same volume. Thus, these measurements should be considered as only rough estimates. HC concentrations were measured while manipulating the nozzle from outside the containment apparatus. Connection and disconnection involved grasping the outside collar of the nozzle and sliding it rearward or forward while pushing or pulling the nozzle on or from the receptacle, as appropriate.

At the third facility, refueling procedures called for the release of gas within the refueling hose after each refueling event. Because of the size of the refueling vent discharge, the containment apparatus used at previous sites to estimate gas release during refueling connection and disconnection was inappropriate. To estimate gas release volume from the vent, the vent discharge was diverted to a known volume pressure vessel, filled multiple times, and measured. A secondary calculation was made to verify the measurements thus obtained.

13.2 FACILITY 1

HC mapping was conducted on a day of normal operations, with the wind out of the southeast at less than 2 mph. On the day of emissions measurements, the outside of one of the buildings on the property was being spray painted. Paint fumes are a likely source of NMHC. Table 2-2 shows that outside HC levels were relatively high (up to 2000 ppM), particularly in areas nearest fresh paint.

Vertical profiles were measured inside the three bus repair zones during normal maintenance periods. These zones have gas-fired heaters near the ceiling and poor ventilation. Values were obtained 1 inch from the uppermost portion of the skylight, at roof level (approximately 18 inches below the skylight), and about every 5 feet down to breathing height. HC concentrations in the repair area did not exceed the range of normal, background concentrations. These measurements are shown in Table 2-3.

Table 2-4 shows concentrations of HC near each of the main CNG components. The gas compressors were not running at the time HC mapping was taking place. Concentrations above the main compressors and up towards the roof are in the range of 5,000 ppm (10% of the lower explosive limit of methane).

Methane and NMHC measurements in the inspection area of the maintenance building are shown in Table 2-5. This is the only facility that had greater NMHC than methane concentrations, which may have been due to the ongoing painting operations. Table 2-6 shows the results of the aldehyde sample collection.

Table 2-7 shows HC concentrations within a few feet of bus refueling connections. These measurements were at background until the distance was within 3 inches of the connection. Estimates of gas release volumes during refueling connection-disconnection operations are shown in Table 2-8. Although not shown on Table 2-8, no emissions were detected during the time CNG fuel was flowing into the buses, but fairly consistent amounts were noted during connection and disconnection.

Table 2-2. Outside Yard Hydrocarbon Concentrations, Facility 1

Area	Reading (ppm)
Downwind of spray painting, building #2	2000
Near newly painted building #2	750-1000
Downwind of paint booth scrubbers	50-80
NW corner of building #3, at the natural gas "tree"	50
All other areas	<=35
Background, parking lot	3

Table 2-3. Hydrocarbon Concentrations in Bus Repair Area, Facility 1

Area	Description	Reading	Reading(roof)
1	Running repairs, lifts - center	8	8 top-bottom
2	Running repairs, lifts - south	8	8 top-bottom
3	Running repairs, pits*	12	10-12 top-bottom
4	Inspection Area	12	10-12 top-bottom

Table 2-4. Hydrocarbon Concentrations Near Main Components, Facility 1

HC Concentrations (ppm)			
Area	**Entrance**	**Middle**	**Roof**
Main Compressor #1 - operating (night)	150	800	5000
Main Compressor #2 - operating (night)	200	5000	5000
Main Compressor #1 - not operating (day)	n/a	100	n/a
Main Compressor #2 - not operating (day)	n/a	200	n/a

Table 2-5. Bag Samples, Facility 1

Sample #	Area	Methane (ppM)	NMHC (ppM)
1	Inspection	3.4	26.6
2	Refuel #2	4.0	6.9

Table 2-6. Formaldehyde Concentration, Facility 1

Sample #	Area	Formaldehyde (parts per million)
3	Inspection	0.0065

Table 2-7. Hydrocarbon Levels Downwind from Refueling Connection, Facility 1

Concentration (ppM)	Distance (inches)
2	36
50	3
100	2
150	1

Table 2-8. Hydrocarbon Concentration During Fueling Process, Facility 1

Run Number	Volume of Escaped Gas (cc)
Run #1	3.7
Run #2	3.1
Run #3	2.5

13.3 FACILITY 2

Measurements were made on a day of normal operations. HC mapping included the perimeter of the service facility, due to the high traffic. Table 2-9 shows HC levels outside the facility. These measurements were 20 ppM or less. Table 2-10 shows HC levels in the repair areas of the maintenance building. HC levels near the main CNG components are shown in Table 2-11. The natural gas compressors were running at the time HC mapping was taking place. HC measurements generally increased with height, and were 120 ppM or less. Thermally switched fans provided intermittent compressor cabinet ventilation, measurements were taken for both running and not running fan conditions. Three compressors were on the site, compressor #2 was out of service for repairs.

Table 2-12 shows the results of bag samples upwind and downwind from refueling operations. The refueling area consisted of two parallel lanes with CNG integrated with diesel. Two bag samples were collected in the refueling area, both at a height of five feet. One bag sample was upwind, at the entrance to the refueling area, the other was downwind of the refueling apparatus. The concentrations are within the range of background levels. Table 2-13 shows the results of an aldehyde sample collected in the refueling area.

Table 2-14 shows HC levels downwind of bus refueling connections. These measurements were at background levels at distances greater than 3 inches from the refueling connection. Concentrations within 3 inches of refueling connection depended upon the bus being refueled, and generally ranged from 20 to 100 ppM (with the exception of a single bus that had an HC concentration of 500 ppM within an inch of the refueling connection). Table 2-15 shows HC releases from refueling nozzle connection and disconnection.

Table 2-9. Hydrocarbon Concentrations Outside, Facility 2

Area	Reading (ppM)
Downwind of New Bus area	10
Downwind of Old Bus area	15
Downwind of refuel area	20
All other areas	15
Background, parking lot	15

Table 2-10. Hydrocarbon Concentrations in Bus Repair Area, Facility 2

Area	Description	Reading	Reading(roof)
1	Old Bus area	15	n/a
2	New Bus area	8	n/a

Table 2-11. Hydrocarbon Concentrations Near Main Components, Facility 2

HC Concentrations (ppM)			
Equipment - Fan Status	**3 feet**	**6 feet**	**9 feet**
Main Compressor #1 - not operating (night)	75	100	120
Main Compressor #2 - (out of service)	n/a	n/a	n/a
Main Compressor #3 - not operating (night)	40	75	100
Main Compressor #1 - operating (night)	50	60	75
Main Compressor #3 - operating (night)	10	15	20
Dehydrator/Tank Storage - operating	60	80	100

Table 2-12. Bag Samples, Facility 2

Sample #	Area	Methane (ppM)	NMHC (ppM)
1	Upwind	1.3	0.0
2	Refuel	17.7	0.0

Table 2-13. Formaldehyde Concentration, Facility 2

Sample #	Area	Formaldehyde (parts per million)
3	Refuel	0.0022

Table 2-14. Hydrocarbon Levels Downwind from Refueling Connections, Facility 2

HC Concentration (ppM)	Distance from Valve (inches)
20	36
30	3
50	2
100	1
500 *	<0.5

* Note: Valve packing replaced later that night.

Table 2-15. Hydrocarbon Releases During Fueling Process, Facility 2

Run Number	Filling Station#/ Pressure (psi)	Average Volume of Vented Gas (cc)
Run #1	#1/2980	4.9
Run #2	#1/2850	4.7
Run #3	#2/3000	6.3
Run #4	#2/3000	5.7

13.4 FACILITY 3

HC mapping took place on an operating weekday. The wind was out of the southeast, generally about 10-15 mph. Monitoring of the maintenance building occurred during the normal nighttime activities. Table 2-16 shows HC concentrations outside the maintenance building and other outside locations. Table 2-17 shows HC concentrations in the repair area. Table 2-18 shows HC levels around the main natural gas delivery components. The main natural gas compressors were monitored when running and when not running. The highest reading, 100 ppM, was measured at a flange near the delivery tree, and near the storage tank manifold. Table 2-19 shows methane and NMHC concentrations from time-weighted bag samples. Table 2-20 shows formaldehyde concentrations. Table 2-21 shows HC concentrations downwind from refueling connections. Estimated volumes of HC releases during refueling connection and disconnection include the volume of gas that is released from venting the refueling hose. This procedure results in the release of more than an order of magnitude more gas during refueling disconnection than was measured at the other facilities. Estimated volumes of fuel release during refueling connection and disconnection at Facility 3 are shown in Table 2-22.

The bus refueling facility has two sources of very substantial leaks: venting of the refueling hose after each refueling operation, and continuous leaks from the venting system. Losses due to venting after fueling averaged about 160 liters per fueling operation. The continuous leak at one fueling island was caused by a needle valve failure in the vent system. The normal torque used to shut off the vent resulted in a continuous discharge, measured by rotameter to be approximately 2.5 liters per minute. This leakage was not apparent at the other stations (which were not in general use). Assuming the leak rate remained constant throughout the day, the combined gas releases of continuous leakage and fueling 8 buses per day was roughly estimated to be 4,880 liters of natural gas per day.

Table 2-16. Hydrocarbon Concentrations Outside, Facility 3

Area	Reading (ppM)
Bus parking yard, North Half	4
Bus parking yard, South Half	8
Outside maintenance building	8
Outside fuel and vacuum building	10
Compressor and fuel storage area	10

Table 2-17. Hydrocarbon Concentrations in Bus Repair Area, Facility 3

Area	Description	Reading	Reading(roof)
1	Inside Building, North Bays	2	N/A
2	Inside Building, South Bays	2	N/A

Table 2-18. Hydrocarbon Concentrations Near Main Components, Facility 3

CNG Component	Reading(ppM)
Natural gas delivery "tree" at utility connection	100
Connection to storage tanks	30-100
Compressor #1	10
Delivery piping and plumbing	10

Table 2-19. Hydrocarbon Concentrations from Bag Samples, Facility 3

Sample #	Area	Methane (ppM)	NMHC (ppM)
1	Upwind	3.1	0.0
2	CNG Refuel	11.3	0.0

Table 2-20. Formaldehyde Concentrations, Facility 3

Sample #	Area	Formaldehyde (parts per million)
3	Refuel	0.0020

Table 2-21. Hydrocarbon Levels Downwind from Refueling Connections, Facility 3

Concentration (ppM)	Distance (inches)
2-10	36
10	3
20	2
50	1
1000*	<0.5

*Note: One bus only, measurements from other buses were typically 20-50 ppM

Table 2-22. Hydrocarbon Releases During Fueling Process, Facility 3

Run Number	Island#/ Pressure	Average Volume of Vented Gas (liters/bus)
Run #1	#1/3600	155.4
Run #2	#1/3000	162.9
Run #3	#2/3600	169.1
Run #4	#3/3600	190.6
Run #5	#4/3600	127.3

13.5 HYDROCARBON AND FORMALDEHYDE FINDINGS

Outside HC concentrations at the three CNG transit facilities visited were typically less than 30 ppM. These measurements are within, or slightly above, the normal background range of HC concentrations. Untypically high HC concentrations were measured at a facility where paint was being applied to the outside of a building. HC concentrations in painting areas were as high as 2000 ppM. It is assumed that the fresh paint was the primary source of HC in these measurements.

HC readings in bus inspection, maintenance, and repair areas were less than 30 ppM. Based on bag sample results, most of the HC in these areas were determined to be methane, suggesting the CNG bus operations as a likely primary source. The site with ongoing painting operations was the only site with greater NMHC than methane.

The highest HC concentrations were consistently found in the compressor sheds. HC levels generally increased with height, reaching 100 ppm at two sites. At the third site, HC levels reached 5000 ppm, or 10% of the LEL for methane. The large number of fittings and frequent vibrations of compressors increases the likelihood of gas leakage from these units. HC concentrations that are 10% of the LEL suggest the importance of installing methane detectors in compressor sheds.

The methods used to estimate the volume of gas released during refueling connection and disconnection limit the precision of these measurements. Assuming connection and disconnection are smoothly operated, gas release volume appears to be very low (i.e., around 5 cc, standard temperature and pressure). The site with procedures that requires venting of the refueling hose after each refueling operation released between 100 and 200 liters of gas (standard temperature and pressure) for each bus refueled. The dispenser at this site also had a valve leaking at a rate of approximately 2.5 liters per minute (measured with a rotameter). Rough estimation of the total daily fuel loss at this site due to refueling operations was 4,880 liters (standard temperature and pressure).

At all sites, HC concentrations measured within an inch of the refueling connection were well below the LEL for methane. Coupling this finding with the fact that connections are grounded during refueling suggests that the likelihood of ignition during normal refueling operations is very small. Nevertheless, from both a fuel loss prevention and climate change perspective, the gas released at sites that vent refueling hoses should be collected.

Formaldehyde concentrations were highest at the site with ongoing painting. However, even the highest formaldehyde concentrations measured were over an order of magnitude below OSHA permissible exposure limits, and thus pose no cause for concern.

14. CONCLUSIONS

To date, the safety record of CNG facilities is satisfactory. No incidents have occurred that caused a loss of life or cost a large amount of money at an FTA facility. However, this record is based on a statistically small base. The number of CNG buses and facilities is growing rapidly. The fact that no serious events have occurred is not statistical evidence that one will not occur in the near future.

A programmatic commitment to safe operation is required for a successful CNG program. Specifically, the proactive involvement of safety professionals in the facility design, day-to-day operations, and personnel training was inversely proportional to the number of safety problems identified at the sites visited.

During the design phase, an analysis of hazards should be performed prior to embarking on a CNG program. From this assessment, the hazards can be systematically mitigated by design modifications and procedural steps. Procedural steps should address CNG-related equipment operation and maintenance, and emergency responses, the later of which should involve local public officials. Following procedure development, management should incorporate an initial and refresher training program, and continually evaluate the field performance of procedures and equipment.

The design characteristic that causes the highest risk in the observed facilities is gas-fired space heaters near CNG buses. CNG will occasionally be released in either a slow or fast leak. A burning space heater is an ideal ignition source. While space heaters are a major safety concern, the overall problem is the lack of clear guidance, standards or criteria for CNG vehicle operations and maintenance. Different safety approaches were observed at each of the three facilities visited. These three safety approaches for maintenance facilities are summarized below:

- One facility allowed no indoor maintenance on CNG vehicles.