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COMPRESSED NATURAL GAS BUS SAFETY:

A QUALITATIVE AND QUANTITATIVE RISK ASSESSMENT

by

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EXECUTIVE SUMMARY

This study assesses the fire safety risks associated with a typical Compressed Natural Gas (CNG) bus system comprising the bus and supporting fuel infrastructure. The primary interest of this study is school buses. Comparisons are then made based on the risk results of CNG bus safety with that of diesel-powered school buses in the United States. The results of the risk comparison will improve understanding of the public acceptance of CNG vehicle safety risks. The intention of this study is to assess the safety risks of CNG buses apart from its potential environmental and health benefits.

This risk assessment uses Probabilistic Risk Assessment (PRA) methodologies as practiced in the nuclear, process and aerospace industries. When appropriate, engineering judgments and assumptions are made to supplement or replace actuarial data. No consideration is given to hazard mitigation or risk reduction.

Analytical modeling of fuel dispersion and mixing was outside of the scope of this study. Instead, a probabilistic ranking of ignition likelihood was assigned to each fire scenario. Only incidents involving risk of fire were considered. This appears to be the only consequence that differentiates CNG vehicle safety risk from other types of fuels, especially diesel. Fire fatality was used as the only risk index of interest. Injuries along with other economic losses were not included.

A typical CNG system was considered as a generic design, for which fire fatality risks were calculated. This study examined risk for:

- Local gas distribution system that provides natural gas to the compression station.
- The compression, storage and dispensing system.
- A typical CNG bus.
- Operational and maintenance practice.

A qualitative evaluation of the hazards associated with the system was completed first. This provided a criticality ranking of the components and human activities that most significantly impact fire risks. It also identified important scenarios for exposure of fire hazards from initiation to final fatality outcomes. The frequencies of initiating hazards were determined from historical data in process and transportation industries. Likelihoods of risk scenarios were determined analytically by using fault tree and event tree modeling techniques along with generic data.

Consequence analysis was done by considering accident locations and computing the physiological damage and lethality effects of heat fluxes generated from fires. Subsequent effects on people located within a certain distance from such fires is estimated. The total risk has been determined by summing the risk associated with each fire/accident scenario.

The projected fatality resulting from an unconstrained fire is 2.2E-5/bus/year. For the 8500 CNG buses in operation in year 2001 in the United States, this would translate to approximately 0.19 deaths/year or a mean time to occurrence of a fatality of 5.4 years/fatality.

If all of the present school buses in the United States are converted to CNG type, then the projected mean fatality would be 9.9/year or a mean time to occurrence of a fire related fatality of 1.2 months/fatality. Accordingly, catastrophic bus-related failure event leading to a fire is certainly a major safety issue in CNG powered buses. The table below summarizes major results of this study.

RESULTS OF QUANTITATIVE RISK ASSESSMENT			
CNG Bus Fire Scenarios Resulting from the Following Causes	**Frequency of Occurrence / Bus/year**	**Risk (Fatalities /Bus/year)**	**Risk (Fatalities 100 M Miles)**
Catastrophic failure of bus or station hardware components.	1.4E-3	2.7E-6	2.8E-2
Degraded failure of bus or station hardware components.	3.7E-3	7.5E-6	7.8E-2
Electrostatic discharge of CNG	1.4E-5	3.7E- 6	3.9E-2
Accidental Impact Mainly due to Collision	3.6E-2	4.6E-6	4.8E-2
Non-CNG Related Fires	3.6E-4	3.1E-6	3.2E-2
Operator Error	4.0E-2	3.5E-7	3.6E-3
Total Fire Fatality Risk		**2.2E-5**	**2.3E-1**

** Assuming 9598 miles of travel per bus per year*

Based on historical data, diesel school bus fire fatality risk is 0.091 total fatalities per 100-million miles and 0.0007 bus-passenger fatalities per 100-million miles of travel. Based on the quantitative analysis results of this study as summarized in the table above, the total fire fatality risk for CNG buses is approximately 0.23 per 100-million miles of operation. Also, the study estimates 0.16 fatalities per 100-million miles for CNG bus passengers only (i.e., 70% of the total fire related fatalities are expected to come from passengers of the bus).

Comparing the estimated results for CNG buses with those of historical diesel school experience, one may conclude that CNG buses are on the average 2.5 times more prone to fire fatality risk than diesel buses. More alarming is the fire risk for passengers of such vehicles. That is, CNG bus passengers' fatal fire risk is more than two orders of magnitude of the fire risk for diesel bus passengers. While these comparative values are based on best estimate averages, the worst case fire scenarios for CNG buses are expected to lead to higher fatalities as compared to worst case fire scenarios of diesel buses.

Reliance of the study on generic bus designs and failure data, is a good approximation for screening purposes. However, a more accurate physics-based model should be supplemented with this study to provide more accurate results. Further, since this study offers a best estimate of risk, it would be important to perform a detailed uncertainty analysis in the future to show the confidence bounds of the computed risks. Finally, risks of non-fatal fire scenarios (those primarily leading to injuries) should also be estimated.

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