ALTERNATIVE-FUEL TRANSIT BUS HAZARD ASSESSMENT MODEL

Prepared for:

National Research Council
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EXECUTIVE SUMMARY

The Alternative-Fuel Transit Bus Hazard Assessment Model estimates the consequences (injuries and property damage) and losses (in dollars) from fuel-related hazards (fire and non-fire) on transit buses. The model compares hazards, expected losses, consequences, and mitigation measures within and across fuel types. The *CRP-CD-4* contains the Reference Case model using survey data, estimates based on statistical data, and engineering estimates and judgments developed by the project team. The Reference Case becomes the Base Case once it is tailored to the characteristics of your particular fleet and facility. The model can then be used to evaluate consequences, expected losses, and the effect of certain mitigation measures on the Base Case. These values were developed for a generalized bus and a fleet of 200 buses using compressed natural gas (CNG) and a fleet using liquefied natural gas (LNG). The findings do not represent any single fleet but rather a composite from across the country. Because of limitations on the availability, quality, and applicability of the data in the model, the results should not be interpreted as exact measures of risk, losses, and so on.

A summary of the findings is presented on Tables ES-1 through ES-4, following the text. Note that the bottom or lower left of each output table identifies the case as the **Base Case** or the **Incremental Case**. The Base Case represents the user's fleet and facility as they exist. It is developed from the Reference Case. The Incremental Case represents the user's analysis of measures that could mitigate the losses from releases, fires, injuries, or property damage.

ES.1 Summary Findings

The Base Case (using the Reference Case in the model) estimates fuel-related losses associated with diesel, CNG, and LNG. Table ES-1, Summary Valuation of Losses, shows the values in more detail.

- Diesel—$48 per bus-year (PBY) or $9,600 per year for a fleet of 200 diesel buses
- CNG— $324 PBY or $64,875 per year for a fleet of 200 CNG buses
- LNG—$480 PBY or $96,015 per year for a fleet of 200 LNG buses.

Summary fuel-related losses from diesel buses are based on survey data. Detailed fuel-related losses for CNG and LNG buses are based on data, estimates, and engineering judgment developed by the researchers.

ES.2 CNG

Losses in the CNG Base Case are estimated at $324 per bus per year. Table ES-1 shows that more than one-half the losses are from public injuries and fatalities. Most of the remaining loss is from property damage from releases and fires. In terms of the number of events and injuries (rather than dollars), the Base Case estimates 0.14 worker injuries per fleet-year, 0.44 public injuries per fleet-year, and 12 release events causing property damage per fleet-year. Most of the injuries and property damage take place in operation or in parking. Parking contributes significantly to losses because the bus is fully fueled. Table ES-2 shows that roughly 90 percent of the losses are attributable to fast releases from pressure relief devices (PRDs) ($228 PBY) and fast releases from cylinders ($64 PBY). The remaining 10 percent of the base losses ($32) are attributable to all other components. This observation suggests that the first place to look for cost-effective point mitigation measures would be PRDs and cylinders, rather than other components or broadly defined non-point mitigation measures. This is a significant observation, because it confirms the importance of the industry's current focus on PRDs and cylinders and the relative unimportance of additional effort addressing all other components and systems. The PRD issues are particularly significant in climates where freezing takes place. Table ES-3 shows that a majority of the losses occur in operation and most of the remaining losses occur in parking. Parking generates relatively large losses, because the bus is fully fueled before it is parked and parking represents about one-third of the daily cycle. The operating stage, while longer than the parking stage and with a lower probability of release, accounts for more losses, because many more people are exposed during operations than during parking.

The estimated loss of $324 PBY is highly sensitive to the release frequencies used in the analysis. Switching from the 1998-99 release frequencies to the 1996-97 frequencies increases the base loss to $601 PBY. Most of the losses are still attributable to fast PRD releases and fast cylinder releases. This observation also confirms the importance of continuing to address PRD and cylinder issues.

Using the Base Case and 1998-99 release frequencies as a basis, the only cost-effective mitigation measure is the replacement of PRDs. The observation that only one mitigation measure appears cost-effective on average, across the industry is important. It suggests that there are no systemic deficiencies in components (except PRDs) or industry practices. Rather, there are individual deficiencies in components, systems, practices, and so on that must be addressed. Point mitigation measures directed at components other than fast releases from PRDs are not cost-effective in the model. Non-point and post-event mitigation measures are also not cost-effective. As with LNG, however, this inference is sensitive to the release probabilities used in the model and the event database behind it. Relatively modest changes in release probabilities in key areas, or in the consequences of key release categories, would significantly change the relationships. The user should verify that the release frequencies are appropriate for his or her situation.

ES.3 LNG

Losses in the LNG Base Case are estimated at $480 per bus per year. Most of the losses are attributable to the following five release points: refueling receptacle ($112); fuel tank rupture ($90); fuel tank vacuum loss ($73); PRD slow release ($71); and fuel line fittings ($61). The remaining $75 in losses is attributable to eight other release points. This observation suggests that point mitigation measures aimed at the five major release points are the most likely ones to be cost-beneficial. The PRD issues are particularly significant in climates where freezing takes place. Table ES-1 shows that about one-half the losses are from property damage from releases and almost one-fifth is from property damage from fires. Most of the rest is attributed to public injuries and fatalities. In terms of events and injuries (rather than dollars), the Base Case estimates 0.06 worker injuries per fleet-year, 0.83 public injuries per fleet-year, and 173 release events causing property damage per fleet-year. Most of the injuries and property damage take place in operation or in parking. Parking contributes significantly to losses because the bus is fully fueled. Table ES-3 shows that most of the losses occur in parking and operation (in that order) versus operation and parking (the reverse order) for CNG. Table ES-4 shows the losses in the Base Case.

Using the Base Case in the model and the 1998-99 release frequencies as a basis, the only cost-effective point mitigation measures are replacing all the PRDs and tightening the fuel line fittings. Installation of spark arresters is a cost-effective non-point mitigation measure, costing $2,000 per fleet-year but reducing losses in the Base Case by about $2,800 per fleet-year. Increasing inspections reduces losses by about $10,000 per fleet-year but costs about $20,000 per fleet-year, making it cost-ineffective. The observation that only a small number of mitigation measures appear cost-effective on average is important. It suggests that there are few systemic deficiencies in components (except PRDs) or industry practices. Rather, there are individual deficiencies in components, systems, practices, etc. that must be addressed. This observation is tied directly to the estimated frequency of releases, however. Fleets with characteristics like those forming the 1996-97 release estimates have much larger estimated losses and many more cost-effective mitigation options. For example, switching from the 1998-99 release frequencies to the 1996-97 frequencies increases the base loss to $9,810 per bus-year. Moreover, it changes the highest risk release points to fast PRD ($4,124), fuel line ($2,394), regulator ($2,003), couplings ($734), and fuel tank vacuum loss ($457). This radical change in both the overall total and the individual components driving the total suggests that the LNG systems and operational practices are exceedingly variable from fleet-to-fleet and over time. This variability is also an indicator of technical and operational immaturity. Note, for example, that fuel lines and regulators are major sources of loss using the 1996-97 data but that the refueling receptacle is not. In the 1998-99 data, the reverse is true. The 1998-99 release frequencies are based on recent experiences at Phoenix Transit. The earlier frequencies are based on earlier experiences at Houston Metro. LNG operators should also be aware that the variations over time and across components and fleets are based on a relatively small database of buses and events. This observation suggests caution in directly translating the values in the model to individual fleets.

ES.4 Other Observations

The model is capable of depicting significant structural, operational, and safety-related mitigation characteristics and practices. However, the precision of the model far exceeds the statistical validity and accuracy of the data. For example, the failure rate values for CNG and LNG rely on statistical, survey, and observational data, but the data suffer from reporting deficiencies, variation in the buses and components, vintage issues, and definition-related issues. These deficiencies are particularly pronounced for LNG. Moreover, the sparseness of the data when divided across multiple dimensions (e.g., releases from a particular bus component in a particular stage of the daily operating cycle) often makes it impossible to isolate the most likely contributors to hazardous events and the consequences of those events. Real-time or near-real-time data collection would improve the quality of the data but would impose a burden on the transit systems. The available failure rate data do, however, confirm significant improvements in the fuel-related systems for CNG and LNG transit fleets over the past few years.

Data on factors such as the probability of ignition, the probability and severity of injuries from each release or fire, and the effect of mitigation measures were estimated by the project team. There are little or no empirical data on these variables for transit buses. The development of national data for these variables may be difficult but would add significant accuracy to the model. The model is designed to permit the use of fleet-specific data and estimates to increase the accuracy of the analysis. Space is provided in the model for including fuel cell and hybrid bus data when they become available.

Finally, it is worth stressing that the overall cost-effective level of systems, operations, and safety practices depends on a relatively high degree of compliance with established safety practices. Researchers have observed substantial occurrences of off-specification safety activities, equipment, facilities, and so on. This degraded adherence to safety standards figures into the losses estimated in the Base Case in the model. Strict adherence to safety standards would lower the base losses and make fewer itemized mitigation measures cost-effective.

Table ES-1. Summary Valuation of Losses

File Edit View Insert Format Tools Data Window Help

VALUATION OF LOSSES

? | Home | Frequency of Losses | Valuation of Losses by Stage of Operation

Valuation of Losses per Bus-Year By Fuel Type

	Diesel	CNG	LNG	Fuel Cell	Hybrid
Worker Injuries		$21	$3		
Worker Fatalities		$5	$6		
Public Injuries		$134	$60		
Public Fatalities		$49	$84		
Property Damage (Release)		$37	$246		
Property Damage (Fire)		$77	$82		
TOTAL	$48	$324	$480		

Valuation of Losses per Fleet-Year By Fuel Type

	Diesel	CNG	LNG	Fuel Cell	Hybrid
	200	200	200		
Worker Injuries		$4,271	$620		
Worker Fatalities		$1,054	$1,102		
Public Injuries		$26,870	$11,989		
Public Fatalities		$9,875	$16,762		
Property Damage (Release)		$7,361	$49,199		
Property Damage (Fire)		$15,445	$16,343		
TOTAL	$9,600	$64,875	$96,015		

Case (BASE/INCREMENTAL)		BASE	BASE		

SUMMARY / DIESEL / CNG / LNG / FUEL CELL / HYBRID / GLOSSARY / GO HOME

Table ES-2. Benefits & Costs (CNG, Base Case Losses)

File Edit View Insert Format Tools Data Window Help

BENEFITS & COSTS ($/bus-yr.)

? Home

RELEASE POINT	Base Loss	Mit'd Loss	Benefit	Cost	Benefit-Cost
	Rank by:	Rank by:	Rank by:	Rank by:	Rank by:
1. Cylinder - slow	$6	$6	$0	$0	0.00
2. Cylinder - fast	$64	$64	$0	$0	0.00
3. PRD - fast	$228	$228	$0	$0	0.00
4. PRD - slow	$4	$4	$0	$0	0.00
5. Refueling device	$1	$1	$0	$0	0.00
6. Fuel line fittings	$1	$1	$0	$0	0.00
7. Fuel line	$7	$7	$0	$0	0.00
8. LP regulator	$3	$3	$0	$0	0.00
9. HP regulator	$5	$5	$0	$0	0.00
10. Solenoid valve	$4	$4	$0	$0	0.00
11. 1/4 turn valve	$3	$3	$0	$0	0.00
12. Other valve	$1	$1	$0	$0	0.00
13. Other	$0	$0	$0	$0	0.00
14. Open	$0	$0	$0	$0	0.00
15. Open	$0	$0	$0	$0	0.00
TOTAL	$324	$324	$0	$0	0.00

BASE

SUMMARY / DIESEL / CNG / LNG / FUEL CELL / HYBRID / GLOSSARY / GO HOME

Table ES-3. Summary Valuation of Losses by Stage of Operation

VALUATION OF LOSSES BY STAGE OF OPERATION

Valuation of Losses per Bus-Year by Stage of Operation

	Operation	Fueling	Prev. Maint.	Corr. Maint.	Parking	TOTAL
Diesel						$48
CNG	$194	$3	$2	$7	$118	$324
LNG	$186	$8	$3	$10	$273	$480
Fuel Cell						
Hybrid						

Valuation of Losses per Fleet-Year by Stage of Operation

	Fleet	Operation	Fueling	Prev. Maint.	Corr. Maint.	Parking	TOTAL
Diesel	200						$9,600
CNG	200	$38,848	$662	$482	$1,382	$23,500	$64,875
LNG	200	$37,239	$1,611	$692	$1,901	$54,571	$96,015
Fuel Cell							
Hybrid							

Case (BASE/INCREMENTAL)

Diesel	
CNG	BASE
LNG	BASE
Fuel Cell	
Hybrid	

Table ES-4. Benefits & Costs (LNG, Base Case Losses)

File Edit View Insert Format Tools Data Window Help

BENEFITS & COSTS ($/bus-yr.)

? Home

RELEASE POINT	Base Loss	Mit'd Loss	Benefit	Cost	Benefit-Cost
	Rank by:	Rank by:	Rank by:	Rank by:	Rank by:
1. Fuel tank (Vac. Loss)	$73	$73	$0	$0	0.00
2. Fuel Tank Rupture	$90	$90	$0	$0	0.00
3. PRD - fast (2/tank)	$10	$10	$0	$0	0.00
4. PRD - slow (2/tank)	$71	$71	$0	$0	0.00
5. Refueling receptacle	$112	$112	$0	$0	0.00
6. Fuel line fittings	$61	$61	$0	$0	0.00
7. Fuel line	$19	$19	$0	$0	0.00
8. Regulator	$10	$10	$0	$0	0.00
9. Vaporizer	$25	$25	$0	$0	0.00
10. Solenoid valve	$3	$3	$0	$0	0.00
11. 1/4 turn valve	$0	$0	$0	$0	0.00
12. Injector (Fuel Valve)	$0	$0	$0	$0	0.00
13. Cryo Pump	$0	$0	$0	$0	0.00
14. Gauges	$6	$6	$0	$0	0.00
15. Couplings	$1	$1	$0	$0	0.00
TOTAL	$480	$480	$0	$0	0.00

BASE

SUMMARY / DIESEL / CNG / LNG / FUEL CELL / HYBRID / GLOSSARY / GO HOME

1.0 PURPOSE AND BACKGROUND

The purpose of the Alternative-Fuel Transit Bus Hazard Assessment Model is to estimate the consequences (injuries and property damage) and losses (in dollars) from fuel-related hazards (fire and non-fire) on transit buses. Detailed analysis is available for buses and facilities using compressed natural gas (CNG) and liquefied natural gas (LNG). CNG and LNG cases may be compared to a fixed case for diesel bus operations. The model includes space for analyzing fuel cell and hybrid electric buses once data from transit usage becomes available.

1.1 Using This Document

This document is partly a users' guide, partly an explanation and discussion of data and statistical issues, and partly an analytical summary. You are encouraged to use the document as a supplement to the model rather than to rely on the document to use the model. In fact, you may skip directly to the One-Page Users' Guide (Section 1.2) and then return to the document only when necessary.

1.1.1 Fonts in the Document and the Model

Within this *document*, special fonts are sometimes used to call attention to key items:

- Bold type with capitals on each word (e.g., **Calculate Base Case**) calls attention to worksheets (e.g., Summary, Diesel, CNG, etc.), input and output screens (e.g., Facility and Fleet Characteristics, Frequency and Valuation of Losses, etc.), and buttons (e.g., Calculate Base Case, Rank By, Home, etc.). Thus, the word summary refers to a total but **Summary** refers to the worksheet that contains the total.

- Bold type with initial capitals and italics (e.g., ***Solenoid valves***) calls attention to input or output variables or values that appear on the screen, including release points, mitigation measures, stages of operation, etc. Thus, a solenoid valve is a component on a bus but a ***Solenoid valve*** is a variable in the model that describes that component.

- Italics are used to call attention to unusual or easily overlooked concepts or usages, e.g., the previous two bullets described the typeface in the *documentation* while the next four bullets describe the typeface in the *model*.

Within the *model*, fonts for key items are as follows:

- Inputs -- **Bold black** characters on a blue background

- Buttons and Help Screens -- Black characters on a grey background

- Outputs (excluding row summations = 1.0 or 100%) -- **Bold black** characters on a yellow background

- Row Summations that must equal 1.0 or 100% -- ***Bold italic black*** characters on a yellow background

- Errors (invalid entries or entries that make a total invalid) -- **Bold black** or ***Bold italic black*** on a red background.

1.1.2 Order of Operation in the Document and the Model

Aside from understanding certain conventions in the document and the model, particularly *type fonts* and *colors* (Section 1.1.1, above) and *how to use* and *how not to use the model* (Sections 3.2 and 3.3), there is no reason to read the document in any order or to read all of the sections. The model includes an on-screen glossary and context-sensitive help (identified with a **?** Button on each screen). You should use the document to supplement the model not the other way around. Users interested in statistical and data quality issues are encouraged to review Appendix C.

Because the parts of the model dealing with CNG and LNG are functionally equivalent and because many of the details of both the model and the report are the same for the two fuels, attention has been given to avoiding repetition. In Section 7 of this report, issues common to CNG and LNG are grouped at the beginning of each subsection. Issues specific to CNG or LNG are described in separately headed subsections. In any section of interest, you should read the common material and then read the fuel-specific material.

Full-page tables in the document are not necessarily grouped immediately after the first reference in text. In some cases they are grouped one or two pages later to avoid disruption of the text.

Once installed (Section 1.2 or 4.1), the model should be used as if it were a game:

- Any worksheet (**Summary**, **Diesel**, **CNG**, **LNG**, **Glossary**, etc.) can be selected at any time and in any order using the tabs at the bottom of the screen.

- Any input or output screen can be selected at any time and in any order by clicking the **Home** button (or **Home** buttons in sequence), returning to the fuel homepage, and selecting the new screen.

- Any button on any screen (e.g., **Home**, **Calculate Base Case**, **?**, **Forward**, **Back**, etc.) can be selected at any time and in any order.

- Any output can be calculated at any time by clicking **Calculate Base Case** or **Calculate Incremental Case** on the screens that offer those options.

- Any rankings of outputs can be performed at any time and in any order by clicking the **Rank by:** button on the screens that offer that option.

Sections 2 through 4 of this document provide an overview on setting up the model, using the model, and understanding the input and output conventions. Section 5 discusses the summary outputs (which compare results across fuels) and a way to access the other worksheets in the model. Section 6 discusses the fuel homepages (primarily CNG and LNG) that control the inputs and outputs for each fuel type. Sections 7 and 8 discuss these input and output screens, variables, and values in detail. Section 9 presents an analysis of the key findings in the Base Case and Incremental Cases for CNG and LNG.

This document also contains the following appendices:

- Appendix A summarizes the literature on the valuation of fatalities and injuries.

- Appendix B summarizes the 1997 SAIC Survey of Gas Releases from CNG Bus Part Failures. This survey is one of the bases for the estimates of the frequency of releases by stage of operation and the type of component.

- Appendix C discusses statistical and data quality issues.

- Appendix D provides background on CNG cylinder ruptures in North America in the 1990s and recent notable CNG bus release and fire events.

1.2 The One-Page User's Guide

Everything you need to know to install and use the model is summarized on the next page.

THE ONE-PAGE USER'S GUIDE

REQUIREMENTS

1. Microsoft Windows 95 or higher; Microsoft Excel 97 or higher.
2. Pentium (or compatible) PC, color monitor, 800 x 600 resolution.
3. Pointing Device (mouse / touchpad); graphics printer (optional).

INSTALLATION FROM CD-ROM

1. At the Windows desktop, insert the CD into your CD drive. Accept the License Agreement if prompted; Acrobat Reader will automatically start.
2. Click "Excel Model;" click "Yes" if asked to allow Excel program to start.
3. Click "Enable Macros" if prompted.
4. Click File / Save As and save the program in your preferred file location.

INSTALLATION FROM WEBSITE

1. Visit the project Web page: http://www4.nationalacademies.org/trb/crp.nsf/All+Projects/TCRP+C-11.
2. Click the "C11.xls" link to download the Excel program (Note: this may take up to 30 minutes. File "C11.zip" is the compressed version, if you have the necessary software).
3. Click "Yes" or "Enable Macros" if prompted.
4. The Model may open in your Browser. Click File / Save As and save the program in your preferred file location. This will allow you to save changes so you do not need to reenter data each time you use the model

NOTE: If the model doesn't fit on your screen, Click View / Full Screen (toggle ON), View / Toolbars (toggle OFF), View / Formula Bar (toggle OFF), and/or View / Status Bar (toggle OFF) to expand the viewing area. If your screen is very large or your resolution very high, you may see adjacent parts of the model on your screen while you are viewing the intended display. Ignore these adjacent parts of the model.

RUN THE MODEL

1. Select any worksheet using the tabs on the taskbar at the bottom of the screen.
   1. Inputs -- Bold black on blue (unprotected cells).
   2. Buttons and Help Screens -- Black on grey.
   3. Outputs (excluding row summations = 1.0 or 100%) -- Bold black on yellow (protected cells).
   4. Row Summations that must equal 1.0 or 100% -- *Bold italic black* on yellow (protected cells).
2. Calculate any case (on screens offering the option).
3. Rank any column (on screens offering the option).
4. Print any input or output sets (Click Summary-Print or Click the question mark button (?) near the upper-right corner of a screen on the CNG or LNG homepages). **Inputs and outputs can only be printed in sets, and only from the menu of selections under the question mark button (?) on the CNG or LNG homepages.**

NOTE: Do not use the keyboard for navigation -- use the mouse or other pointing device only! If you shift the display, off-center, Click Home on any screen or the Go Home tab on the taskbar at the bottom of the screen. Use Ctrl-Home to re-center the screen on the Homepage.

HELP

1. Click the question mark button (?) near the upper-right corner of a screen.
2. Place the cursor below and to the left of a red triangle (on screens offering red triangles).
3. Click the Glossary tab at the bottom of the screen.
4. Review other sections of this document.
5. Call SAIC -- Harry Chernoff (programmer / economist) at 703.676.5816 (chernoffh@saic.com) or David Friedman (project manager / transit expert) at 703.676.4559 (friedmand@saic.com).

2.0 COMPUTER REQUIREMENTS AND SETTINGS

Table 2-1 shows hardware and software requirements to run the model.

Table 2-1. Hardware and Software Requirements

Requirement	Unacceptable
Pentium, Celeron or equivalent PC running Microsoft Windows 95 or higher	All other processors and operating systems, including Windows 3.1.
Microsoft Excel 97 or higher	Excel 95 or lower
Color monitor with 800 x 600 resolution	Monochrome monitor or 640 x 480 color monitor.
Pointing Device (mouse, touchpad, point-stick)	
Printer, with standard graphics capability	Text printer

Any standard Pentium, Celeron, or equivalent PC operating under Windows will have sufficient RAM, hard disk, and video capacity to operate the model. No knowledge of Excel or spreadsheets is required.

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3.0 USING THE MODEL

This section describes the uses and limitations of the model. The following topics are covered:

- Who Should Use the Model?
- How Should the Model be Used?
- How Should the Model Not be Used?
- How Does the Model Work?
- What Do Base Case and Incremental Case Mean
- What are Mitigation Measures?
- How Should the Results Be Interpreted?
- What If I Need On-Screen Help?

3.1 Who Should Use the Model?

The model analyzes and quantifies fuel-related risks and losses in transit operations. Individuals who might benefit from this analysis include risk managers, loss prevention managers, facility and fleet designers, safety engineers, financial administrators, workers' compensation managers, insurance estimators, and health and safety staff. Different types of people may obtain different benefits from the model. For example, a risk manager may want to identify the largest financial risks. Health and safety staff may want to determine if safety devices, e.g., alarms and vents, would be beneficial. Safety engineers may want to determine if different maintenance or replacement schedules would be cost-effective. Statistical and data quality issues are discussed in Appendix C.

3.2 How Should You Use the Model?

The model should be used interactively, like a game. The following points are important:

- Base Case -- You configure the **Base Case** from the Reference Case to represent the characteristics of your operation.

- Incremental Case -- You configure the **Incremental Case** to test the effects of mitigation measures and changes in other variables in the Base Case.

- Off-Center Display -- If you inadvertently hit an arrow, tab, or page key, the display may shift off the screen. Reorient yourself by clicking any button (if visible) or the **Go Home** tab on the taskbar at the bottom of the screen. No data will be lost.

- Reference Case -- The **Reference Case** is the case on the distribution disk.

- Save -- Click File / Save (or File / Save As) on the taskbar at the top of the screen.

- Screen Navigation -- Mouse and on-screen buttons only. Do not use arrow, tab, or page keys.

You may select any input or output screen, edit any variable available for editing (blue background on the screen), print any screen or series of screens, or click any button on any screen in any order. You may alternate between worksheets using the tabs at the bottom of the screen at any time. Values not available for editing are shown on a yellow background on the screen.

3.3 How Should You Not Use the Model?

Do not use the keyboard for navigation or the mouse for any block functions, including scrolling. Use a pointing device, such as a mouse or touchpad to navigate around the screen -- not off the screen -- and click the buttons. Using the keyboard (e.g., arrow, tab, page) for any function except entering a character or saving the file may cause the display to shift off the screen. Reorient yourself by clicking any button and then returning to the original screen. You may also click the **Go Home** tab at the extreme bottom of the screen to start over. No data will be lost.

Each worksheet in the model (shown as a tab on the taskbar at the bottom of the screen) is a flat worksheet with different parts of the model in different areas. Incorrect navigation may move the display so far off the screen that an unrelated display appears. This display will not necessarily be updated correctly if it has been accessed incorrectly.

3.4 How Does the Model Work?

The following simplified sequence shows how the model works.

1. Facility and fleet characteristics are defined, e.g., number of buses in the fleet, amount of time in each of the five stages of operation (operation, fueling, preventive maintenance, corrective maintenance, parking), amount of time indoors, etc.

2. Fuel release points on buses are identified, e.g., cylinders, fuel lines, valves, etc.

3. Survey data is used to estimate the probability of fuel releases and fires per bus per year from each of these points.

4. Probabilities for fuel releases and fires are allocated to each of the five stages of operation.

5. Fatal and non-fatal injuries to the public and to the workers are estimated for the type of releases and fires that might be expected at each release point.

6. Dollar values of losses are estimated for non-fatal injuries, fatalities, and property damage.

7. Summary outputs are developed to show the losses by hazard, stage, type of loss, etc.

8. The upper right-corner of each printout shows the name of the program (C11), the worksheet containing the screen being printed (typically Summary, CNG, or LNG), the date, and the time. These printouts do not include the Excel tabs or taskbar icons shown on the printouts in the Users' Guide.

3.5 What Do Reference Case, Base Case, and Incremental Case Mean?

The model is distributed with a **Reference Case** that represents a typical facility and fleet, typical release points, rates, injuries, etc. Although this case can be used, you should configure the model to represent your fleet and facilities, especially the number of buses, the percentage of time the average bus spends in each of the five stages of the daily operating cycle, the average number of passengers, etc. Your version of the Reference Case is the **Base Case**. When you display outputs in the Base Case the word BASE appears near the bottom of the screen. An **Incremental Case** is the Base Case as modified for incremental mitigation measures, changes in operating procedures, changes in facility characteristics, and similar factors. When you display outputs in the Incremental Case the word INCREMENTAL (or sometimes INCR.) appears near the bottom of the screen. See Section 3.6, for a comparison of **Mitigation Measures** in the Base and Incremental Cases.

3.6 What Are Mitigation Measures?

Fuel releases, fires, damages, etc. can be mitigated in various ways. Mitigation measures may take place at a release point prior to a release (**Point Mitigation**), on a bus or in a facility prior to a release (**Non-point Mitigation**), or after a release (**Injury Mitigation** and **Property Mitigation**). The model calculates the costs and benefits of the mitigation measures you select and displays **Costs**, **Benefits**, and **Benefit-cost Ratios**.

Mitigation measures may be selected for the Base Case, the Incremental Case, or not at all. An individual mitigation measure may not be part of both cases simultaneously but may be alternated between cases. Mitigation measures selected for the Base Case have no cost (i.e., they are already in place at your facility and fleet) and no impact on the **Mitigated Loss**, Benefits, Costs, or the Benefit-cost Ratio. Rather, they reduce the **Base Loss**, i.e., the expected loss in the Base Case.

3.7 How Should You Interpret the Results?

The results in the model depend on numerous assumptions. While many of the key assumptions are based on surveys or observational data, many data sets are sparse and substitute data and values are often necessary. These substitute data and values are based on engineering judgment and analogies to other industries. Details on statistical and data quality issues are presented in Appendix C.

The key to interpreting the results is understanding the absolute and relative magnitude of the various inputs and how the inputs relate to each other. Insights into the composition of the losses from non-fatal injuries, fatalities, and property damage can be gleaned from examining the frequency of hazards by the stage of the daily cycle, by the contribution of releases and fires to the total, by the effect of various types of mitigation measures, and so forth. The output tables make these comparisons clear.

3.8 What if I Need On-Screen Help?

On-Screen help is provided via the question mark (**?**) Button, **Red Triangles**, and the **Glossary**.

3.8.1 Question Mark

Most screens have a question mark button (**?**) near the upper-right corner of the display. Clicking on this button provides context-sensitive help.

3.8.2 Red Triangles

Some screens have small **Red Triangles** on the upper-right corner of individual cells. Positioning the cursor below and to the left of a triangle provides a comment on that cell.

3.8.3 Glossary

A **Glossary** is available at any time from any screen. Click on the Glossary tab on the taskbar at the bottom of the screen. To return to your previous location outside the Glossary, click the tab for that worksheet (e.g., **Summary, CNG, LNG**).

4.0 OVERVIEW OF MODEL STRUCTURE AND MODEL USAGE

The model C11.XLS is an Excel 97 spreadsheet. Using the model requires Excel 97 to be installed on the computer. No knowledge of Excel or spreadsheets is required.

4.1 Starting the Model (See updated One-Page User's Guide)

The model is distributed on a 1.44 MB floppy disk in a self-extracting zip file. To unzip the file and run the model, do the following:

1. At the Windows desktop, insert the disk into your 1.44 MB floppy disk drive (A:).

2. Click Start / Programs / Windows Explorer. Copy C11.EXE on A: and Paste it into the default folder for Excel programs on your hard disk. Usually, this is My Documents on drive C.

3. Double-click on C11.EXE. (The executable file will unzip the model and add C11.XLS to the folder.)

4. Close the DOS Window.

5. Double-click C11.XLS.

6. Choose "Enable Macros" if prompted by anti-virus software.

7. Click any button to get started.

NOTE: If the model doesn't fit on your screen, Click View / Full Screen (toggle ON), View / Toolbars (toggle OFF), View / Formula Bar (toggle OFF), and/or View / Status Bar (toggle OFF) to expand the viewing area. If your screen is very large or your resolution very high, you may see adjacent parts of the model on your screen while you are viewing the intended display. Ignore these adjacent parts of the model.

NOTE: Do not use the keyboard for navigation -- use the mouse only! If you shift the display, off-center, Click any button on any screen or the Go Home tab on the taskbar at the bottom of the screen. You may use Ctrl-Home to re-center the screen on the Homepage.

4.2 Worksheets

Worksheets are shown as tabs on the taskbar at the bottom of the screen. The model contains eight worksheets, each of which is described below. You may switch among any of these worksheets in any order at any time. The tab for the active worksheet will be highlighted.

- **Summary --** The **Summary** worksheet contains the title page, the main menu and three sets of comparative outputs for diesel, CNG, and LNG: (1) **Frequency of Losses**, (2) **Valuation of Losses**, and (3) **Valuation of Losses by Stage of Operations**.

- **Diesel** -- The **Diesel** worksheet contains an entry for the number of buses in the fleet (for comparison with CNG and LNG) and a fixed value for the fuel-related losses per bus-year. These values may be edited. There are no detailed diesel data.

- **CNG** -- The **CNG** worksheet contains the inputs, equations, and outputs for CNG bus operations.

- **LNG --** The **LNG** worksheet contains the inputs, equations, and outputs for LNG bus operations.

- **Fuel Cell** -- The **Fuel Cell** worksheet is a placeholder that can be expanded and populated when data from fuel cell bus operations becomes available.

- **Hybrid --** The **Hybrid** worksheet is a placeholder that can be expanded and populated when data from hybrid bus operations becomes available.

- **Glossary --** The **Glossary** is an alphabetized listing of important terms in the model.

- **Go Home --** The **Go Home** worksheet is a navigation aid. If you become lost in the program or inadvertently shift the display off the screen, click the **Go Home** tab to return to any of the fuel-specific worksheets or the summary.

4.3 Inputs, Outputs, and Printing

The screen display shows different colors and fonts for different types of variables, as outlined below:

- ***Inputs*** -- **Bold black** characters on a blue background.

- ***Buttons*** and ***Help*** Screens -- Black characters on a grey background.

- ***Outputs*** (excluding row summations = 1.0 or 100%) -- **Bold black** characters on a yellow background.

- ***Row Summations*** that must equal 1.0 or 100% -- ***Bold italic black*** characters on a yellow background.

- ***Errors*** (invalid entries or entries that make a total invalid) -- **Bold black** or ***Bold italic black*** on a red background.

Screens are printed in groups. In the summary worksheet, all screens are printed as a group. In the CNG and LNG worksheets, the screens may be printed in any of the following groups:

- All inputs, excluding individual point mitigation measures

- Individual point mitigation measures

- All outputs.

Any group can be printed at any time. The upper right-corner of each printout shows the name of the program (C11), the worksheet containing the screen being printed (typically Summary, CNG, or LNG), the date, and the time. These printouts do not include the Excel tabs or taskbar icons shown on the printouts in the Users' Guide. Click **?** from the CNG or LNG homepages or Summary - Print from the Summary homepage, as appropriate, to print various screens.

4.4 Making Changes

The Summary or Title Page of the model is entitled "National Research Council Transportation Research Board -- Alternative Fuel Transit Bus Hazard Assessment Model." The CNG and LNG homepages contain ten **Input** and seven **Output** options.

- **Inputs** -- Six of the ten input options are for editing only, as indicated by the **Edit** buttons on the right of the page. The other four permit editing and calculating, as shown by the **Edit / Calc.** buttons. You may click any Edit button to review and edit the data variables and values. To calculate the impact of your changes, click one of the four Edit / Calc. buttons and then click **Calculate Base Case** or **Calculate Incremental Case**, as appropriate.

- **Outputs** -- Four of the seven options are for viewing only, and are marked by the **View** buttons on the right of the page. The other three are for viewing and ranking the model outputs as indicated by the **View / Rank** buttons. You may view or view and rank any model outputs at any time. Note that some outputs are per bus-year and some are per fleet-year.

- **Saving --** Click File / Save or File / Save As at the taskbar on the top of the screen to save the file.

Most screens display a **?** button. Clicking this button provides help and explanatory information. Clicking the Home button from the help page returns the user to the previous page.

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5.0 SUMMARY WORKSHEET

The **Summary** worksheet contains the main menu (Table 5-1) and three summary output tables (described below). Detailed outputs are shown for **CNG** and **LNG**. A summary estimate for **Diesel** is also provided. No values for fuel cell or hybrid buses are included in the current model.

5.1 Frequency of Losses

Table 5-2 shows the output screen for **Frequency of Losses** (injuries, fatalities, property damage). For example, a frequency of 0.00071 worker injuries per CNG bus per year (i.e., per bus-yr) in the BASE case is about one worker injury per 1,400 buses per year (1/0.00071 = 1,408). The frequency of property damage incidents in the CNG release case for the representative 200-bus fleet is estimated at about 12.1 per year. This number refers to the frequency of release (and fire) incidents giving rise to losses in the fleet each year, not the number of buses affected each year. Beneath each fuel column is the word BASE or INCREMENTAL, representing the displayed case for that fuel.

Note that the frequency of property damage from releases is equal to the number of releases and the frequency of property damage from fires is equal to the number of fires. All releases and all fires generate property damage but not all fires or releases generate injuries. Note also that the frequency of fires is a subset of the frequency of releases. Thus, the number of fires and non-fire releases is the number of releases, not the sum of fires and releases. For fatal injuries and non-fatal injuries, the number of injuries is the sum of non-fatal and fatal injuries.

5.2 Valuation of Losses

Table 5-3 shows the output screen for **Valuation of Losses**. Valuations are shown per bus-year and per year for the fleet by fuel type for (1) worker injuries, (2) worker fatalities, (3) public injuries, (4) public fatalities, (5) property damage from releases, and (6) property damage from fires. The valuations for injuries and fatalities are based on the concept of Willingness-to-Pay (WTP). Property damage valuations are based on direct and indirect repair and replacement costs and associated indirect costs, e.g., administrative overhead, facility clean-up, investigation. Beneath each fuel column is the word BASE or INCREMENTAL, representing the displayed case for that fuel.

5.3 Valuation of Losses by Stage of Operation

Table 5-4 shows the **Valuation of Losses by Stage of Operation**. The valuation totals on Table 5-4 are the same as those on Table 5-3 except that the disaggregation is by stage of operation (operation, fueling, parking, preventive maintenance, and corrective maintenance). At the lower left of the screen each fuel is the word BASE or INCREMENTAL, representing the selected case for that fuel.

Table 5-1. Summary Worksheet Main Menu

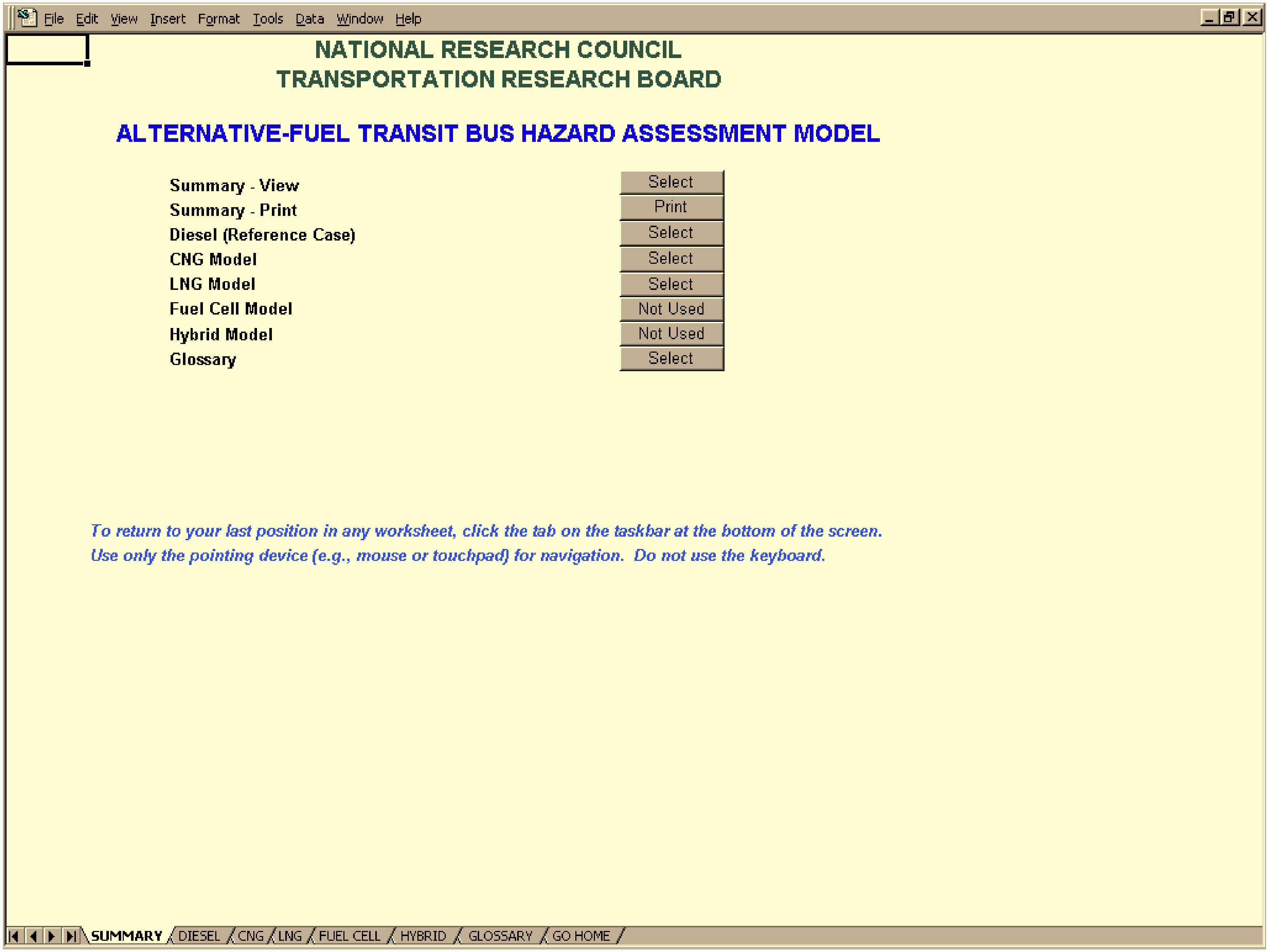

Table 5-2. Summary Frequency of Losses

File Edit View Insert Format Tools Data Window Help

FREQUENCY OF LOSSES

? | Home | Valuation of Losses | Valuation of Losses by Stage of Operation

Frequency of Losses per Bus-Year By Fuel Type

	Diesel	CNG	LNG	Fuel Cell	Hybrid
Worker Injuries		0.00071	0.00029		
Worker Fatalities		0.00000	0.00000		
Public Injuries		0.00220	0.00416		
Public Fatalities		0.00001	0.00002		
Property Damage (Release)		0.06067	0.86479		
Property Damage (Fire)		0.00006	0.00202		

Frequency of Losses per Fleet-Year By Fuel Type

	Diesel	CNG	LNG	Fuel Cell	Hybrid
Size of Fleet	200	200	200		
Worker Injuries		0.14161	0.05706		
Worker Fatalities		0.00042	0.00044		
Public Injuries		0.44047	0.83142		
Public Fatalities		0.00198	0.00335		
Property Damage (Release)		12.13370	172.95708		
Property Damage (Fire)		0.01194	0.40410		

Case (BASE/INCREMENTAL)		BASE	BASE		

SUMMARY / DIESEL / CNG / LNG / FUEL CELL / HYBRID / GLOSSARY / GO HOME

Table 5-3. Summary Valuation of Losses

File Edit View Insert Format Tools Data Window Help

VALUATION OF LOSSES

? Home

Valuation of Losses per Bus-Year By Fuel Type

	Diesel	CNG	LNG	Fuel Cell	Hybrid
Worker Injuries		$21	$3		
Worker Fatalities		$5	$6		
Public Injuries		$134	$60		
Public Fatalities		$49	$84		
Property Damage (Release)		$37	$246		
Property Damage (Fire)		$77	$82		
TOTAL	$48	$324	$480		

Frequency of Losses

Valuation of Losses by Stage of Operation

Valuation of Losses per Fleet-Year By Fuel Type

	Diesel	CNG	LNG	Fuel Cell	Hybrid
	200	200	200		
Worker Injuries		$4,271	$620		
Worker Fatalities		$1,054	$1,102		
Public Injuries		$26,870	$11,989		
Public Fatalities		$9,875	$16,762		
Property Damage (Release)		$7,361	$49,199		
Property Damage (Fire)		$15,445	$16,343		
TOTAL	$9,600	$64,875	$96,015		

Case (BASE/INCREMENTAL)		INCR.	BASE		

SUMMARY / DIESEL / CNG / LNG / FUEL CELL / HYBRID / GLOSSARY / GO HOME

Table 5-4. Summary Valuation of Losses by Stage of Operation

File Edit View Insert Format Tools Data Window Help

VALUATION OF LOSSES BY STAGE OF OPERATION

? | Home | Frequency of Losses | Valuation of Losses

Valuation of Losses per Bus-Year by Stage of Operation

	Operation	Fueling	Prev. Maint.	Corr. Maint.	Parking	TOTAL
Diesel						$48
CNG	$194	$3	$2	$7	$118	$324
LNG	$186	$8	$3	$10	$273	$480
Fuel Cell						
Hybrid						

Valuation of Losses per Fleet-Year by Stage of Operation

	Fleet	Operation	Fueling	Prev. Maint.	Corr. Maint.	Parking	TOTAL
Diesel	200						$9,600
CNG	200	$38,848	$662	$482	$1,382	$23,500	$64,875
LNG	200	$37,239	$1,611	$692	$1,901	$54,571	$96,015
Fuel Cell							
Hybrid							

Case (BASE/INCREMENTAL)

Diesel	
CNG	INCR.
LNG	BASE
Fuel Cell	
Hybrid	

SUMMARY / DIESEL / CNG / LNG / FUEL CELL / HYBRID / GLOSSARY / GO HOME

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6.0 FUEL HOMEPAGE

Each fuel has a homepage. The CNG, LNG, and Diesel homepages each have a question mark button (**?**) on the top bar. For **Diesel**, clicking on the ? only summarizes the limited options on the screen. For **CNG** and **LNG**, clicking on the ? provides you with print options and directions to the glossary. You may also return to the homepage by clicking the **Home** button.

6.1 Diesel

The homepage for diesel contains two questions: How many diesel buses are in your fleet at a single facility? and (2) What is the overall estimated fuel-related loss per bus-year? The **Reference Case** values for these variables are 200 and $48, respectively. You may want to make the number of diesel buses equal the number of alternative fuel buses to provide an equal fleet-size comparison.

6.2 CNG and LNG

The homepages for CNG and LNG are functionally equivalent. Each presents 10 input screen options and seven output screen options. Tables 6-1C and 6-1L show the CNG and LNG homepages.

6.2.1 Printing

The **?** Button on the CNG and LNG homepages provides printing functions, as follows:

- **Print Input Screens --** Prints the 10 summary input screens, but not the 15 individual **Point Mitigation** input screens.

- **Print Point Mitigation Measures (Detail)** -- Prints the 15 Point Mitigation input screens.

- **Print Output Screens --** Prints the seven output screens.

These printouts include the name of the worksheet, the date, and the time. They do not include the Excel tabs or taskbar icons shown on the printouts in the Users' Guide.

6.3 Fuel Cell and Hybrid

The homepages for fuel cell and hybrid transit buses are place-holders only, pending the development of actual industry data on releases and fires.

Table 6-1C. Fuel Homepage (CNG)

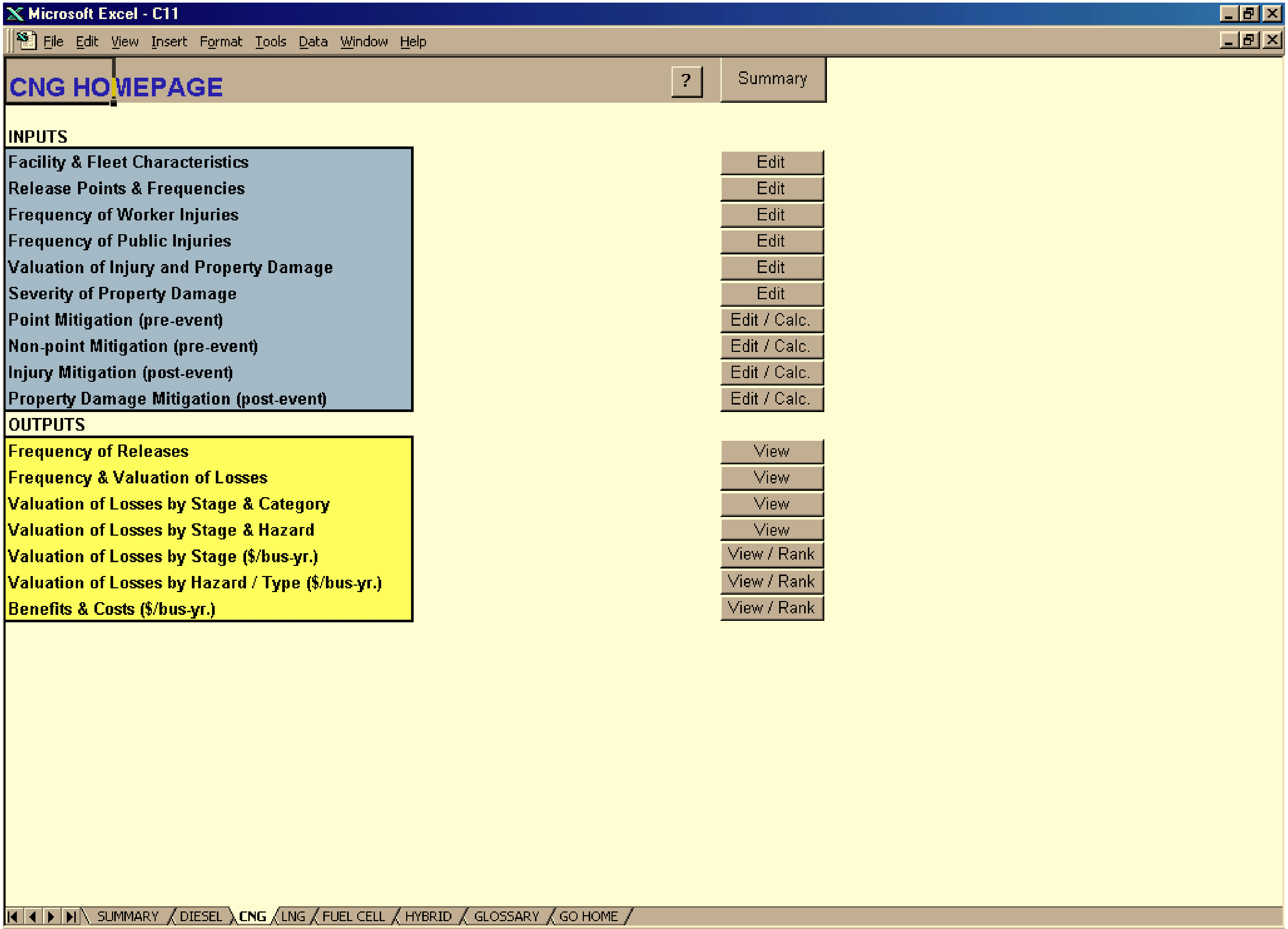
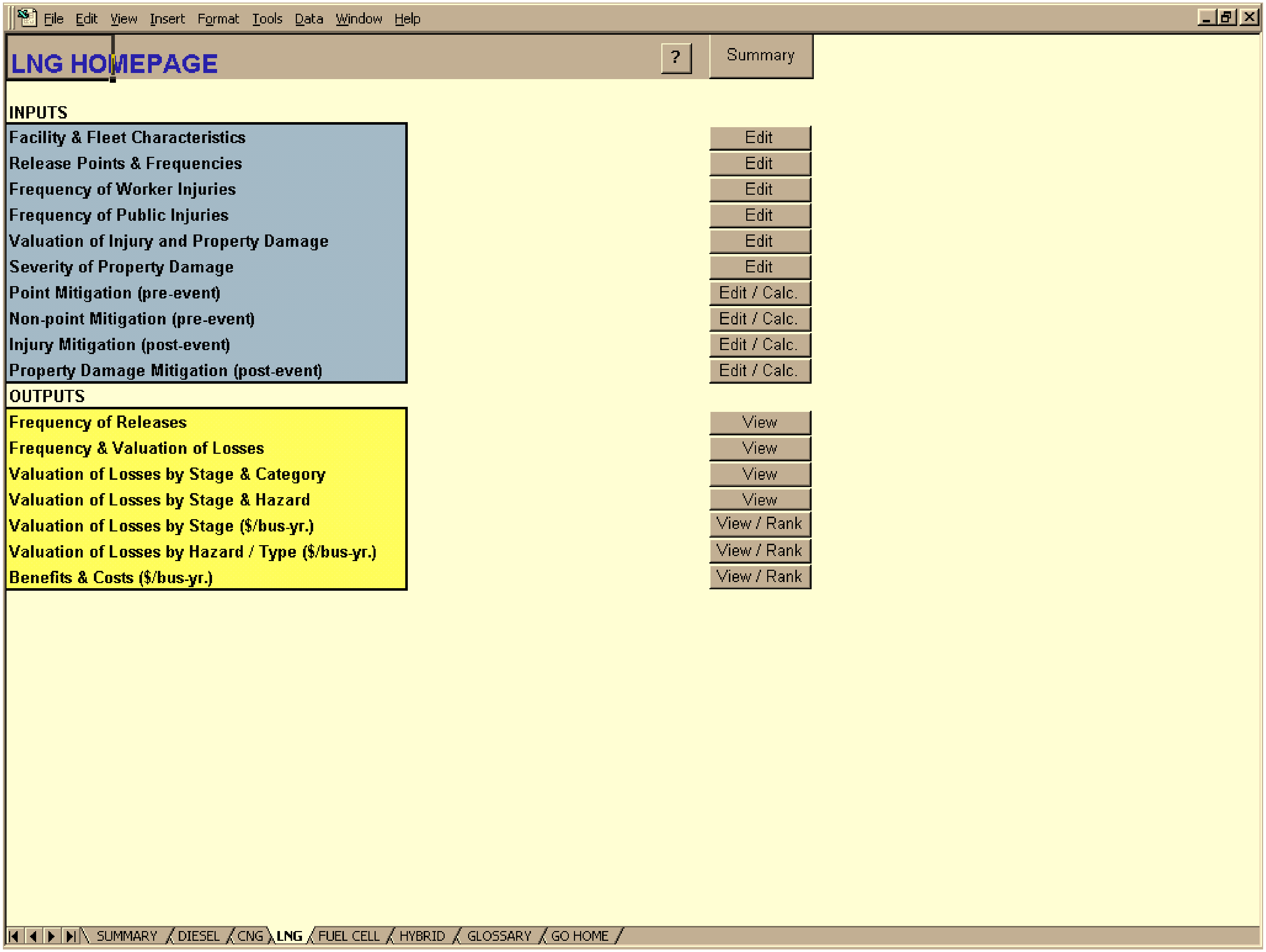


Table 6-1L. Fuel Homepage (LNG)



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7.0 INPUTS

Tables 6-1C and 6-1L (previous pages) showed the input screens on the CNG and LNG homepages. Details of the screens in general and the specifics of usage for CNG and LNG individually are discussed below.

7.1 Facility and Fleet Characteristics

Tables 7-1C and 7-1L show the input categories for the **Facility and Fleet Characteristics**. All activities in the model take place in one of five operating stages ***(operations, fueling, preventive maintenance, corrective maintenance,*** or ***parking***). The model calculates releases, fires, exposures, injuries, property damage, etc. by stage of activity. Within each stage, the **Reference Case** provides an estimate of the duration of the stage, the number of exposed workers, the number of exposed members of the public, the probability of a release, the probability of an ignition, and so forth.

- ***Facility* --** A single bus fleet site or depot.

- ***Buses in Fleet* --** The buses at the facility. Other types of buses are not considered. The reserve fleet, if fueled, is part of the fleet.

- ***Operations* --** In, en-route, or returning from revenue service or being driven, towed, or moved on public roads.

- ***Fueling* --** Indoor fueling is the time the bus is inside the fueling facility. Outdoor fueling is the time the bus is standing, being fueled, cleaned, serviced or washed at a fueling or defueling isle plus the amount of time the bus is within 15 feet of another bus that is being fueled or defueled. Fueling includes the time it takes to drive to the next stage (parking, maintenance, etc.). Standing in a queue (outdoors) more than 15 feet from another bus is parking.

- ***Preventive Maintenance (PM)*** -- The bus (containing fuel) at the PM site (indoors or outdoors), whether standing, being maintained, cleaned or serviced. Standing in a queue to enter the PM site is parking.

- ***Corrective Maintenance (CM)*** -- The bus (containing fuel) at the CM site (indoors or outdoors), whether standing, being maintained, cleaned or otherwise serviced. CM conducted on a public road by the operator or the road call crew is included. Standing in a queue to enter the CM site is parking.

- ***Parking*** -- The bus (containing fuel) at the parking facility (indoors or outdoors), with the engine on or off, standing in a queue in other stages (as discussed above), while being inspected (pull-out inspection), or otherwise stored. The reserve fleet, if defueled, is not considered.

- ***% Of Time in Stage*** -- The fraction of time spent by an average bus (as defined by bus model, vintage, duty cycle, etc.) in each stage. The **Reference Case** bus has an average daily duty cycle of 200 miles. The percent of time in the five stages must sum to 100 percent. Invalid entries (i.e., individual durations less than zero or summed durations exceeding 100%) cause the invalid entry or sum to appear against a red background.

- ***% Of Stage Indoors*** -- The fraction of time spent indoors by the average bus in each stage.

- **#** ***Of Exposed Workers*** -- The average number of bus organization employees (staff) within 15 feet of any part of a bus containing fuel (not defueled or vented).

- **#** ***Of Exposed Members Of Public*** -- The average number of non-employee individuals (passengers, pedestrians, occupants of nearby vehicles, etc.) within 15 feet of the bus containing fuel (not defueled or vented).

- ***Pr. Of Fire (Indoor, Given Release)*** **--** See Sections 7.1.1 (CNG) and 7.1.2 (LNG).

- ***Pr. Of Fire (Outdoor, Given Release)*** -- See Sections 7.1.1 (CNG) and 7.1.2 (LNG).

- ***Release Frequency*** -- See Sections 7.2 and 8.1 and Appendix B.

- ***Duration-Adjusted Frequency*** -- See Sections 7.2 and 8.1 and Appendix B.

- ***Normalized Frequency*** **--** See Sections 7.2 and 8.1 and Appendix B.

Table 7-1C. CNG Facility and Fleet Characteristics

FACILITY & FLEET CHARACTERISTICS

CHARACTERISTICS	Operation	Fueling	Prev. Maint.	Corr. Maint.	Parking	Total or Wtd. Avg.
Buses in fleet	200	----	----	----	----	200
% of time in stage	57.0%	1.0%	2.0%	5.0%	35.0%	*100.0%*
% of stage indoors	0.0%	100.0%	100.0%	95.0%	0.0%	7.8%
# of exposed workers	1.0	1.0	2.0	2.5	0.1	0.78
# of exposed members of public	12.0	0.0	0.0	0.0	0.0	6.84
Pr. fire (indoor, given release)	2.0%	1.5%	2.0%	2.0%	2.0%	0.2%
Pr. fire (outdoor, given release)	0.2%	0.3%	0.3%	0.3%	0.1%	0.1%
Release frequency	1.7%	29.3%	6.9%	6.9%	55.2%	*100.0%*
Duration-adjusted frequency	1.0%	0.3%	0.1%	0.3%	19.3%	21.1%
Normalized frequency	4.6%	1.4%	0.7%	1.6%	91.7%	*100.0%*

Table 7-1L. LNG Facility and Fleet Characteristics

File Edit View Insert Format Tools Data Window Help

FACILITY & FLEET CHARACTERISTICS

? Home

CHARACTERISTICS	Operation	Fueling	Prev. Maint.	Corr. Maint.	Parking	Total or Wtd. Avg.
Buses in fleet	200	----	----	----	----	200
% of time in stage	60.0%	1.5%	2.0%	6.0%	30.5%	*100.0%*
% of stage indoors	0.0%	0.0%	95.0%	95.0%	100.0%	38.1%
# of exposed workers	1.0	1.0	2.0	2.5	0.1	0.8355
# of exposed members of public	12.0	0.0	0.0	0.0	0.0	7.2
Pr. fire (indoor, given release)	0.0%	1.5%	2.0%	2.0%	1.0%	0.5%
Pr. fire (outdoor, given release)	0.2%	0.3%	0.3%	0.3%	0.1%	0.1%
Release frequency	4.0%	30.0%	8.0%	8.0%	50.0%	*100.0%*
Duration-adjusted frequency	2.4%	0.5%	0.2%	0.5%	15.3%	18.7%
Normalized frequency	12.8%	2.4%	0.9%	2.6%	81.4%	*100.0%*

SUMMARY / DIESEL / CNG / LNG / FUEL CELL / HYBRID / GLOSSARY / GO HOME

7.1.1 CNG

The starting point for defining the facilities, buses, and activities are the observations made by the project team between 1995 and 1999 at Pierce Transit (Tacoma, Washington) and Sacramento RT (Sacramento, California). Observations at Pierce Transit form the basis for the values for ***% of Time in Stage***, ***% of Stage Indoors*** and ***# of Exposed Workers***. Observations at Sacramento RT provided data relating to indoor fueling and facility characteristics. Release Frequencies by Stage are based on SAIC's 1995 and 1997 CNG bus failure rate survey (Section 8.1 and Appendix B).

Values for such factors as ***Probability of Fire*** were determined on a relative basis, assuming a designed but deteriorated adherence to codes, standards, regulations, and best practices. This is based on observed behavior at numerous CNG transit facilities where buses, facilities, and practices were mostly but not entirely in compliance with safety regulations. Non-compliant characteristics include inoperative gas detectors, smoking in non-smoking areas, use of spark-generating tools, erosion in CNG-related knowledge level (lack of re-training), and relaxed inspections.

Specific **Facility and Fleet Characteristics** for the CNG **Reference Case** are as follows:

- ***Facility* --** The facility has indoor fueling. a connected preventive and corrective maintenance facility, a connected body shop, and outdoor parking. All comply with NFPA-52 CNG modification (ventilation, alarm, spark-proof heating systems, trained personnel, etc.). The facility (site, buildings, and operations) is modeled after Pierce Transit. However, the setting for indoor fueling is similar to Sacramento RT.

- ***Fueling* --** Fueling is conducted indoors in a roofed, two-sided structure, (approximate depiction of Sacramento RT) with the capability to simultaneously fuel four buses, in two parallel lanes, with an additional two buses waiting in a queue, indoors. Washing takes place outside after fueling.

- ***Preventive Maintenance* --** PM is conducted on fully fueled and sometimes freshly-fueled (defined as within 30 minutes of fueling) buses. Four buses can be maintained at one time.

- ***Corrective Maintenance*** -- CM is conducted on buses that may be in any stage of fueling. Buses are sometimes fully fueled and sometimes "run dry" (cylinders shut, bus idling until the fuel in the fuel lines is exhausted). Sometimes, the bus is emptied (but not empty) of fuel through defueling, venting, or run empty.[1] The buses are vented only

[1] When a CNG bus is "run dry" the CNG in the fuel lines is at the lowest operating pressure of the engine (commonly 50 to 250 psi). When de-fueled, the fuel system, including the non-isolated cylinders, contains natural gas at the pressure of the natural gas supply line into which the CNG is injected (commonly 20 - 100 psi). When vented the cylinders and fuel lines may contain natural gas at atmospheric pressure. Active purging is required to empty the bus of all fuel.

if non-isolatable fuel system work is being performed (pressure relief valve, cylinder, main valve, etc.).

- ***Parking* --** Parking takes place after fueling and washing. Outdoor parking is adjacent to the fueling and maintenance facility, with at least a 20-foot clearance from each. Approximate depiction of Pierce Transit.

- ***Buses in Fleet* --** 200 buses, reflecting some economies of scale, activities at Pierce Transit, and coinciding with the scale in another TCRP study.[2] The buses are all 40', 1-year-old, with 12 roof-mounted cylinders isolated into three banks of four cylinders each. Each cylinder is fitted with two, free-venting (not manifolded), temperature-activated relief valves. The cylinders are lightweight, carbon/carbon, type IV, containing 16,000 scf of natural gas. This reflects the approximate configuration of an average CNG bus in 1999 -- the period used in the Reference Case.

- ***% Of Time in Stage* --** Based on 1995 estimates obtained by project staff at Pierce Transit. The estimates include observed time, time derived from corrective maintenance documents, calculations based on throughput (primarily for fueling and PM), time estimates based on revenue service requirements, and estimates provided by Pierce Transit staff for 1994.

- ***% Of Stage Indoor* --** Approximate depiction of Pierce Transit.

- ***# Of Exposed Workers*** -- Based on estimates made by the project team at Pierce Transit, Sacramento RT, Los Angeles County MTA, and Cleveland, and estimates provided by Pierce Transit staff for fueling, CM, and PM. Estimates for operation represent one driver.

- ***# Of Exposed Members Of Public*** -- Estimated from "medium motor buses" (refers to the size of agencies) in the 1996 SAMIS report.[3] The data indicates that for this category of agencies (similar to Pierce Transit) there were 257 passengers per bus, per day, traveling an average of 4.46 miles (defined here as a 20-minute trip), yielding an average bus occupancy of 3.57 passengers on a 24-hour basis. Further adjusting for the utilization factor (operation is estimated at 57%, but revenue service with passengers on the bus is estimated at 50%) yields an average occupancy of 7.14 passengers for a bus in operation. The project team assumed that on the average there would be the equivalent of one passenger car with two occupants within 15 feet of the bus, and three pedestrians,

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[2] Transportation Research Board, Guidebook for Evaluating, Selecting, and Implementing Fuel Choices for Transit Bus Operations, TCRP Report 38, National Academy Press, Washington, D.C., 1998.

[3] U.S. Department of Transportation, Federal Transit Administration, Safety Management Information Statistics (SAMIS), 1996 Annual Report, Final Report, Washington, D.C. 1998.

for a total of 12.14 exposed members of the public (rounded to 12.0).[4]

- ***Probability of Fire (Indoor, Given Release)*** -- The probability is based on a worst-case release remaining for 10 minutes throughout the facility during the most active part of the day. Assumes natural gas released from the PRD equals one bank (four cylinders). It includes the probability of fire from a non-CNG-related fire, such as an engine compartment fire (with a 100% probability of ignition of the released CNG). There is some non-compliance with standards and recommended practices. For example, smoking, use of welding equipment, fans, and other ignition sources (per observations). The following are the assumed probabilities of fire by stage:

  Operation -- The model does not allow indoor operation.

  Fueling -- 1.5%. There have been a few PRD releases in this setting. None are known to have resulted in a fire. However, all of these cases occurred in a two-sided building and in at least two cases the affected bus was pushed outdoors to complete the venting.

  PM -- 2%. There are more types of ignition-inducing operations with less stringent oversight than in fueling.

  CM -- 2%. Assumes some non-compliance with regulations, availability of ignition sources from operations (electric tools, torches, lights, etc.). There are many more ignition-inducing operations than in PM, albeit with generally more stringent adherence to codes and regulations. Three fires have been reported. All were attributed to open-flame heaters. While NFPA 88B specifically disallows such heaters, the Reference Case allows for some level of non-compliance (per observations) and considers the probability that in some cases open-flame heaters or other sources of ignition from disallowed appliances will continue to occur.

  Parking -- 1%. Assumes some non-compliance with regulations and greater potential for the accumulation of gas. However, with the exception of bus engine operations, smoking by personnel, and negligence (operation of open flame heaters), there are few sources of ignition in a parking garage.

- ***Probability of Fire (Outdoor, Given Release)*** -- Assumes that a flammable mixture exists for 10 minutes within 15 feet of the bus. Assumes natural gas released from the

[4] CNG buses are used predominantly by transit organizations serving large urban areas, such as LA, NY, Cleveland, Sacramento, and Atlanta. These areas have greater passenger, traffic, and pedestrian densities. In these areas, the estimated public exposure should be raised accordingly.

PRD equals one bank (four cylinders). It includes the probability of fire from a non-CNG-related fire, such as an engine compartment fire (with a 100% probability of ignition of the released CNG). There is some non-compliance with standards and recommended practices. For example, smoking, use of welding equipment, fans, and other ignition sources. The following are the assumed probabilities of fire by stage:

Operation -- 0.2%. Assumes release in urban, open area with available ignition sources (fire on the bus, pedestrians smoking, street traffic, etc.). There have been at least five such fires where an engine compartment fire resulted in the ignition of natural gas released from the PRD. The probability of ignition is lower than for an indoor release because there are fewer sources of ignition and faster dissipation of the released fuel.

Fueling -- 0.3%. Assumes a roofed canopy and some non-compliance with regulations, etc. There was one such fire in the early 1990's. Ignition was attributed to static electricity.

PM -- 0.3%. Assumes open-air work, similar environment to fueling, and lower attention to hazards than in outdoor fueling.

CM -- 0.3%. Assumes open-air work, similar environment to fueling, and lower attention to hazards than in outdoor fueling but more ignition-type activities than in PM.

Parking -- 0.1%. Assumes little availability of ignition sources. While this is an unlikely event, the probability is greater than zero due to smoking, static electricity, sparks from other vehicles, and ignition from non-CNG vehicle fires on the bus or other nearby fires.

7.1.2 LNG

The starting point for fleet and facility values is a series of observations made by the project team between at several LNG transit facilities between 1994 and 1999. The most important observations come from Houston Metro, the Phoenix Transit System, Tri-Met (Portland), Dallas, and Baltimore. Failure rate estimates were obtained from Houston for the years 1995 through 1998 and from Phoenix for 1999. These were estimated failure rates (and costs) based on the LNG program managers files and recollections. No statistically valid data is maintained by the LNG industry on failure rates. (The Reference Case uses the 1999 data from Phoenix.)

Values for such factors as probability of ignition were determined on a relative basis, assuming a designed but deteriorated adherence to codes, standards, regulations, and best practices. This is based on observed behavior at the LNG transit facilities, where buses, facilities, and practices, mostly (but not totally) comply with those prescribed. Observed non-compliance includes inoperative gas detectors, smoking in non-smoking areas, use of spark-generating tools, erosion in LNG-related knowledge (lack of re-training), and relaxed inspection. No data are available for LNG releases by stage. The stage-specific statistics for CNG were used as a proxy for LNG.

Specific Facility and Fleet Characteristics for the LNG Reference Case are as follows:

- ***Facility* --** The reference facility has outdoor fueling and outdoor parking. The structure contains fueling capabilities, a connected preventive and corrective maintenance facility, and a connected body shop. All comply with NFPA-52 and NFPA-57 LNG modification (ventilation, alarm, spark-proof heating systems, trained personnel, etc.). The facility (site, buildings, and operations) is similar to that of Houston Metro.

- ***Fueling* --** Fueling is conducted outdoors under a canopy. The fueling station can simultaneously fuel two buses in one lane with two additional buses waiting in a queue. Washing is outside after fueling.

- ***PM*** -- Buses brought into PM are always fully fueled.

- ***CM*** -- CM may be conducted on buses that may be in any stage of fueling. Buses are sometimes fully fueled and sometimes "run dry" (cylinders shut, bus idling until the fuel in the fuel lines is exhausted). Sometimes, the bus is emptied (but not empty) of fuel through defueling, venting, or run empty.[5] The buses are vented only if non-isolatable fuel system work is being performed (pressure relief valve, fuel tank, main valve, etc.).

- ***Parking* --** Parked buses are freshly fueled for the first 30 minutes and fully fueled thereafter. The outdoor parking is under a canopy, adjacent to the fueling and maintenance facility, with at least a 20-foot clearance from each. Approximate depiction of Houston Metro's West facility.

- ***Buses in Fleet* --** The reference fleet has 200 buses, or roughly the same range as Houston Metro and Phoenix and the same as that used in another TCRP study.[6] The buses are standard 40' units, 1-year-old, with two connected fuel tanks. Each fuel tank is fitted with two, manifolded, pressure-activated relief valves. The fuel tanks are aluminum and cryogenic steel, containing 160 gallons of LNG. (The Houston LNG buses used one large LNG tank).

- ***% Of Time in Stage* --** Based on 1995 observations and measurements obtained for CNG buses by project staff at Pierce Transit. The estimates include observed time, time

[5]When an LNG bus is emptied but not purged it contains a layer of liquid and a layer of gas at atmospheric pressure.

[6]Transportation Research Board, Guidebook for Evaluating, Selecting, and Implementing Fuel Choices for Transit Bus Operations, TCRP Report 38, National Academy Press, Washington, D.C., 1998.

derived from corrective maintenance documents, calculations based on throughput (primarily for fueling and PM), time estimates based on revenue service requirements, and estimates provided by Pierce Transit staff for 1994.

- ***% Of Stage Indoors* --** Approximate depiction of Pierce Transit.

- # ***Of Exposed Workers* --** Based on observations made by the project team at Pierce Transit, Sacramento RT, LACMTA, and Cleveland, and estimates provided by Pierce Transit staff for fueling, CM, and PM. Estimates for operation represent one driver.

- # ***Of Exposed Members Of Public*** --Utilized data for "medium motor buses" (refers to the size of agencies) in the 1996 SAMIS report.[7] The data indicates that for this category of agencies (similar to Pierce Transit) there were 257 passengers per bus, per day, traveling an average of 4.46 miles (defined here as a 20 minute trip), yielding an average bus occupancy of 3.57 passengers on a 24-hour basis. Further adjusting for the utilization factor (operation is estimated at 60%, but revenue service with passengers on the bus is estimated at 50%) yields an average occupancy of 7.14 passengers for a bus in operation. The **Reference Case** also assumes that on the average there would be the equivalent of one passenger car with two occupants within 15 feet of the bus, and three pedestrians, for a total of 12.14 exposed members of the public (rounded to 12.0).

- ***Probability of Fire (Indoor, Given Release)* --** The probability is based on a worst-case release remaining for 10 minutes throughout the facility during the most active part of the day. The values assume the equivalent of two fuel tanks are released through the PRD. They include the probability of ignition from a non-LNG-related fire, such as an engine compartment fire (with a 100% probability of ignition of the released LNG). The values reflect some non-compliance with codes, standards, regulations, and recommended practices. The following are the assumed probabilities of fire by stage, indoors, given a release.

  Operation -- The model does not allow indoor operation.

  ***Fueling* --** 1.5%. There have been several PRD releases in this setting, mostly due to over-pressurization. Also, there are frequent releases of LNG during the nozzle connection / disconnection process. None are known to have resulted in a fire. All occurred outdoors.

  ***PM* --** 2%. There are more types of ignition-inducing operations with less stringent oversight than in fueling.

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[7] U.S. Department of Transportation, Federal Transit Administration, Safety Management Information Statistics (SAMIS), 1996 Annual Report, Final Report, Washington, D.C. 1998.

***CM* --** 2%. Assumes some non-compliance with regulations, availability of ignition sources from operations (electric tools, torches, lights, etc.). There are many more ignition-inducing operations than in PM, albeit with generally more stringent adherence to codes and regulations. There was one incident involving LNG, where the released LNG was ignited by the air-conditioning system on the bus. Three agencies reported similar fires with CNG buses, both attributed to open-flame heaters. While NFPA 88B specifically disallows the use of such heaters, the Reference Case allows for observed levels of non-compliance.

***Parking* --** 1%. Assumes some non-compliance with regulations and greater potential for the accumulation of gas. However, with the exception of bus engine operations, smoking by personnel, and negligence (open-flame heaters) there are few sources of ignition in a parking garage.

- ***Probability of Fire (Outdoor, Given Release)*** -- Assumes that a flammable mixture exists for 10 minutes within 15 feet of the bus. The values assume the equivalent of two fuel tanks are released through the PRD. They include the probability of ignition from a non-LNG-related fire, such as an engine compartment fire (with a 100% probability of ignition of the released LNG). The values reflect some failure to maintain total compliance with codes, standards, regulations, and recommended practices. The following are the assumed probabilities of fire by stage, outdoors, given a release.

***Operation* --** 0.2%. Assumes release in urban, open area with available ignition sources (fire on the bus, pedestrians smoking, street traffic, etc.). There have been at least five such fires on CNG buses where an engine compartment fire resulted in the ignition of natural gas released from the PRD. The probability of ignition is lower than for an indoor release because there may be fewer sources of ignition and faster dissipation of the released fuel.

***Fueling* --** 0.3%. Assumes a roofed canopy and some non-compliance with regulations. There was one such fire in the early 1990's involving CNG. The ignition source was attributed to static electricity.

***PM* --** 0.3%. Assumes open-air work, similar environment to fueling, lower attention to hazards than in outdoor fueling.

***CM* --** 0.3%. Assumes open-air work, similar environment to fueling, lower attention to hazards than in outdoor fueling but more ignition-type activities than in PM.

Parking -- 0.1%. Assumes little availability of ignition sources. While this is an unlikely event, the probability is greater than zero due to smoking, static electricity, sparks from other vehicles, and ignition from non-LNG vehicle fires on the bus or other nearby fires.

7.2 Release Points and Frequencies

One of the key risk variables in the model is probability of fuel released during each stage of the operating cycle (Tables 7-2C and 7-2L). The model defines a fuel release as a component failure that releases fuel, a release from an accident, or intentional venting. Component failures that do not release fuel (e.g., another component prevents the release) are excluded. This conservative interpretation of fuel release may understate the commonly used meaning of a failure (i.e., any release from any cause whether it is negated by another component or not).

Release frequencies may, in some cases, be most accurately assigned on the basis of the age of the bus, the mileage of the bus, the number of operating cycles of the equipment, the frequency of high-risk activities, etc. The model addresses these relationships by incorporating the percent of time the average bus spends in each stage of the operating cycle (i.e., operations, fueling, parking, preventive maintenance, corrective maintenance). Thus, a bus (or more accurately, a fleet) with high mileage will also spend more time in fueling (one of the high risk stages) and more time in operations (which exposes the most people to hazards). This time-weighted approach captures the key issues associated with mileage, fuel usage, cycling, age, etc.

Table 7-2C. Release Points and Frequencies (CNG)

File Edit View Insert Format Tools Data Window Help

RELEASE POINTS & FREQUENCIES (per bus-yr.)

? Home

Release Points	Select	Select	Select	Select	
	1994-95	1996-97	1998-99	User Data	x to deselect
1. Cylinder - slow	0.00697	0.00348	0.00261		
2. Cylinder - fast	0.00071	0.00036	0.00027		
3. PRD - fast	0.03430	0.01715	0.00858		
4. PRD - slow	0.08623	0.04312	0.01078		
5. Refueling device	0.02001	0.01001	0.00750		
6. Fuel line fittings	0.02490	0.01245	0.00934		
7. Fuel line	0.01090	0.00545	0.00273		
8. LP regulator	0.01415	0.00708	0.00531		
9. HP regulator	0.02616	0.01308	0.00981		
10. Solenoid valve	0.03040	0.01520	0.00760		
11. 1/4 turn valve	0.02317	0.01159	0.00869		
12. Other valve	0.00460	0.00230	0.00173		
13. Other	0.01098	0.00549	0.00412		
14. Open	0.00000	0.00000	0.00000		x
15. Open	0.00000	0.00000	0.00000		x

SUMMARY / DIESEL / CNG / LNG / FUEL CELL / HYBRID / GLOSSARY / GO HOME

Table 7-2L. Release Points and Frequencies (LNG)

File Edit View Insert Format Tools Data Window Help

RELEASE POINTS & FREQUENCIES (per bus-yr.)

? Home

Release Points	Select	Select	Select	Select	
	1994-95	1996-97	1998-99	User Data	x to deselect
1. Fuel tank (Vac. Loss)	3.00000	0.30000	0.04762		
2. Fuel Tank Rupture	0.00005	0.00003	0.00040		
3. PRD - fast (2/tank)	12.50000	0.37500	0.00095		
4. PRD - slow (2/tank)	2.50000	0.02500	0.29524		
5. Refueling receptacle	4.00000	0.04000	1.00000		
6. Fuel line fittings	7.00000	0.70000	2.00000		
7. Fuel line	2.00000	0.20000	0.00159		
8. Regulator	2.00000	2.00000	0.00952		
9. Vaporizer	0.00020	0.00010	0.47619		
10. Solenoid valve	0.10000	0.05000	0.01665		
11. 1/4 turn valve	1.00000	0.10000	0.00095		
12. Injector (Fuel Valve)	3.00000	0.00000	0.00000		
13. Cryo Pump	3.00000	0.00000	0.00000		x
14. Gauges	1.00000	0.10000	0.03330		
15. Couplings	2.00000	1.00000	0.00095		

SUMMARY / DIESEL / CNG / LNG / FUEL CELL / HYBRID / GLOSSARY / GO HOME

7.2.1 CNG

The data used in the first two numeric columns on Table 7-2C are based on CNG bus component failure statistics from SAIC's 1995 and 1997 CNG Bus Component Failure Rate Surveys. The first survey to collect CNG bus component failure rate data was fielded in 1994 to collect failure-rate information from the beginning of CNG bus usage at a facility through the point of survey completion. The survey frame was all known U.S. transit agencies with CNG buses. Data were collected from 19 agencies, covering 332 CNG buses, with an average age of 1.6 years per bus, and 14.6 million miles of service. Most of the data points reflect mid-1990s operation.

The second survey was fielded in late 1996 and responses were received through mid-1997. For this survey SAIC removed a number of small transit agencies from the frame to focus on the larger agencies. The 1997 survey frame included 70-90% of all the CNG transit buses operating in the U.S. during the period. Responses were received from 13 transit agencies. As a result of the rapid adoption of CNG buses at several transit agencies, the average age of the buses fell below one year, but the total number of buses increased from 332 in 1995, to 703 in 1997, and the total mileage increased to 23.5 million.

The **Reference Case** uses data for 1999, presented in the third numeric column. These data adjust for the improvement in PRD reliability for fast and slow leaks since the mid-1990s. The 1999 data also reduce failures for the other components generally by 25% to reflect system reliability improvements and to better approximate the partial reports of failure in 1999. This estimation approach supersedes data from a sample survey of five agencies conducted by SAIC for the project. The data obtained in the sample survey were inconsistent within and across agencies. Known releases were omitted and unrealistically low consequences (e.g., omission of administrative costs for major repairs) were reported. The project team is reviewing the results with the agencies to determine how to obtain more accurate and complete data at a future time. See Appendices B and C.

To select a data set for use in the model, click on the button above the column. You may also deselect any component within a column by entering "x" in the deselect column of the appropriate row.

The release points used in the model are as follows:

- ***Cylinder – Slow*** -- Slow leaks from the cylinder body. This was a common issue with composite cylinders that were discontinued but are still in wide use. It also refers to leaks from valve/cylinder connections reported by some as a valve leak or an O-ring leak.

- ***Cylinder – Fast* --** Major leak, usually a burst cylinder.

- ***PRD – Fast* --** Activation of a PRD, includes proper and spurious releases.

- ***PRD – Slow* --** A slow leak through the valve body. Some surveys included O-ring leaks.

- ***Refueling Device*** -- The fuel receptacles.

- ***Fuel Line Fittings*** -- All fuel line connections (threaded and non-threaded).

- ***Fuel Lines* --** A set of high pressure tubes, usually stainless steel specifically designed to channel high-pressure gas.

- ***LP and HP Regulators*** -- Low-pressure and high-pressure control devices.

- ***Solenoid Valves*** -- Electrically controlled, in-line isolation valves.

- ***Other valves* --** 1/4 turn valves, check valves, flow control valves, etc.

- ***Other*** -- Everything not specifically included above.

7.2.2 LNG

The selection of failure rate data for the **Reference Case** is a critical factor in the risk and valuation estimates in the model. The overall release frequencies used in Table 7-2L are based on LNG bus component failure data obtained from the two largest LNG bus organizations: Houston Metro and the Phoenix Transit System.[8] As of this writing, Houston Metro is conducting an experiment with five similar LNG, CNG, and diesel buses. Most of the original 200 LNG buses are operating on diesel fuel or were decommissioned.

The **Reference Case** statistics are based on operations at Phoenix Transit. These data, obtained in the fall of 1999, reflect approximately 200 LNG buses and one year of operations. Although they include many failures attributable to start-up-related issues, they are significantly more favorable than the contemporaneous data from Houston. The project team also selected the Phoenix data for the Reference Case because the LNG systems and components on the Phoenix buses more closely reflect the types of systems and components that are available on new LNG buses.[9]

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[8]The values by stage are allocated using the CNG data. No similar data for LNG are available.

[9]Many of the components used on the Houston LNG buses are not generally part of systems currently being shipped for use at transit agencies. Also, certain components used at Houston (e.g., engine, regulators, and fuel

Also note that the relatively high failure rates at both sites are to some extent due to the new designs, system configurations, components, and inexperience of the transit staff with LNG. The first year is considered the break-in period during which both the system designers and users are making improvements. It is reasonable to expect fuel releases at Phoenix to decrease in 2000-01. However, there is little information on the long-term durability and integrity of the new systems and components. Finally, while year-one failures are covered by manufacturers' warranties, costs were considered regardless of liability.

The failure rate data at Houston and Phoenix were obtained through interviews with the LNG project managers at the respective agencies. Both provided approximations of frequencies and costs and neither relied extensively on documented data. However, each program manager was with the LNG program from its start and each was in a good position to know about releases and failures.

Table 7-2L showed three sets of release frequencies and a fourth (blank) column for user-defined data. You may select one of the three sets of release frequencies or construct one for testing. Click on the button above a column to select it. You may also deselect any component within a column by entering "x" in the deselect column of the appropriate row.

The release points used in the model are as follows:

- ***Fuel Tank (Vacuum Loss)* --** Loss of tank insulation, leading to a steady leak from the PRD to relieve tank over-pressure.

- ***Fuel Tank Rupture* --** A major leak from the tank, usually from an accident.

- ***PRD* Fast --** Activation of a PRD, whether appropriate or inappropriate.

- ***PRD Slow* --** A slow leak through the valve body, usually due to improper resetting of the valve.

- ***Refueling Receptacle* --** A fuel receptacle leak, usually due to improper resetting of the valve.

- ***Fuel Line Fittings* --** Any fuel line connection (threaded and non-threaded).

- ***Fuel Line* --** A set of tubes specifically designed to channel cryogenic liquids.

- ***Regulator* --** Pressure and fuel flow control device.

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pump) are no longer available.

- ***Vaporizer* --** A heated coil to vaporize the LNG.

- ***Solenoid Valves* --** Electrically controlled, in-line isolation valves.

- ***1/4-Turn Valves* --** 1/4-turn shut-off or isolation valves, check valves, and other flow control valves.

- ***Injector (fuel valve)* --** Some engines (e.g., Houston's DDC) use one injector per cylinder to deliver the fuel into the combustion chamber.

- ***Cryogenic Pump* --** Used in some systems to pump the LNG from the tank to the engine.

- ***Gauges* --** Pressure measuring devices.

- ***Couplings* --** Tank-to-fuel line connectors.

7.3 Frequency of Worker Injuries

The data shown in Table 7-3C and 7-3L present a conceptual evaluation of the probability of an injury (by degree of severity) from a release and from a fire at each release point. The tables address two questions: Assuming a worst-case release at each release point, and a single (statistical) member of the bus agency's workforce within 15 feet of the bus:

- What would be his or her likelihood of receiving a release-related injury at each level of severity?

- Assuming that he or she survived the release and that there was an ensuing fire, what would be his or her likelihood of receiving a fire-related injury at each level of severity?

In all cases, fatalities are a subset of injuries, i.e., fatal injuries. Releases and fires are evaluated separately. Thus, the total probability of all injuries (including fatal injuries and no injuries) is 1.0 for releases and 1.0 for fires. The model adjusts for less than worst-case releases and the probability that more or less than one person may be within 15 feet of the bus during each stage. Invalid entries (i.e., individual probabilities less than zero or summed probabilities in a row exceeding 1.0) cause the invalid entry or sum to appear against a red background.

Table 7-3C. Frequency of Worker Injuries (CNG)

File Edit View Insert Format Tools Data Window Help

FREQUENCY OF WORKER INJURIES

? Home

RELEASE POINT	FROM RELEASES					FROM FIRES				SUM
	None	Minor	Mod.	Severe	Fatal	Minor	Mod.	Severe	Fatal	
1. Cylinder - slow	0.990	0.005	0.000	0.000	0.000	0.005	0.000	0.000	0.000	1.000
2. Cylinder - fast	0.090	0.000	0.050	0.150	0.300	0.000	0.010	0.100	0.300	1.000
3. PRD - fast	0.089	0.300	0.100	0.050	0.001	0.300	0.100	0.050	0.010	1.000
4. PRD - slow	0.989	0.005	0.001	0.000	0.000	0.005	0.001	0.000	0.000	1.000
5. Refueling device	0.999	0.001	0.000	0.000	0.000	0.001	0.000	0.000	0.000	1.000
6. Fuel line fittings	0.999	0.001	0.000	0.000	0.000	0.001	0.000	0.000	0.000	1.000
7. Fuel line	0.089	0.300	0.100	0.050	0.001	0.300	0.100	0.050	0.010	1.000
8. LP regulator	0.988	0.001	0.000	0.000	0.000	0.010	0.001	0.000	0.000	1.000
9. HP regulator	0.988	0.001	0.000	0.000	0.000	0.010	0.001	0.000	0.000	1.000
10. Solenoid valve	0.988	0.001	0.000	0.000	0.000	0.010	0.001	0.000	0.000	1.000
11. 1/4 turn valve	0.988	0.001	0.000	0.000	0.000	0.010	0.001	0.000	0.000	1.000
12. Other valve	0.988	0.001	0.000	0.000	0.000	0.010	0.001	0.000	0.000	1.000
13. Other	0.988	0.001	0.000	0.000	0.000	0.010	0.001	0.000	0.000	1.000
14. Open	1.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	1.000
15. Open	1.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	1.000

SUMMARY / DIESEL / CNG / LNG / FUEL CELL / HYBRID / GLOSSARY / GO HOME

Table 7-3L. Frequency of Worker Injuries (LNG)

File Edit View Insert Format Tools Data Window Help

FREQUENCY OF WORKER INJURIES

? Home

	FROM RELEASES					FROM FIRES				SUM
RELEASE POINT	None	Minor	Mod.	Severe	Fatal	Minor	Mod.	Severe	Fatal	
1. Fuel tank (Vac. Loss)	0.883	0.001	0.000	0.000	0.000	0.100	0.010	0.005	0.001	*1.000*
2. Fuel Tank Rupture	0.150	0.250	0.100	0.050	0.025	0.250	0.100	0.050	0.025	*1.000*
3. PRD - fast (2/tank)	0.883	0.001	0.000	0.000	0.000	0.100	0.010	0.005	0.001	*1.000*
4. PRD - slow (2/tank)	0.998	0.001	0.000	0.000	0.000	0.001	0.000	0.000	0.000	*1.000*
5. Refueling receptacle	0.883	0.001	0.000	0.000	0.000	0.100	0.010	0.005	0.001	*1.000*
6. Fuel line fittings	0.998	0.001	0.000	0.000	0.000	0.001	0.000	0.000	0.000	*1.000*
7. Fuel line	0.873	0.010	0.001	0.000	0.000	0.100	0.010	0.005	0.001	*1.000*
8. Regulator	0.998	0.001	0.000	0.000	0.000	0.001	0.000	0.000	0.000	*1.000*
9. Vaporizer	0.998	0.001	0.000	0.000	0.000	0.001	0.000	0.000	0.000	*1.000*
10. Solenoid valve	0.998	0.001	0.000	0.000	0.000	0.001	0.000	0.000	0.000	*1.000*
11. 1/4 turn valve	0.998	0.001	0.000	0.000	0.000	0.001	0.000	0.000	0.000	*1.000*
12. Injector (Fuel Valve)	0.998	0.001	0.000	0.000	0.000	0.001	0.000	0.000	0.000	*1.000*
13. Cryo Pump	0.988	0.001	0.000	0.000	0.000	0.010	0.001	0.000	0.000	*1.000*
14. Gauges	0.998	0.001	0.000	0.000	0.000	0.001	0.000	0.000	0.000	*1.000*
15. Couplings	0.978	0.010	0.001	0.000	0.000	0.010	0.001	0.000	0.000	*1.000*

SUMMARY / DIESEL / CNG / LNG / FUEL CELL / HYBRID / GLOSSARY / GO HOME

Injuries are classified at five levels: none, minor, moderate, severe, and fatal. They are defined as follows:

- ***None* --** No injury or injuries creating no financial impact or legal liability.

- ***Minor Injury* --** No hospitalization and no permanent injury (minor inhalation, dizziness, nausea, etc.).

- ***Moderate Injury* --** Hospitalization but no permanent injury (fractures, burns, poisoning, etc.)

- ***Severe Injury* --** Hospitalization and permanent injury (paralysis, amputation, etc.)

- ***Fatality* --** Injury resulting in death.

A release-induced injury can result in a subsequent fire-related injury or death. However, a death from a release precludes further injury. The model is structured to prevent double-counting. Where a release and fire lead to two separate injuries, the more severe of the two is selected.

7.3.1 CNG

Most of the injuries associated with CNG buses in the U.S. have been worker-related. These include hearing injuries and pressure-related injuries. No fatalities or severe injuries are known to have occurred. Severe injuries have occurred as a result of several cylinder ruptures in CNG vehicles unrelated to transit bus operations.

On an empirical basis, almost all of the risk of injury is likely to arise from 1) fast releases from cylinders and PRDs and 2) fuel line breaks. All other releases are relatively minor. The general likelihood of injuries at each release point is summarized below:

- ***Cylinder Slow* --** Mainly injury to a worker measuring, tracking, or replacing a cylinder that is known to have a slow leak. Certain types of cylinders are more prone to surface leaks and leaks from the valve seat. This produces injuries 1% of the time.

- ***Cylinder Fast* --** A major leak, usually a burst cylinder. Assuming the presence of a worker, as defined above, injury and fatality are very likely. In the reference case, 91% of the time there would be a fatal or non-fatal injury to worker when present. However, if a cylinder rupture occurs during passenger service, there is 100% likelihood of a claim being filed for injury or death. In the single CNG bus cylinder burst at a transit agency, the fueling attendant had left the site prior to the event. In the cases involving light-duty trucks, when a worker was present, there were at least moderate injuries.

- ***PRD Fast* --** There have been several hundred PRD activations in the past ten years in the U.S. Most of these were spurious events associated with inadequate component design.[10] However, employees have made claims against transit organizations regarding hearing loss and other injuries. An event at one transit agency resulted in a fire, an injury to a fireman, and about $80,000 of damage, predominantly associated with the clean-up of the water mixtures from the fire extinguishing efforts. c and PRDs used in cold climates are more prone to fast leaks.

- ***PRD Slow*** **--** Mostly injuries are to workers inspecting and replacing a PRD. Such work takes place on top of a bus and requires isolating and emptying the affected cylinder (usually through defueling and venting). Older PRD designs (recalled by the manufacturer) and generally PRDs used in cold climates are more prone to slow leaks. Slow PRD releases are estimated to result in injuries 1% of the time.

- ***Refueling Device*** **--** Slow leaks from the engine disconnect mechanism, the fueling manifold, and the receptacles are common and often neglected. In one case failure in these components resulted in a major fire. Despite this occurrence, refueling device leaks are estimated to result in injuries 0.1% of the time.

- ***Fuel Line Fittings*** **--** Fuel line fittings often leak small amounts of CNG. Only in rare instances do these become large leaks. However, in a parked bus, there is an opportunity for the gas to accumulate in a facility or in enclosed crevices of a bus, resulting in a potentially hazardous condition. The most serious threat to workers is during repair (tightening), which is commonly attempted while the lines are pressurized.

- ***LP and HP Regulators*** **--** LP and HP regulators are in the engine compartment. In this environment, fuel leaks can be hazardous.

- ***Solenoid Valves*** **--** Solenoid valves do not commonly leak, rather it is a failure of the device to effectively isolate fuel systems. Even though fuel system work should not be performed when the only isolation is through solenoid valves, this is a common practice. Such failure could result in leaks and pressure-related injuries.

- ***Other Valves*** **--** Other valves are located throughout the system. Leaking quarter-turn valves, check valves, flow control valves, etc. can cause pressure-related injuries.

[10] Proper PRD activation (e.g., in response to pressure, usually from overheating), is not a component failure but does carry a small risk. Proper placement of the PRD or venting of the gas typically reduces this risk to an inconsequential level.

7.3.2 LNG

Most of the injuries associated with LNG buses, including cryogenic burns and pressure injuries, have affected workers. No fatalities or severe injuries are known to have occurred with LNG buses in the U.S. The method and severity of injuries by release point are summarized below. Except for the very unlikely event of a fuel tank rupture, the values assigned for injuries and fatalities from leaks and from fires are generally inconsequential. Typically, a small value is assigned in the minor injury category. The most significant event is a fuel tank rupture, which is assumed to have a 49% probability of resulting at least in an injury when a worker is within 15 feet of the bus. The next most significant events are a break in the fuel-line, leaks from couplings, and vacuum loss.

- ***Fuel Tank (Vacuum Loss)* --** Mostly assumes an injury while measuring, tracking, or replacing a fuel tank that has lost vacuum. After the LNG has gasified there is usually natural gas in the fuel tanks at pressures just below the PRD activation level.

- ***Fuel Tank Rupture* --** Mostly from a major accident, a fall from a lift, or if the bus is lowered onto a sharp object. It can also occur when both PRDs (and the burst disc) fail to relieve over-pressure. No such incidents are known to have occurred.

- ***PRD Fast* --** There have been hundreds of PRD activations resulting in the release of gas (not LNG) in the U.S. Unlike the case for CNG, most of these were proper engagements to relieve over-pressure. These are usually short bursts at roof level. When these releases occur outdoors they are benign.

- ***PRD* Slow --** A slow leak through the valve body, usually due to improper resetting of the valve. This can be a frequent event due to ice build-up and wear.

- ***Refueling Device* --** Slow leaks at the engine disconnect mechanism, the fueling manifold, or the receptacles are common and often neglected.

- ***Fuel Line Fittings* --** Slow leaks are common due to thermal flux. Only rarely does the thermal flux result in a major leak. However, in a parked bus, there is an opportunity for the gas to accumulate in a facility or enclosed crevices of a bus, resulting in a potentially hazardous condition. The most serious threat to workers is during repair (tightening), which is commonly attempted while the lines are pressurized.

- ***Regulators* --** Regulators are located in the engine compartment. In this area, a leak has a high probability of ignition.

- ***Solenoid Valves* --** Solenoid valve failure does not release fuel, but fails to isolate fuel systems. Even though fuel system work should not be performed when the only isolation is through solenoid valves, this practice is common. Failure could result in leaks and temperature-and pressure-related injuries.

- ***1/4-Turn Valves* --** 1/4-turn shut-off or isolation valves, check valves, and other flow control valves can leak. More commonly they fail to isolate, resulting in a potentially hazardous situation. Also (not considered in the release data), manual (unprotected) operation of these valves can result in minor to moderate hand injuries.

- ***Injector (Fuel Valve)* --** Some engines use one injector per cylinder to deliver the fuel into the combustion chamber. When these devices fail in the open position, they can leak gas into the engine compartment, resulting in a hazardous situation.

- ***Cryogenic Pump* --** Cryogenic pumps were used in the Houston system to pump the LNG from the tank to the engine. Some leaked at the point of connection to the tank. These devices frequently failed and required removal.

- ***Gauges* --** Pressure measuring devices are known to fail and leak. Their replacement, if not properly isolated (see discussion of 1/4-turn valves above), can result in the release of fuel.

- ***Couplings* --** These tank-to-fuel-line connectors are subject to stresses that in early models resulted in frequent failures. Certain types of failures can result in uncontrolled release of LNG.

7.4 Frequency of Public Injuries

Tables 7-4C and 7-4L show the frequency of public injuries from releases and fires at each release point. Anecdotal evidence indicates that the public is very sensitive to the odor of natural gas, resulting in injury claims by the public, and service and financial losses to the operator. For example, in one southern city, passengers claimed smelling gas odors, resulting in interruption of service, hospitalization, and ultimate claims by more passengers than were on the bus when the incident was noted. The bus was taken back to the facility to check for leaks. None was found. Moreover, the only natural gas on the bus was un-odorized LNG, which cannot be detected by a human nose.

From a loss perspective, it is important to consider claims of injury that result in losses to the agency, rather than literal physical injury. For this reason, the Reference Case values are somewhat higher for nuisance leaks than for those used in worker injuries. The types of injuries claimed by the public include nausea, dizziness, and difficulty breathing. No fatalities or severe injuries are known to have occurred with CNG or LNG buses in the U.S.

The tables address two questions: Assuming a worst-case release at each release point, and a single (statistical) member of the public within 15 feet of the bus:

- What would be his or her likelihood of receiving a release-related injury at each level of severity?

- Assuming that he or she survived the release and that there was an ensuing fire, what would be his or her likelihood of receiving a fire-related injury at each level of severity?

Injuries are classified at five levels: none, minor, moderate, severe, and fatal. They are defined as follows:

- ***None* --** No injury or injuries creating no financial impact or legal liability.

- ***Minor Injury* --** No hospitalization and no permanent injury (minor inhalation, dizziness, nausea, etc.).

- ***Moderate Injury* --** Hospitalization but no permanent injury (fractures, burns, poisoning, etc.)

- ***Severe Injury* --** Hospitalization and permanent injury (paralysis, amputation, etc.)

- ***Fatality* --** Injury resulting in death.

A release-induced injury can result in a subsequent fire-related injury or death. However, a death from a release precludes further injury. The model is structured to prevent double counting. Where a release and fire lead to two separate injuries, the more severe of the two is selected. Invalid entries (i.e., individual probabilities less than zero or summed probabilities in a row exceeding 1.0) cause the invalid entry or sum to appear against a red background.

Table 7-4C. Frequency of Public Injuries (CNG)

FREQUENCY OF PUBLIC INJURIES

RELEASE POINT	FROM RELEASES					FROM FIRES				SUM
	None	Minor	Mod.	Severe	Fatal	Minor	Mod.	Severe	Fatal	
1. Fuel tank (Vac. Loss)	0.882	0.002	0.000	0.000	0.000	0.100	0.010	0.005	0.001	1.000
2. Fuel Tank Rupture	0.250	0.200	0.100	0.050	0.025	0.200	0.100	0.050	0.025	1.000
3. PRD - fast (2/tank)	0.768	0.100	0.010	0.005	0.001	0.100	0.010	0.005	0.001	1.000
4. PRD - slow (2/tank)	0.997	0.002	0.000	0.000	0.000	0.001	0.000	0.000	0.000	1.000
5. Refueling receptacle	0.997	0.002	0.000	0.000	0.000	0.001	0.000	0.000	0.000	1.000
6. Fuel line fittings	0.997	0.002	0.000	0.000	0.000	0.001	0.000	0.000	0.000	1.000
7. Fuel line	0.768	0.100	0.010	0.005	0.001	0.100	0.010	0.005	0.001	1.000
8. Regulator	0.997	0.002	0.000	0.000	0.000	0.001	0.000	0.000	0.000	1.000
9. Vaporizer	0.997	0.002	0.000	0.000	0.000	0.001	0.000	0.000	0.000	1.000
10. Solenoid valve	0.997	0.002	0.000	0.000	0.000	0.001	0.000	0.000	0.000	1.000
11. 1/4 turn valve	0.997	0.002	0.000	0.000	0.000	0.001	0.000	0.000	0.000	1.000
12. Injector (Fuel Valve)	0.997	0.002	0.000	0.000	0.000	0.001	0.000	0.000	0.000	1.000
13. Cryo Pump	0.986	0.002	0.000	0.000	0.000	0.010	0.002	0.000	0.000	1.000
14. Gauges	0.997	0.002	0.000	0.000	0.000	0.001	0.000	0.000	0.000	1.000
15. Couplings	0.977	0.010	0.001	0.000	0.000	0.010	0.002	0.000	0.000	1.000

Table 7-4L. Frequency of Public Injuries (LNG)

FREQUENCY OF PUBLIC INJURIES

	FROM RELEASES					FROM FIRES				SUM
RELEASE POINT	None	Minor	Mod.	Severe	Fatal	Minor	Mod.	Severe	Fatal	
1. Fuel tank (Vac. Loss)	0.882	0.002	0.000	0.000	0.000	0.100	0.010	0.005	0.001	*1.000*
2. Fuel Tank Rupture	0.250	0.200	0.100	0.050	0.025	0.200	0.100	0.050	0.025	*1.000*
3. PRD - fast (2/tank)	0.768	0.100	0.010	0.005	0.001	0.100	0.010	0.005	0.001	*1.000*
4. PRD - slow (2/tank)	0.997	0.002	0.000	0.000	0.000	0.001	0.000	0.000	0.000	*1.000*
5. Refueling receptacle	0.997	0.002	0.000	0.000	0.000	0.001	0.000	0.000	0.000	*1.000*
6. Fuel line fittings	0.997	0.002	0.000	0.000	0.000	0.001	0.000	0.000	0.000	*1.000*
7. Fuel line	0.768	0.100	0.010	0.005	0.001	0.100	0.010	0.005	0.001	*1.000*
8. Regulator	0.997	0.002	0.000	0.000	0.000	0.001	0.000	0.000	0.000	*1.000*
9. Vaporizer	0.997	0.002	0.000	0.000	0.000	0.001	0.000	0.000	0.000	*1.000*
10. Solenoid valve	0.997	0.002	0.000	0.000	0.000	0.001	0.000	0.000	0.000	*1.000*
11. 1/4 turn valve	0.997	0.002	0.000	0.000	0.000	0.001	0.000	0.000	0.000	*1.000*
12. Injector (Fuel Valve)	0.997	0.002	0.000	0.000	0.000	0.001	0.000	0.000	0.000	*1.000*
13. Cryo Pump	0.986	0.002	0.000	0.000	0.000	0.010	0.002	0.000	0.000	*1.000*
14. Gauges	0.997	0.002	0.000	0.000	0.000	0.001	0.000	0.000	0.000	*1.000*
15. Couplings	0.977	0.010	0.001	0.000	0.000	0.010	0.002	0.000	0.000	*1.000*

7.4.1 CNG

Fast releases from cylinders and PRDs and fuel line breaks have the potential to cause significant public injuries. Excluding these events, the potential for injuries is small. However, the frequency of injuries for these events is higher for the public than for workers because of the strong emphasis on claims of injury and consequent liability.

- ***Cylinder* Slow --** Mostly assumes claims of injury to bus passengers when a gas leak is detected. Panic exits from the bus could be a main contributor to injuries. However, since the cylinders are roof-mounted in the Reference Case, the likelihood that anyone would notice the gas inside the bus is small. Certain types of discontinued composite cylinders are more prone to surface leaks and leaks from the valve seat. It is estimated that 1.5% of the leaks result in injuries. For buses with composite cylinders under the chassis, claims of minor injuries are likely to be higher.

- ***Cylinder Fast* --** A fast cylinder release is usually a burst cylinder. There would be injuries, including fatalities, 100% of the time anyone was within 15 feet of the bus. In the single CNG bus cylinder burst at a transit agency, severe injuries and fatalities would have resulted from flying debris, over-pressure, and possibly asphyxiation had the bus been occupied. While there was no fire in that incident, the risk is clear.

- ***PRD Fast* --** There have been several PRD activations in the past ten years in public settings. Most of these were spurious events associated with inadequate component design.[11] However, more recently, at one transit agency, there were several activations on demand, in response to fires in the engine compartment. It is estimated that there will be claims of injury or fatalities from fast PRD releases 11% of the time. Most of the assumed claims are for injuries received during evacuation, including hearing damage and inhalation-related injuries.

- ***PRD Slow* --** Most slow releases will not be detected. Unlike other components, PRDs are vented at the top of the bus. However, some slow leaks are intense enough to result in an audible sound or be detectable by smell. Older PRD designs (recalled by the manufacturer) and generally PRDs used in cold climates are more prone to leaks. Minor injuries or greater are estimated to result 1% of the time.

- ***Refueling Device* --** Slow leaks at the engine disconnect mechanism, the fueling manifold, and the receptacles are common but infrequently seep into the passenger compartment. This could result in a few claims of injury and liability.

[11]Proper PRD activation (e.g., in response to pressure, usually from overheating), is not a component failure but does carry a small risk. Proper placement of the PRD or venting of the gas typically reduces this risk to an inconsequential level.

- ***Fuel Line Fittings* --** Fuel line fittings often leak small amounts of CNG. Only in rare instances do these leaks result in odor or audible detection by passengers or pedestrians.

- ***Fuel Line* --** A fuel line rupture is a very infrequent event. Most often it is expected to occur from some sort of impact, such as during a collision (most recently this occurred when a CNG bus hit a bridge overpass), from road debris, and during maintenance. Most fuel lines in a CNG bus are under high pressure at all times. However, when the solenoid valves are engaged, the isolated fuel line down-stream from the solenoid valve contains only a small amount of fuel. Ruptures that occur upstream from the isolation point will likely continue under pressure until there is mitigation (manual valve closure) or until all of the fuel is gone.

- ***LP and HP Regulators* --** LP and HP regulators are in the engine compartment. In this environment, gas released from these devices is commonly not noticed by passengers. However, a fire can occur and result in public injury and fatalities.

- ***Solenoid* Valves --** Solenoid valves generally do not leak, rather they fail to isolate fuel systems. Failure to isolate cylinders or banks of cylinders during a fuel release from other causes could significantly increase the volume of released gas and increase the severity of injuries and the probability of injuries and fatalities.

- ***Other Valves* --** Other valves are located throughout the system. Leaking 1/4-turn valves, check valves, flow control valves, etc. are treated the same as leaking fuel line fittings.

7.4.2 LNG

Fast releases from tanks and, to a lesser extent, fuel line breaks and leaks from couplings have the potential to cause significant public injuries. Excluding these events, the potential for injuries is small. However, the frequency of injuries to the public for these events is higher than for workers because of the emphasis on claims of injury and consequent liability. Still, only a small value is assigned, mostly in the minor injury category. The most significant event is a fuel tank burst, which is assumed to have an almost 60% probability of an injury when a member of the public is within 15 feet. The next most significant events are a break in the fuel-line and leaks from couplings.

- ***Fuel Tank (Vacuum Loss)* --** Mostly assumes claims of injury by bus passengers when a gas leak is detected. Panic exits from the bus could be a main contributor to injuries. However, since the LNG is not odorized, the likelihood of detecting gas in the bus is very small and many leaks will go undetected unless the gas penetrates a bus equipped with gas detectors (most LNG buses have gas detectors). Injuries are estimated to occur in 12 percent of the cases.

- ***Fuel Tank Rupture* --** Refers to a major release of fuel, usually a burst fuel tank.

Assuming the presence of members of the public within 15 feet, there would be a fatal or non-fatal injury 75 percent of the time. No tank bursts have been reported in the U.S. However, if there were an LNG fuel tank burst, a boiling puddle of LNG would form and the bus could quickly be engulfed in natural gas. Severe or fatal injuries from asphyxiation or fire could result. This event is very unlikely. New bus designs, where the tanks are placed above the engine compartment or on the roof, further reduce its likelihood.

- ***PRD Fast* --** There have been hundreds of PRD activations in the U.S. resulting in the release of gas (not LNG). Commonly, these releases do not occur during operation because the use of the fuel lowers the tank pressure. Injuries are expected in 23 percent of the cases.

- ***PRD Slow* --** A slow leak through the valve body, usually due to improper resetting of the valve. This can be a frequent event due to ice build-up and wear. The release can be accompanied by a whistling sound. On-board detectors would alert the driver and the passengers.

- ***Refueling Device* --** The symptoms and impact of this failure are similar to those from a slow PRD release. However, this release occurs at waist level as the public passes by the bus and may be more readily noticed.

- ***Fuel Line Fittings* --** Fittings often leak small amounts of liquid or gaseous LNG due to thermal flux. Only in rare instances does the thermal flux result in a major leak. Most minor leaks during revenue service go unnoticed.

- ***Fuel Line* --** A fuel line rupture is an very infrequent event. Most often it is expected to occur from some sort of impact, such as during a collision, from road debris, or during maintenance. Most fuel lines are under pressure containing cryogenic fuel. When severed, the fuel will likely continue to escape under pressure until all of the fuel is gone.

- ***Regulators* --** Regulators are in the engine compartment. In this environment, a failure that results in a fuel leak can be hazardous. As the bus moves, it is more difficult for the gas to accumulate in the engine compartment and thus leaks may escape public notice. Ignitable mixtures may accumulate and activate gas detectors during stops, generally before a major hazard develops.

- ***Solenoid Valves* --** Solenoid valves do not commonly release fuel but rather they fail to isolate fuel systems. This type of failure poses little danger to the public.

- ***1/4-Turn Valves* --** Quarter turn shut-off or isolation valves, check valves, and other flow control valves can leak. This type of failure poses little danger to the public.

- ***Injector (Fuel Valve)* --** Some engines used one injector per cylinder to deliver the fuel to the combustion chamber. When these devices fail in the open position they can leak gas into the engine compartment, resulting in a hazardous situation, particularly if ignitable mixtures accumulate during stops. Commonly, LNG buses have gas detectors in the engine compartment and will activate before a major hazard develops.

- ***Cryogenic Pump* –** One transit system used a cryogenic pump to pump the LNG from the tank to the engine. Some leaked at the point of connection to the tank. These leaks are generally nuisance leaks.

- ***Gauges* --** Pressure measuring devices are known to fail and leak. These leaks are generally nuisance leaks.

- ***Couplings* --** These tank-to-fuel-line connectors are subject to stresses and, in early systems, resulted in frequent failures. Certain rare types of failures can result in uncontrolled release of LNG directly from the tank.

7.5 Valuation of Injury and Property Damage

Tables 7-5C and 7-5L show the input screens for the valuation of injury and property damage for CNG and LNG. Injury valuations are the same for all fuel types. Injury frequencies and property damage frequencies and valuations differ among fuel types. The frequency of injuries is converted to a dollar figure by assigning a value to injuries according to severity. The valuation for property damage is assigned using a different measure of severity.

7.5.1 Injuries

The model classifies and values injuries at five levels of severity:

- ***None* --** No injury or injuries creating no financial impact or legal liability.

- ***Minor Injury* --** No hospitalization and no permanent injury (minor inhalation, dizziness, nausea, etc.).

- ***Moderate Injury* --** Hospitalization but no permanent injury (fractures, burns, poisoning, etc.).

- ***Severe Injury* --** Hospitalization and permanent injury (paralysis, amputation, etc.)

- ***Fatality* --** Injury resulting in death.

The Reference Case values injuries and fatalities on the concept of Willingness-to-Pay (WTP). WTP is based on value, rather than cost. Worker injuries and fatalities are, in general, valued at less than public injuries because workers are assumed to accept certain risks inherent in a job while the public is less willing to accept similar risks from the use of the service. Worker injuries are valued at about 1/2 the value of public injuries. You may prefer an alternative valuation method, e.g., valuing worker injuries according to the much lower value assigned by Workers' Compensation. The technical details provided in Appendix A discuss the ranges for the most widely used valuation methods.

Table 7-5C. Valuation of Injury & Property Damage (CNG)

File Edit View Insert Format Tools Data Window Help

VALUATION OF INJURY & PROPERTY DAMAGE

? | Home

INJURY (Release or Fire)	Minor	Moderate	Severe	Fatal
Worker	$2,500	$25,000	$250,000	$2,500,000
Public	$5,000	$50,000	$500,000	$5,000,000

PROPERTY (Release)	Operation	Fueling	Prev. Maint.	Corr. Maint.	Parking
Bus	$640,000	$640,000	$640,000	$640,000	$640,000
All Other	$640,000	$640,000	$640,000	$640,000	$800,000

PROPERTY (Fire)					
Bus	$64,000	$64,000	$64,000	$64,000	$64,000
All Other	$300,000	$1,000,000	$1,000,000	$1,000,000	$2,000,000

Severity

SUMMARY / DIESEL / CNG / LNG / FUEL CELL / HYBRID / GLOSSARY / GO HOME

Table 7-5L. Valuation of Injury & Property Damage (LNG)

File Edit View Insert Format Tools Data Window Help

VALUATION OF INJURY & PROPERTY DAMAGE

? Home

INJURY (Release or Fire)	Minor	Moderate	Severe	Fatal
Worker	$2,500	$25,000	$250,000	$2,500,000
Public	$5,000	$50,000	$500,000	$5,000,000

PROPERTY (Release)	Operation	Fueling	Prev. Maint.	Corr. Maint.	Parking
Bus	$10,000	$10,000	$10,000	$10,000	$10,000
All Other	$10,000	$10,000	$10,000	$10,000	$10,000

PROPERTY (Fire)					
Bus	$320,000	$320,000	$320,000	$320,000	$320,000
All Other	$300,000	$900,000	$900,000	$900,000	$2,000,000

Severity

SUMMARY / DIESEL / CNG / LNG / FUEL CELL / HYBRID / GLOSSARY / GO HOME

Table 7-6 shows the **Reference Case** valuation of injuries for the public and for workers according to the WTP criterion.

Table 7-6. Valuation of Injuries by Severity ($)

	None	Minor	Moderate	Severe	Fatal
Worker	0	2,500	25,000	250,000	2.5M
Public	0	5,000	50,000	500,000	5M

Source: Appendix A

7.5.2 Property Damage

The model classifies and values property damage in four categories:

- ***Release Bus*** **--** The release-related losses to the bus on which the failure occurred, and associated direct and indirect costs, including administrative, investigation, purchasing, reporting, etc.

- ***Release Other*** **--** The release-related losses of property (excluding the bus on which the failure occurred) plus associated direct and indirect costs, including administrative, investigation, purchasing, reporting, etc.

- ***Fire Bus*** **--** The fire-related losses to the bus on which the release and fire occurred plus associated direct and indirect costs, including administrative, investigation, purchasing, reporting, etc.

- ***Fire Other*** **--** The fire-related losses of property (excluding the bus on which the failure occurred) plus associated direct and indirect costs, including administrative, investigation, purchasing, reporting, etc.

Valuation begins with an estimate of the maximum damage in each of the four categories above. All other damage estimates are assigned some fraction of this maximum. For example, if the maximum loss in the **Release Bus** category is $640,000, the worst case event is a cylinder rupture (100 percent of the maximum damages), and a cylinder rupture has a frequency of 0.00027 per bus per year, the loss valuation for the cylinder rupture is $640,000 * 1.0 * .00027 per bus per year, or $172.80 per bus per year. This process continues for all release points in each category. The losses are then summed.

7.5.2.1 CNG

The Reference Case values were developed by the project team, based on knowledge of approximate replacement costs of components, assuming $50 per hour fully-loaded labor costs, approximate time of repair estimates, etc. Since these data vary widely depending on the model and manufacturer of the part, the replacement practice employed, the efficiency of the labor force, the degree of related work necessary, and so forth, these estimates should be adjusted by the user. The most important valuations are for damage from cylinder rupture, fires resulting from a fast PRD release, breaks in the fuel line, and releases from the regulators. Changes in the other cost categories are negligible. Maximum losses are summarized below. No costs for a reserve bus or loss of revenue service due to the inability to field a reserve bus are included.

- ***Release Bus*** **--** $640,000. Assumes $320,000 for the total loss of a 1-year-old bus plus the administrative expenses (accident investigation, etc.). Assumes no rental costs because a reserve bus is available.

- ***Release Other*** **--** $800,000. Assumes 50% destruction of two adjacent buses with the same value as above for a total of $320,000, $320,000 in building property damage, and $160,000 in administrative costs, hazardous materials clean-up, equipment and facilities redesign, reporting, etc.

- ***Fire Bus*** **--** $64,000. Assumes a maximum of $64,000 for the loss that can be incurred by the worst (non-burst-related) fire. In the case of CNG, these are fires resulting from a fuel line break or fires from leaks that occur in the engine compartment, i.e., regulators. Administrative costs and fire clean-up are included.

- ***Fire Other*** **--** $300,000 to $2,000,000. There are significant cost differences at different stages (operations, fueling, parking, etc.) for the fire-related category "all other." For losses during operation, it is assumed that the event occurs outdoors with a maximum property damage of $300,000. For an indoor fire in fueling, preventive, or corrective maintenance, the maximum value for "other" fire-related losses is assumed to be $1,000,000. For indoor parking, the possibility that other buses would catch on fire increases the maximum loss to $2,000,000. If any of these stages is not indoors, or if the values at the user's facility are different, these values should be adjusted. Costs assume facility fire damage above the release-related damages and include clean-up, major repairs, loss of use, insurance impacts, and other administrative costs.

7.5.2.2 LNG

The project team developed the Reference Case values based on replacement cost data provided by Houston Metro and Phoenix Transit. Since these data vary widely depending on the model and manufacturer of the part, the replacement practice employed, and the efficiency of the labor force, etc. the user should adjust these estimates. The most significant valuations are from fuel tank rupture, fires resulting from a fast PRD release, breaks in the fuel line, and releases from the regulators. Changes in other cost categories are negligible. Maximum losses are summarized below. No costs for a reserve bus or loss or revenue service due to the inability to field a reserve bus are included.

- ***Release Bus* --** $10,000. Assumes partial loss of the on-board LNG fuel system, damage to adjacent material destroyed by the LNG, and administrative costs.

- ***Release Other* --** $10,000. Assumes some damage to adjacent property, such as parts of a nearby bus, tools, etc.

- ***Fire Bus* --** $320,000. Assumes the total loss of a new bus (to reflect the current vintage of LNG buses) with a replacement value of $300,000, $10,000 of economic losses, mostly administrative and for accident investigation, and $10,000 for related clean-up costs.

- ***Fire Other* --** $300,000 to $2,000,000. There are significant cost differences at different stages (operations, fueling, parking, etc.) for the fire-related category "all other." For losses during operation, it is assumed that the event occurs outdoors with a maximum property damage of $300,000. For an indoor fire in fueling, preventive, or corrective maintenance, the maximum value for "other" fire-related losses is assumed to be $1,000,000. For indoor parking, the possibility that other buses would catch on fire increases the maximum loss to $2,000,000. If any of these stages is not indoors, or if the values at the user's facility are different, these values should be adjusted. Costs assume facility fire damage above the release-related damages and include clean-up, major repairs, loss of use, insurance impacts, and other administrative costs.

7.6 Severity of Property Damage

Tables 7-7C and 7-7L show the estimated severity of property damage by release point for each category (**Release Bus, Fire Bus, Release Other, Fire Other**). A brief summary of the cost components used to generate the severity percentage is included in each cell on the table. You may view these summaries (identified by the **Red Triangle**) by pointing the cursor to the left and below the triangle. If you change the value in the cell, you may want to edit the comment. To edit the comment, left click on the cell, right click to bring up a cell menu, and left click Edit Comment. Section 7.5 discussed the valuation of the maximum property damage from releases and fires.

7.6.1 CNG

Table 7-7C shows the input screen for the severity of property damage for CNG releases and fires.

7.6.2 LNG

Table 7-7L shows the input screen for the severity of property damage for LNG releases and fires.

7.7 Mitigation

Mitigation refers to changes in components, policies, activities, schedules, etc. that reduce the risk of a release or fire or reduce the consequences of a release or fire. Mitigation may take place in one or more of four ways:

- **Point Mitigation** -- Mitigation of the likelihood of a release or fire at the point of release, e.g., by replacing an existing component with a more reliable component or by inspecting and maintaining a component differently. The model allows for up to three mitigation measures at up to 15 release points, e.g., cylinders, valves, fuel lines, etc. Point mitigation is always a pre-event activity, i.e., it reduces the likelihood of a release or fire, not consequences of a release or fire.

- **Non-Point Mitigation** -- Mitigation of the likelihood of a release or fire in general (not at a particular release point), e.g., by improving maintenance procedures in general, upgrading worker training, etc. The model allows for up to three non-point mitigation measures for releases and up to three non-point mitigation measures for fires. Non-point mitigation is always a pre-event activity, i.e., it reduces the likelihood of a release or fire, not consequences of a release or fire.

- **Injury Mitigation** -- Mitigation of an injury from a release or fire in general (not at a particular release point), e.g., by shielding the workers, by installing different alarms or fire suppression devices, etc. The model allows for up to four injury mitigation measures. The value of the mitigation measures in reducing injuries to workers and injuries to the public may differ. Injury mitigation is always a post-event activity, i.e., it reduces the consequences of a release or fire, not likelihood of a release or fire.

Table 7-7C. Severity of Property Damage (CNG)

File Edit View Insert Format Tools Data Window Help

SEVERITY OF PROPERTY DAMAGE

? Home

Severity of Damage by Release Point (% of maximum)

RELEASE POINT	Release (Bus)	(Other)	Fire (Bus)	(Other)
1. Cylinder - slow	0.39%	0.10%	5.00%	2.00%
2. Cylinder - fast	100.00%	100.00%	0.00%	100.00%
3. PRD - fast	0.05%	1.00%	50.00%	4.50%
4. PRD - slow	0.05%	0.01%	10.00%	1.00%
5. Refueling device	0.02%	0.01%	10.00%	1.00%
6. Fuel line fittings	0.02%	0.01%	10.00%	1.00%
7. Fuel line	0.05%	1.00%	100.00%	4.50%
8. LP regulator	0.08%	0.01%	100.00%	5.00%
9. HP regulator	0.08%	0.01%	100.00%	5.00%
10. Solenoid valve	0.08%	0.01%	10.00%	1.00%
11. 1/4 turn valve	0.05%	0.01%	10.00%	1.00%
12. Other valve	0.05%	0.01%	10.00%	1.00%
13. Other	0.00%	0.00%	0.00%	0.00%
14. Open	0.00%	0.00%	0.00%	0.00%
15. Open	0.00%	0.00%	0.00%	0.00%
MAXIMUM VALUATION	$640,000	$800,000	$64,000	$2,000,000

Valuation

SUMMARY / DIESEL / CNG / LNG / FUEL CELL / HYBRID / GLOSSARY / GO HOME

Table 7-7L. Severity of Property Damage (LNG)

File Edit View Insert Format Tools Data Window Help

SEVERITY OF PROPERTY DAMAGE

? Home

Severity of Damage by Release Point (% of maximum)

RELEASE POINT	Release (Bus)	(Other)	Fire (Bus)	(Other)
1. Fuel tank (Vac. Loss)	17.25%	0.10%	1.56%	2.50%
2. Fuel Tank Rupture	100.00%	100.00%	100.00%	45.00%
3. PRD - fast (2/tank)	0.50%	0.10%	1.56%	2.50%
4. PRD - slow (2/tank)	1.50%	0.10%	0.31%	2.50%
5. Refueling receptacle	5.00%	0.10%	0.31%	0.05%
6. Fuel line fittings	0.40%	1.00%	0.31%	0.05%
7. Fuel line	2.50%	10.00%	1.56%	2.50%
8. Regulator	2.00%	10.00%	1.56%	0.50%
9. Vaporizer	9.70%	3.00%	1.56%	0.50%
10. Solenoid valve	1.30%	0.10%	0.31%	0.05%
11. 1/4 turn valve	3.00%	1.00%	0.31%	0.05%
12. Injector (Fuel Valve)	9.00%	1.00%	1.56%	2.50%
13. Cryo Pump	18.00%	0.10%	1.56%	2.50%
14. Gauges	1.50%	0.10%	0.31%	0.05%
15. Couplings	3.50%	1.00%	1.56%	2.50%
MAXIMUM VALUATION	$10,000	$10,000	$320,000	$2,000,000

Valuation

SUMMARY / DIESEL / CNG / LNG / FUEL CELL / HYBRID / GLOSSARY / GO HOME

- **Property Damage Mitigation** -- Mitigation of property damage from a release or fire in general (not at a particular release point), e.g., by shielding sensitive equipment from over-pressure or cryogenic exposure, by increasing fire suppression. Property damage mitigation measures are the same as injury mitigation measures but may affect buses and other property differently. Property damage mitigation is always a post-event activity, i.e., it reduces the consequences of a release or fire, not the likelihood of a release or fire. The case selection options for the **Injury Mitigation** screen ("b" for BASE or "x" for INCREMENTAL) are not shown on the Property Damage Mitigation screen since the program requires the measures chosen for Injury Mitigation to be used in Property Damage Mitigation.

The following other points apply to all mitigation options:

- **Base Case** and **Incremental Case** -- All mitigation measures are available for use in the Base Case or the Incremental Case. You may alternate between cases at any time. In the Base Case, the mitigation measures reduce the **Base Loss**. They do not create a cost for the transit agency since the model assumes that the mitigation measures already exist. In the Incremental Case, the mitigation measure reduces the **Incremental Loss**. It creates a **Cost,** a **Benefit**, and a **Benefit-cost Ratio**.

- **Select Base Mitigation, Select Incremental Mitigation --** Where selection of mitigation measures is offered, you may enter "b" for the Base Case, "x" for the Incremental Case, or blank for no case (i.e., deselection).

- **Calculate Base Case, Calculate Incremental Case** -- You may calculate the Base Case or the Incremental Case from any of the mitigation screens at any time and in any order. The output screens will show the selected case as BASE or INCREMENTAL (or INCR. in some cases).

- **Percentage Reductions** -- All mitigation measures are expressed in terms of the percentage reduction in risk or consequences. No absolute reductions are used.

- **Negative Mitigation** -- Mitigation measures may be treated as *increasing* risks or consequences, depending on the configuration of the facility, fleet, etc. The model accepts negative numbers to represent negative mitigation. An example of a potentially negative mitigation would be an alarm that sounds so frequently that it desensitizes the workers and the public, who then ignore it during a real hazard.

7.8 Point Mitigation (pre-event)

The model coordinates point mitigation through a **Point Mitigation** menu. Tables 7-8C and 7-8L show the main **Point Mitigation** menu screens for CNG and LNG, respectively. The menu shows each of the fifteen release points and an associated button numbered 1-15. Clicking on a button displays the individual input screen for that particular release point and set of point mitigation measures. You may also select any or all of the mitigation measures for inclusion in the **Base Case** or **Incremental Case** by marking "b" or "x", respectively, in the appropriate blue boxes on the screen. The release points and the mitigation measures are shown on a yellow background and cannot be edited on the summary screen for Point Mitigation (i.e., the present screen). They are edited at the numbered individual Point Mitigation screens (accessed via the buttons).

7.8.1 Point Mitigation (1-15, CNG and LNG)

Tables 7-9C and 7-9L show Point Mitigation input screen 1 (**Point Mitigation 1**) for CNG and LNG, respectively. A total of fifteen similar screens (Numbers 2-14 are not shown) is available for each fuel type. You may use as many or as few as you want. You may navigate amongst the fifteen screens by using the **Forward** button and the **Back** button. The **Menu** button returns you to the main Point Mitigation screen.

The mitigation measures selected and included in the model are based on a draft study conducted by SAIC for the Gas Research Institute in 1995,[12] transit industry input, and the opinions of the NGV safety staff at SAIC. This is not a complete set of options and may be neither appropriate nor workable at your transit operation. There is no statistical data on the impact of each selected mitigation measure. Rather, the impacts are hypothesized based on some systematic observations, anecdotal evidence, and conceptualization of the effect. Users are encouraged to use their own assessment of impacts, or use data as they become available. Costs will vary widely, depending on such factors as weather, facility layout, existing component brands, current maintenance programs, etc.

[12] SAIC, "Low Cost/No Cost Transit Facility Designs and Practices," Draft Report, Prepared for the Gas Research Institute (GRI), May 1995. Unpublished report is available from SAIC on request.

Table 7-8C. Point Mitigation (CNG, menu)

File Edit View Insert Format Tools Data Window Help

POINT MITIGATION (pre-event) ? Home

ENTER "B" FOR BASE CASE OR "X" FOR INCRMENTAL CASE

1. Cylinder - slow	1	b	Inspect & replace		Replace all cylinders		Park and service outdoors
2. Cylinder - fast	2	b	Visual inspect/replace 1/yr		Pressure Test - 1/ 3 years		Keep outdoors when f.f.
3. PRD - fast	3		Replace all PRDs		Manifold to outdoors		Isolate cylinders & solenoids
4. PRD - slow	4		Inspect/replace 2/yr		Replace all PRDs		Park and service outdoors
5. Refueling device	5		Inspect/test monthly		Replace 1x/3 yr		Add / maintain Fuel Filter
6. Fuel line fittings	6		Inspect/correct 2x/yr		Tighten 1/yr		Replace O-Ring 1x/4yr
7. Fuel line	7	b	Protect lines, add step plates		Isolate and defuel		Add manul iso. valves
8. LP regulator	8		Replace 1x/3 yr		Encase and vent	b	Engine fire supress. sys.
9. HP regulator	9		Replace 1x/3 yr		Upgrade and replace 1x/6yr	b	engine fire supress. sys.
10. Solenoid valve	10		Test, 1/year		Replace at 4 yrs.		Double for redundancy
11. 1/4 turn valve	11		Replace at 4 yrs.		Replace O-Ring 1x/2yr		Upgrade
12. Other valve	12		Replace at 4 yrs.		Replace O-Ring at 2 yrs		Upgrade
13. Other	13		0		0		0
14. Open	14		0		0		0
15. Open	15		0		0		0

Calculate Base Case Calculate Incremental Case

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Table 7-8L. Point Mitigation (LNG, menu)

File Edit View Insert Format Tools Data Window Help

POINT MITIGATION (pre-event) ? Home

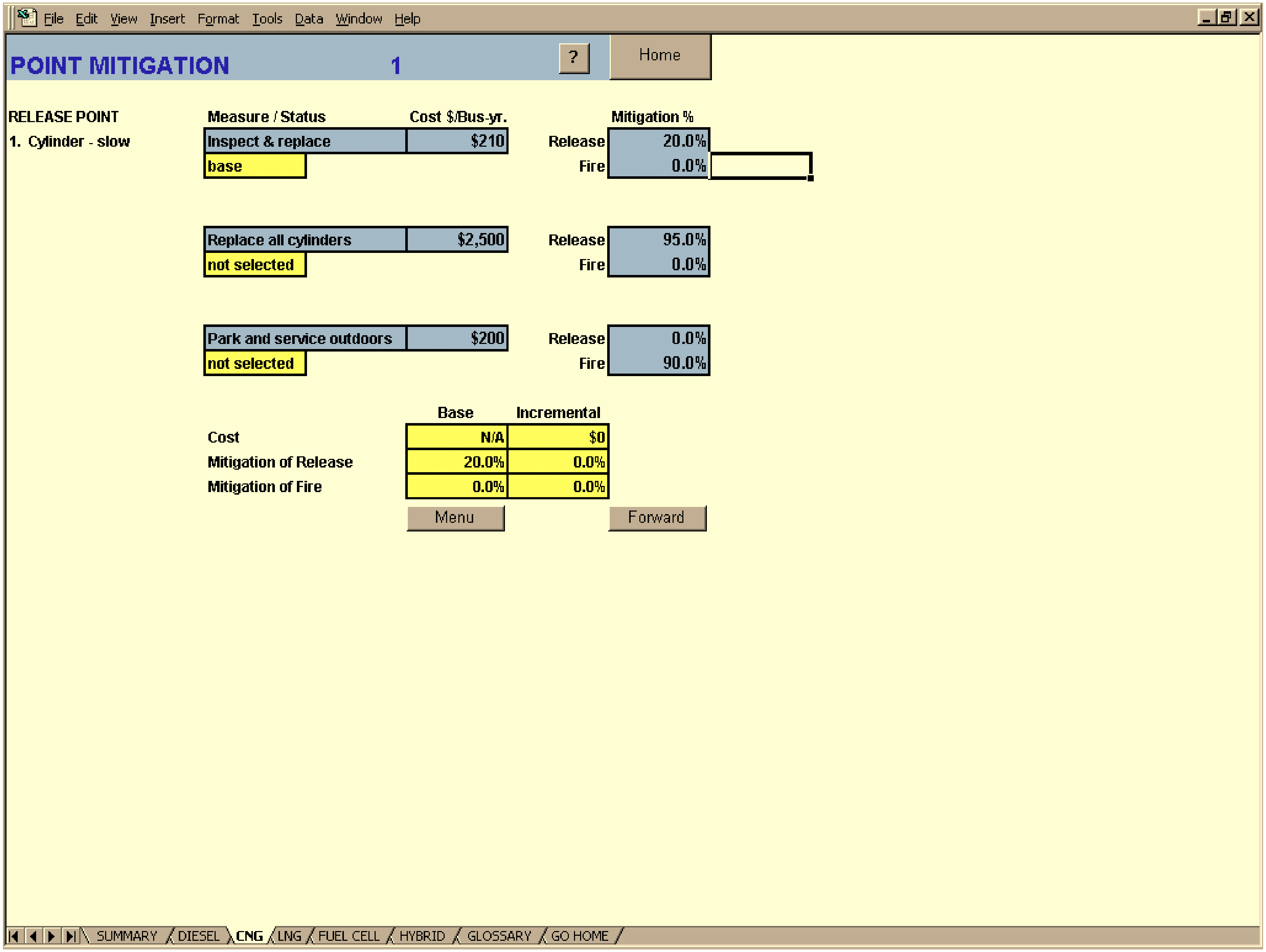
ENTER "B" FOR BASE CASE OR "X" FOR INCRMENTAL CASE

1. Fuel tank (Vac. Loss	1		Change brand		Modify intrusive connections		Park and service outdoors
2. Fuel Tank Rupture	2		Protective armor		Reposition inside frame		Reposition to top of bus
3. PRD - fast (2/tank)	3		replace all PRDs		Manifold to outdoors		Change to different brand
4. PRD - slow (2/tank)	4		Inspect/replace 2/yr		Replace all PRDs (4 years)		Park and service outdoors
5. Refueling receptacl	5	b	Inspect/test monthly		Replace 1x/3 yr		Add gas detector
6. Fuel line fittings	6	b	Inspect/correct 2x/yr		Tighten 1/yr		Replace O-Ring 1x/4yr
7. Fuel line	7		Protect lines, add steel plates		Isolate, shock absorb., etc.		Alarm and manul iso valves
8. Regulator	8		Replace 1x/3 yr		Encase and vent	b	Engine fire supress. sys.
9. Vaporizer	9		Replace 1x/3 yr	b	Upgrade and replace 1x/6yr	b	Engine fire supress. sys.
10. Solenoid valve	10		Test, 1/year		Replace at 4 yrs.		Double for redundancy
11. 1/4 turn valve	11		Replace at 4 yrs.		Replace O-Ring 1x/2yr		Upgrade
12. Injector (Fuel Valve	12		Replace at 4 yrs.		Eliminate (use new system)		Engine fire suppression
13. Cryo Pump	13		Replace seals 2x/year		Change to no pump system		System has no pump
14. Gauges	14		Replace gauges every 4 years		Replace seals every 2 years		Electric sensors
15. Couplings	15		Inspect 2/year		Jacket lines and couplings		Replace with improved type

Calculate Base Case | Calculate Incremental Case

SUMMARY / DIESEL / CNG / LNG / FUEL CELL / HYBRID / GLOSSARY / GO HOME

Table 7-9C. Point Mitigation No. 1 (CNG)



File Edit View Insert Format Tools Data Window Help

POINT MITIGATION 1

? | Home

RELEASE POINT	Measure / Status	Cost $/Bus-yr.		Mitigation %
1. Cylinder - slow	Inspect & replace	$210	Release	20.0%
	base		Fire	0.0%
	Replace all cylinders	$2,500	Release	95.0%
	not selected		Fire	0.0%
	Park and service outdoors	$200	Release	0.0%
	not selected		Fire	90.0%

	Base	Incremental
Cost	N/A	$0
Mitigation of Release	20.0%	0.0%
Mitigation of Fire	0.0%	0.0%

Menu | Forward

SUMMARY / DIESEL / CNG / LNG / FUEL CELL / HYBRID / GLOSSARY / GO HOME

Table 7-9L. Point Mitigation No. 1 (LNG)

File Edit View Insert Format Tools Data Window Help

POINT MITIGATION 1

? | Home

RELEASE POINT	Measure / Status	Cost $/Bus-yr.		Mitigation %
1. Fuel tank (Vac. Loss)	Change brand	$1,500	Release	90.0%
	not selected		Fire	0.0%
	Modify intrusive connections	$150	Release	50.0%
	not selected		Fire	0.0%
	Park and service outdoors	$200	Release	0.0%
	not selected		Fire	90.0%

	Base	Incremental
Cost	N/A	$0
Mitigation of Release	0.0%	0.0%
Mitigation of Fire	0.0%	0.0%

Menu | Forward

SUMMARY / DIESEL / CNG / LNG / FUEL CELL / HYBRID / GLOSSARY / GO HOME

Each numbered Point Mitigation screen (1-15) has the following attributes:

- ***Release Point*** -- Name and number of release point, from **Release Points and Frequencies** screen.

- ***Mitigation Measure*** -- Names of up to three mitigation measures, input on this screen.

- ***Mitigation Status*** -- Base or incremental, from the main **Point Mitigation** screen (**Menu** button, at bottom).

- ***Mitigation Costs ($/bus-year)*** -- Cost of mitigation measure in $/bus-year, input on this screen.

- ***Mitigation Percentage for Release and Fire*** -- Mitigation percentages for release and fire, input on this screen.

- ***Cost*** -- Cost in the **Base Case** (N/A or not applicable) and in the **Incremental Case** (sum for the measures selected as incremental at this release point). The cost assumes that the mitigation action will be implemented fleet-wide. The reference case includes capital, installation, and labor costs over a 12-year bus life.

- ***Mitigation of Release*** -- Percentage mitigation of release (at this release point) in the **Base Case** (relative to the **Reference Case**) and the **Incremental Case** (relative to the Base Case).

- ***Mitigation of Fire*** --Percentage mitigation of fire (at this release point), assuming a release, in the **Base Case** (relative to the **Reference Case**) and the **Incremental Case** (relative to the Base Case).

7.8.2 CNG

Table 7-10C summarizes the point mitigation measures, costs, and effects in the CNG Reference Case.

7.8.3 LNG

Table 7-10L summarizes the point mitigation measures, costs, and effects in the LNG Reference Case.

Table 7-10C. CNG Point Mitigation Measures, Costs, and Effects

Release Point	Action	Cost ($/bus-yr.)	% Reduction in Release Pr.	% Reduction in Fire Pr.
Cylinder - Slow	Inspect annually and replace (defective cylinders only)	210	20	0
	Replace all cylinders	2,500	95	0
	Park & service outdoors (or defuel prior to going inside)	200	0	90
Cylinder - Fast	Inspect annually and replace (defective cylinders only)	210	90	0
	Pressure test all cylinders every three years	300	90	0
	Keep freshly fueled buses outdoors	100	0	90
PRD - Fast	Replace all PRDs[13]	160	90	0
	Manifold to outdoors	850	0	80
	Isolate cylinders	200	0	80
Refueling Receptacle	Park & service outdoors (or defuel prior to going inside)	200	0	90
	Inspect monthly and replace leakers	20	75	0
	Replace manifold assembly every three years	100	80	0
	Add / maintain fuel filters	8	50	0

[13] The Reference Case uses generation 2.5 Mirada PRDs. Note that the model does not consider compound effects. If this measure is selected, the same selection needs to be made for PRD - Slow, with a cost of $0.00.

Release Point	Action	Cost ($/bus-yr.)	% Reduction in Release Pr.	% Reduction in Fire Pr.
Fuel Line Fittings	Inspect every six months and correct	100	80	0
	Tighten connections annually	100	90	0
	Replace O-rings every four years	150	50	0
Fuel Lines	Protect fuel lines	100	90	0
	Isolate and defuel prior to heavy maintenance or fuel line / connector adjustments	200	95	0
	Add manual isolation valves	50	0	75
LP and HP Regulators	Replace every three years	150	80	0
	Encase and vent	100	0	95
Solenoid Valves	Test annually and replace, as needed, prior to system maintenance	200	99	0
	Replace every four years	600	95	0
	Double valve (redundancy)	200	0	85
1/4 Turn Valves	Replace every four years	250	90	0
	Replace O-rings every two years	100	99	0
	Upgrade to a better valve	100	90	0

Source: SAIC

Table 7-10L. LNG Point Mitigation Measures, Costs, and Effects

Release Point	Action	Cost ($/bus-yr.)	% Reduction in Release Pr.	% Reduction in Fire Pr.
Fuel Tank - Vacuum Loss	Change brand	1,500	90	0
	Modify intrusive connections	150	50	0
	Park & service outdoors (or defuel prior to indoor activities)	200	0	90
Fuel Tank - Rupture	Add protective plates (protect from road hazards)	250	75	0
	Reposition inside frame	167	90	0
	Reposition on top of bus	167	90	0
PRD - Fast	Replace all PRDs (not known for frequent failures but repeated use on demand, may have cryogenic fatigue)	75	15	0
	Manifold to outdoors	100	0	80
	Change to maximum reliability brand	33	60	0
PRD - Slow	Inspect twice/year and replace leakers	75	80	0
	Replace periodically to minimize cryogenic fatigue	50	75	0
	Park and service outdoors	200	0	90
Refueling Receptacle	Inspect monthly and replace leakers	20	75	0
	Replace every three years	200	80	0
	Add gas detector	200	0	90

Release Point	**Action**	**Cost ($/bus-yr.)**	**% Reduction in Release Pr.**	**% Reduction in Fire Pr.**
Fuel Line Fittings	Inspect and repair every six months	100	80	0
	Tighten annually	50	90	0
	Replace O-rings every four years	150	50	0
Fuel Lines	Add impact protection plates (negative effect on future inspection times)	120	80	0
	Redesign to reduce or isolate road shock and thermal expansion and contraction	167	80	0
	Add alarm and more manual isolation valves	50	0	75
Regulator	Replace every three years (minimize gas buildup in engine compartment from leaks)	50	80	0
	Encase and vent to roof	25	0	95
Vaporizer	Replace every three years (same as regulator)	243	80	0
	Upgrade and replace every six years	200	95	0
Solenoid Valves	Replace every year (minimize isolation failure risk)	200	80	0
	Replace every four years	43	90	0
	Double valve (redundancy)	22	95	0
1/4 Turn Valves	Replace every four years (minimize isolation failure risk)	150	90	0
	Replace O-rings every two years	100	90	0

Release Point	Action	Cost ($/bus-yr.)	% Reduction in Release Pr.	% Reduction in Fire Pr.
	Upgrade to a better valve (Used in an early implementation, deselected here)	88	80	0
Injector (Fuel Valve)				
Cryogenic Pump	(Used in an early implementation, deselected here)			
Gauges	Replace every four years	75	80	0
	Replace every two years	63	90	0
	Use non-intrusive electronic system	100	99	0
Couplings	Inspect every six months	50	90	0
	Enclose (with lines) and vent	167	0	95
	Replace with best brand	100	80	0

Source: SAIC

7.9 Non-point Mitigation (pre-event)

Tables 7-11C and 7-11L show the Reference Case Non-point Mitigation measures for CNG and LNG. These tables incorporate mitigation measures and impacts for CNG and LNG that affect more than one release point. The structure and values used for CNG and LNG are the same because the selected mitigation measures address the common hazards. Mitigation may be for releases or fires. Each of these categories contains up to three examples of specific non-point mitigation measures. The three non-point mitigation measures selected for the release category are:

- ***Training*** -- Defined as general, operational, safety, and response training to all staff members who can come in contact with buses using the specified fuel. This measure was selected for the Reference Case because all transit agencies adopting new fuels engage in some type of training. Column three shows a site-specific cost of $10,000. The impact of this measure is estimated to be 20% across all five stages.

- ***Inspection*** -- Defined as validation that the agency complies with the standard operating practices associated with the specified fuel. This measure was not selected for the Reference Case because not all transit agencies are engaged in this process. Column three shows a site-specific cost of $20,000. This cost assumes that 1/4 of a trained inspector's time is spent on this function. The impact of this measure is estimated to be 20% in fueling and corrective maintenance and less in the other areas. This differentiation is in accordance with the level of human influence on a release.

- ***Increased Maintenance*** -- Defined as increased inspection and replacement of suspect components prior to their scheduled replacement. This measure was not selected for the Reference Case because few transit agencies are engaged in this process. Column three shows a site-specific cost of $75,000. The impact of this measure is estimated to be 20% across all five stages.

Table 7-11C. Non-Point Mitigation (CNG)

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NON-POINT MITIGATION (pre-event)

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MITIGATION OF RELEASE	"b" or "x"	Cost ($/fleet-yr.)	Operation	Fueling	Prev. Maint.	Corr. Maint.	Parking
			Mitigation Percentage, by Stage				
Training	b	$10,000	20.0%	20.0%	20.0%	20.0%	20.0%
Inspection		$20,000	10.0%	20.0%	5.0%	20.0%	10.0%
Increased Maint.		$75,000	20.0%	20.0%	20.0%	20.0%	20.0%
		Base	20.0%	20.0%	20.0%	20.0%	20.0%
		Non-point Increment	0.0%	0.0%	0.0%	0.0%	0.0%
FIRE							
Fans	b	$50,000	0.0%	0.0%	50.0%	75.0%	0.0%
Spark Arresters		$2,000	0.0%	0.0%	5.0%	30.0%	0.0%
No Flame (SOP)	b	$5,000	5.0%	50.0%	30.0%	80.0%	0.0%
		Base	5.0%	50.0%	65.0%	95.0%	0.0%
		Non-point Increment	0.0%	0.0%	0.0%	0.0%	0.0%

Calculate Base Case | Calculate Incremental Case

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Table 7-11L. Non-Point Mitigation (LNG)

File Edit View Insert Format Tools Data Window Help

NON-POINT MITIGATION (pre-event)

? | Home

MITIGATION OF RELEASE	"b" or "x"	Cost ($/fleet-yr.)	Operation	Fueling	Prev. Maint.	Corr. Maint.	Parking
			Mitigation Percentage, by Stage				
Training	b	$10,000	20.0%	20.0%	20.0%	20.0%	20.0%
Inspection		$20,000	10.0%	20.0%	5.0%	20.0%	10.0%
Increased Maint.		$75,000	20.0%	20.0%	20.0%	20.0%	20.0%
		Base	20.0%	20.0%	20.0%	20.0%	20.0%
		Non-point Increment	0.0%	0.0%	0.0%	0.0%	0.0%
FIRE							
Fans	b	$50,000	0.0%	0.0%	50.0%	75.0%	50.0%
Spark Arresters		$2,000	0.0%	0.0%	5.0%	30.0%	50.0%
No Flame (SOP)	b	$5,000	5.0%	50.0%	30.0%	80.0%	50.0%
		Base	5.0%	50.0%	65.0%	95.0%	75.0%
		Non-point Increment	0.0%	0.0%	0.0%	0.0%	0.0%

Calculate Base Case | Calculate Incremental Case

SUMMARY / DIESEL / CNG / LNG / FUEL CELL / HYBRID / GLOSSARY / GO HOME

The three non-point mitigation measures selected for the fire category are:

- Fans -- Fans that are automatically activated when a certain level of natural gas is detected in the facility has been made part of the Reference Case because all transit agencies adopting gaseous fuels install these types of fans. Column three shows a site-specific cost of $50,000. The impact of this measure is estimated to be 0% for operations, outdoor refueling, and parking and 50% or more for the other stages.

- Spark Arresters -- Spark arresters assume that a system maintains a high level of humidity to reduce the probability of ignition from static electricity and perhaps from other sources. This measure was not selected for the Reference Case because it is not practiced by any transit agency. Column three shows a site-specific cost of $2,000. This cost assumes the installation and annual cost of operating a commercial humidifier. The impact of this measure is estimated to be 30% for corrective maintenance and zero to 5% for the other stages.

- No-Flame Standard Operating Procedure -- This measure was selected for the Reference Case because many transit agencies adopting gaseous fuels are stricter about the enforcement of these SOPs. Column three shows a site-specific cost of $5,000. This cost assumes frequent inspections and reminders. The impact of this measure is estimated to be low in operation and very high in fueling and corrective maintenance (50% and 80%, respectively).

7.10 Injury Mitigation (post-event)

Tables 7-12C and 7-12L show the Reference Case Injury Mitigation measures for CNG and LNG. Except for protective clothing (gloves, masks, etc.), the impacts for CNG and LNG are similar. For each fuel, the same mitigation measures apply to the public and to workers but the mitigation effects may differ. Injury Mitigation selections are also used for Property Damage Mitigation.

- ***Protective Clothing --*** Protective clothing is primarily designed to prevent LNG fueling personnel from receiving cryogenic burns. This measure is part of the Reference Case for LNG workers but is not part of Reference Case for CNG workers. Protective clothing has no effect on injuries to the public.

- ***Alarms --*** Alarms are designed to alert and activate safety systems in enclosed areas where there might be a release or fire. Alarms may increase the number of minor injuries (or claimed but nonexistent injuries) while decreasing the number of more severe or fatal injuries. The increase in minor (or claimed) injuries is attributable to false alarm exits from facilities and buses, especially panic exits by the public. The impact of alarms on CNG and LNG transit operations are the same.

- ***Fire Extinguishers --*** Fire extinguishers are designed to provide early response and control of small fires. Fire extinguishers are also valuable in dousing a fire that has reached a person. On the other hand, it is difficult and hazardous to control CNG or LNG fires with a typical, small fire extinguisher. Sometimes the use of fire extinguishers protects property at the expense of personal safety. For this reason, some transit agencies discourage the use of the devices. The effect on CNG and LNG transit operations is the same.

- ***Other*** **--** Unspecified. You may enter any other measure that applies to your transit operation.

7.11 Property Damage Mitigation (post-event)

Tables 7-13C and 7-13L show the Reference Case Property Damage Mitigation measures for CNG and LNG. For each fuel, the same mitigation measures apply to the bus and to the other property but the mitigation effects may differ. In reality, there are relatively few post-event property mitigation measures that are likely to generate an appreciable and cost-effective benefit. Most mitigation measures in this category, e.g., alarms and fire extinguishers, are standard at transit agencies. The Case selections ("b" for BASE or "x" for INCREMENTAL) for Property Damage Mitigation are made on the **Injury Damage Mitigation** screen. The program requires them to be the same.

- ***Protective Clothing*** -- Protective clothing is available to protect workers from the danger of LNG spillage. These include gloves, face protection shields, and aprons. Refuelers have used CNG face shields.

- ***Alarms*** **--** Alarms are designed to activate safety systems in enclosed areas where there may be a release or fire. As noted in Section 7.10, the use of alarms may reduce property damage while increasing personal injuries. While the use of alarms will have little or no impact on property damage from a release, it may have a significant impact in the event of a fire. A 15% reduction in fire damage across all stages of the operating cycle is estimated for alarms.

- ***Fire Extinguishers*** **--** As with alarms, fire extinguishers may reduce property damage while increasing personal injuries. Fire extinguishers are estimated to reduce property damage 15 to 25% across the stages of the operating cycle.

- ***Other*** **--** Unspecified. You may enter any other measure that applies to your transit operation.

Table 7-12C. Injury Mitigation (CNG)

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INJURY MITIGATION (post-event)

? | Home

WORKERS	"b" or "x"	Cost $/yr.	% Change in Worker Inj. (Release) Minor	Mod.	Severe	Fatal	% Change in Worker Inj. (Fire) Minor	Mod.	Severe	Fatal
Protective Clothing		$5,000	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Alarms	b	$20,000	-10.0%	5.0%	10.0%	25.0%	-10.0%	5.0%	10.0%	25.0%
Fire Exinguishers		$1,000	0.0%	0.0%	0.0%	0.0%	-10.0%	-5.0%	10.0%	5.0%
Other		$5,000	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
		Base Reduction	-10.0%	5.0%	10.0%	25.0%	-10.0%	5.0%	10.0%	25.0%
		Incremental Reduction	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%

PUBLIC	% Change in Public Inj. (Release) Minor	Mod.	Severe	Fatal	% Change in Public Inj. (Fire) Minor	Mod.	Severe	Fatal
Protective Clothing	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Alarms	-25.0%	-15.0%	-5.0%	0.0%	-10.0%	5.0%	10.0%	25.0%
Fire Exinguishers	0.0%	0.0%	0.0%	0.0%	-10.0%	-5.0%	10.0%	5.0%
Other	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Base Reduction	-25.0%	-15.0%	-5.0%	0.0%	-10.0%	5.0%	10.0%	25.0%
Incremental Reduction	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%

Calculate Base Case | Calculate Incremental Case | Property Damage Mitigation

SUMMARY / DIESEL / CNG / LNG / FUEL CELL / HYBRID / GLOSSARY / GO HOME

Table 7-12L. Injury Mitigation (LNG)

File Edit View Insert Format Tools Data Window Help

INJURY MITIGATION (post-event)

? Home

WORKERS	"b" or "x"	Cost $/yr.	% Change in Worker Inj. (Release) Minor	Mod.	Severe	Fatal	% Change in Worker Inj. (Fire) Minor	Mod.	Severe	Fatal
Protective Clothing	b	$5,000	30.0%	20.0%	10.0%	0.0%	10.0%	10.0%	5.0%	0.0%
Alarms	b	$20,000	-10.0%	5.0%	10.0%	25.0%	-10.0%	5.0%	10.0%	25.0%
Fire Exinguishers		$3,000	0.0%	0.0%	0.0%	0.0%	30.0%	20.0%	10.0%	5.0%
Other		$5,000	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
		Base Reduction	23.0%	24.0%	19.0%	25.0%	1.0%	14.5%	14.5%	25.0%
		Incremental Reduction	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%

PUBLIC	% Change in Public Inj. (Release) Minor	Mod.	Severe	Fatal	% Change in Public Inj. (Fire) Minor	Mod.	Severe	Fatal
Protective Clothing	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Alarms	-25.0%	-15.0%	-5.0%	0.0%	-10.0%	5.0%	10.0%	25.0%
Fire Exinguishers	0.0%	0.0%	0.0%	0.0%	30.0%	20.0%	10.0%	5.0%
Other	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Base Reduction	-25.0%	-15.0%	-5.0%	0.0%	-10.0%	5.0%	10.0%	25.0%
Incremental Reduction	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%

Calculate Base Case | Calculate Incremental Case | Property Damage Mitigation

SUMMARY / DIESEL / CNG / LNG / FUEL CELL / HYBRID / GLOSSARY / GO HOME

Table 7-13C. Property Mitigation (CNG)

File Edit View Insert Format Tools Data Window Help

PROPERTY DAMAGE MITIGATION (post-event)

? | Home

BUS	% Change in Bus Damage (Release) Ops.	Fueling	P.M	C.M.	Parking	% Change in Bus Damage (Fire) Ops.	Fueling	P.M	C.M.	Parking
Protective Clothing	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Alarms	0.0%	0.0%	0.0%	0.0%	0.0%	15.0%	15.0%	15.0%	15.0%	15.0%
Fire Exinguishers	0.0%	0.0%	0.0%	0.0%	0.0%	20.0%	25.0%	25.0%	25.0%	15.0%
Other	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Base Reduction	0.0%	0.0%	0.0%	0.0%	0.0%	15.0%	15.0%	15.0%	15.0%	15.0%
Incremental Reduction	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%

OTHER PROPERTY	% Change in Other Damage (Release) Ops.	Fueling	P.M	C.M.	Parking	% Change in Other Damage (Fire) Ops.	Fueling	P.M	C.M.	Parking
Protective Clothing	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Alarms	0.0%	0.0%	0.0%	0.0%	0.0%	15.0%	15.0%	15.0%	15.0%	15.0%
Fire Exinguishers	0.0%	0.0%	0.0%	0.0%	0.0%	20.0%	25.0%	25.0%	25.0%	15.0%
Other	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Base Reduction	0.0%	0.0%	0.0%	0.0%	0.0%	15.0%	15.0%	15.0%	15.0%	15.0%
Incremental Reduction	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%

Calculate Base Case | Calculate Incremental Case | Injury Mitigation

SUMMARY / DIESEL / CNG / LNG / FUEL CELL / HYBRID / GLOSSARY / GO HOME

Table 7-13L. Property Mitigation (LNG)

File Edit View Insert Format Tools Data Window Help

PROPERTY DAMAGE MITIGATION (post-event)

? Home

	% Change in Bus Damage (Release)					% Change in Bus Damage (Fire)				
BUS	Ops.	Fueling	P.M	C.M.	Parking	Ops.	Fueling	P.M	C.M.	Parking
Protective Clothing	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Alarms	0.0%	0.0%	0.0%	0.0%	0.0%	15.0%	15.0%	15.0%	15.0%	15.0%
Fire Exinguishers	0.0%	0.0%	0.0%	0.0%	0.0%	20.0%	25.0%	25.0%	25.0%	15.0%
Other	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Base Reduction	0.0%	0.0%	0.0%	0.0%	0.0%	15.0%	15.0%	15.0%	15.0%	15.0%
Incremental Reduction	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%

	% Change in Other Damage (Release)					% Change in Other Damage (Fire)				
OTHER PROPERTY	Ops.	Fueling	P.M	C.M.	Parking	Ops.	Fueling	P.M	C.M.	Parking
Protective Clothing	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Alarms	0.0%	0.0%	0.0%	0.0%	0.0%	15.0%	15.0%	15.0%	15.0%	15.0%
Fire Exinguishers	0.0%	0.0%	0.0%	0.0%	0.0%	20.0%	25.0%	25.0%	25.0%	15.0%
Other	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Base Reduction	0.0%	0.0%	0.0%	0.0%	0.0%	15.0%	15.0%	15.0%	15.0%	15.0%
Incremental Reduction	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%

Calculate Base Case Calculate Incremental Case Injury Mitigation

SUMMARY / DIESEL / CNG / LNG / FUEL CELL / HYBRID / GLOSSARY / GO HOME

8.0 OUTPUTS

Tables 6-1C and 6-1L (Section 6) showed the fuel homepages for CNG and LNG with the output options at the bottom. Of the seven outputs, one (**Frequency of Releases**) is a restatement of the input screen for **Release Points & Frequencies** (Tables 7-2C and 7-2L) with frequencies allocated by release point across the five stages of operation (operation, fueling, preventive maintenance, corrective maintenance, parking).

The remaining six output screens show calculated values for the frequency of releases, fires, injuries, property damage, etc. and the valuation of losses from injuries and property damage. The seven output screens are summarized below.

8.1 Frequency of Releases

Tables 7-14C and 7-14L show the **Frequency of Releases** output screen for CNG and LNG, respectively. The release points on the tables are those entered and selected on the **Release Points & Frequencies** input screens (Tables 7-2C and 7-2L). The overall release frequencies are shown in the column labeled ***Survey Period***, with a date or dates below it. The date or dates indicate the survey period that was selected on the Release Points & Frequencies input screen.

The release frequencies are allocated across the five stages of operation (***operation, fueling, preventive maintenance, corrective maintenance, parking***) using a normalized, duration-adjusted release frequency. The normalized, duration-adjusted release frequency is calculated as follows:

- Stage-specific release frequencies (obtained from survey data) for each stage are multiplied by stage specific durations (obtained from survey data and observations). For example, in the Reference Case the operation stage for CNG buses is estimated to represent 57% of the time in an average day and 1.7% of the releases. The product of these two numbers is approximately 1.0%. Stage-specific release frequencies must sum to 100 percent. Invalid entries on the **Facility and Fleet Characteristics** input screen (i.e., individual values less than 0 or summed values not equaling 100%) cause the invalid entry or sum to appear against a red background.

- The duration-adjusted frequencies calculated above are summed. The Reference Case summations are 21.1% for CNG and 18.7% for LNG.

- The duration-adjusted frequencies calculated by stage are normalized as a percentage of the sum of the duration-adjusted frequencies. For example, in the Reference Case for CNG the normalized frequency of release in operation is 1.0% / 21.1%, or about 4.6%.

Table 7-14C. Frequency of Releases (CNG)

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FREQUENCY OF RELEASES (per bus-yr.)

? Home

RELEASE POINTS	Survey Period 1998-99	Operation	Fueling	Prev. Maint.	Corr. Maint.	Parking
		(Allocated by normalized, duration-adjusted release frequency)				
1. Cylinder - slow	0.00261	0.000120	0.000036	0.000017	0.000043	0.002397
2. Cylinder - fast	0.00027	0.000012	0.000004	0.000002	0.000004	0.000245
3. PRD - fast	0.00858	0.000394	0.000119	0.000056	0.000140	0.007865
4. PRD - slow	0.01078	0.000496	0.000150	0.000071	0.000177	0.009886
5. Refueling device	0.00750	0.000345	0.000104	0.000049	0.000123	0.006883
6. Fuel line fittings	0.00934	0.000430	0.000130	0.000061	0.000153	0.008565
7. Fuel line	0.00273	0.000125	0.000038	0.000018	0.000045	0.002500
8. LP regulator	0.00531	0.000244	0.000074	0.000035	0.000087	0.004868
9. HP regulator	0.00981	0.000451	0.000136	0.000064	0.000161	0.008997
10. Solenoid valve	0.00760	0.000350	0.000106	0.000050	0.000124	0.006970
11. 1/4 turn valve	0.00869	0.000400	0.000121	0.000057	0.000142	0.007969
12. Other valve	0.00173	0.000079	0.000024	0.000011	0.000028	0.001583
13. Other	0.00412	0.000189	0.000057	0.000027	0.000067	0.003775
14. Open	0.00000	0.000000	0.000000	0.000000	0.000000	0.000000
15. Open	0.00000	0.000000	0.000000	0.000000	0.000000	0.000000

SUMMARY / DIESEL / CNG / LNG / FUEL CELL / HYBRID / GLOSSARY / GO HOME

Table 7-14L. Frequency of Releases (LNG)

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FREQUENCY OF RELEASES (per bus-yr.) ? Home

RELEASE POINTS	Survey Period 1999	Operation	Fueling	Prev. Maint.	Corr. Maint.	Parking
		(Allocated by normalized, duration-adjusted release frequency)				
1. Fuel tank (Vac. Loss)	0.04762	0.006098	0.001143	0.000407	0.001220	0.038751
2. Fuel Tank Rupture	0.00040	0.000051	0.000010	0.000003	0.000010	0.000323
3. PRD - fast (2/tank)	0.00095	0.000122	0.000023	0.000008	0.000024	0.000775
4. PRD - slow (2/tank)	0.29524	0.037811	0.007089	0.002521	0.007562	0.240255
5. Refueling receptacle	1.00000	0.128068	0.024013	0.008538	0.025614	0.813767
6. Fuel line fittings	2.00000	0.256137	0.048026	0.017076	0.051227	1.627535
7. Fuel line	0.00159	0.000203	0.000038	0.000014	0.000041	0.001292
8. Regulator	0.00952	0.001220	0.000229	0.000081	0.000244	0.007750
9. Vaporizer	0.47619	0.060985	0.011435	0.004066	0.012197	0.387508
10. Solenoid valve	0.01665	0.002132	0.000400	0.000142	0.000426	0.013549
11. 1/4 turn valve	0.00095	0.000122	0.000023	0.000008	0.000024	0.000775
12. Injector (Fuel Valve)	0.00000	0.000000	0.000000	0.000000	0.000000	0.000000
13. Cryo Pump	0.00000	0.000000	0.000000	0.000000	0.000000	0.000000
14. Gauges	0.03330	0.004265	0.000800	0.000284	0.000853	0.027098
15. Couplings	0.00095	0.000122	0.000023	0.000008	0.000024	0.000775

SUMMARY / DIESEL / CNG / LNG / FUEL CELL / HYBRID / GLOSSARY / GO HOME

The interpretation of the normalized, duration-adjusted release frequency is as follows: Given a release, what is the probability that it occurred in any specific stage?

- The normalized, duration-adjusted release frequency for each stage is then used to allocate the release frequency for each release point. In the Reference Case for CNG, for example, the release frequency for Cylinder - Slow is .002621. The normalized, duration-adjusted release frequency for operation is 4.6% (previous bullet). The product of these two values is .00012, or the normalized, duration-adjusted frequency of Cylinder - Slow releases during operation.

The interpretation of this allocation of release frequencies by release point to individual stages is that the release depends on the activities in the stage in general (e.g., fueling is riskier than operation) but not to the stage in particular (i.e., the likelihood of a release by release point is uniformly distributed within each stage).

8.2 Frequency and Valuation of Losses

Tables 7-15C and 7-15L show the screens for the frequency and valuation of losses for CNG and LNG, respectively. Losses are divided into six categories: (1) ***worker injuries***, (2) ***worker fatalities***, (3) ***public injuries***, (4) ***public fatalities***, (5) ***property damage from releases*** and (6) ***property damage from fires.*** Frequencies are shown per bus-year and for the fleet for the year. The number of buses in the fleet is shown at the lower right. The word BASE or INCREMENTAL at the lower left of the screen shows which case is active.

8.3 Valuation of Loss by Stage and Category

Tables 7-16C and 7-16L show the screens for the valuation of loss by stage and category for CNG and LNG, respectively. Losses are shown per bus-year and for the fleet by stage (operation, fueling, preventive maintenance, corrective maintenance, and parking) and category (workers, public, property). Losses from injuries to the public take place only in operation. The word BASE or INCREMENTAL at the lower left of the screen shows which case is active.

8.4 Valuation of Loss by Stage and Hazard

Tables 7-17C and 7-17L show the screens for the valuation of loss by stage and hazard for CNG and LNG, respectively. Losses are shown per bus-year and for the fleet by release and fire hazards, type (non-fatal injury, fatality, and property damage), and stage (operation, fueling, preventive maintenance, corrective maintenance, and parking). The word BASE or INCREMENTAL at the lower left of the screen shows which case is active.

Table 7-15C. Frequency and Valuation of Losses (CNG)

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FREQUENCY & VALUATION OF LOSSES

? Home

	Per Bus-Year		Per Fleet	
TYPE OF LOSS	Frequency	Loss	Frequency	Loss
Worker Injuries	0.00071	$21	0.14161	$4,271
Worker Fatalities	0.00000	$5	0.00042	$1,054
Public Injuries	0.00220	$134	0.44047	$26,870
Public Fatalities	0.00001	$49	0.00198	$9,875
Property Damage (Release)	0.06067	$37	12.13370	$7,361
Property Damage (Fire)	0.00006	$77	0.01194	$15,445
TOTAL		$324		$64,875
BASE				

200 buses in fleet

SUMMARY / DIESEL / CNG / LNG / FUEL CELL / HYBRID / GLOSSARY / GO HOME

Table 7-15L. Frequency and Valuation of Losses (LNG)

File Edit View Insert Format Tools Data Window Help

FREQUENCY & VALUATION OF LOSSES

? Home

	Per Bus-Year		Per Fleet	
TYPE OF LOSS	Frequency	Loss	Frequency	Loss
Worker Injuries	0.00029	$3	0.05706	$620
Worker Fatalities	0.00000	$6	0.00044	$1,102
Public Injuries	0.00416	$60	0.83142	$11,989
Public Fatalities	0.00002	$84	0.00335	$16,762
Property Damage (Release)	0.86479	$246	172.95708	$49,199
Property Damage (Fire)	0.00202	$82	0.40410	$16,343
TOTAL		$480		$96,015

BASE

200 buses in fleet

SUMMARY / DIESEL / CNG / LNG / FUEL CELL / HYBRID / GLOSSARY / GO HOME /

Table 7-16C. Valuation of Losses by Stage & Category (CNG)

File Edit View Insert Format Tools Data Window Help

VALUATION OF LOSSES BY STAGE & CATEGORY

? Home

PER BUS-YEAR	Operation	Fueling	Prev. Maint.	Corr. Maint.	Parking	TOTAL
Workers	$6	$2	$2	$5	$12	$27
Public	$184	------------	------------	------------	------------	$184
Property	$5	$1	$1	$2	$106	$114
TOTAL	$194	$3	$2	$7	$118	$324

PER FLEET-YEAR	Operation	Fueling	Prev. Maint.	Corr. Maint.	Parking	TOTAL
Workers	$1,191	$364	$342	$1,058	$2,370	$5,324
Public	$36,745	------------	------------	------------	------------	$36,745
Property	$913	$298	$140	$324	$21,130	$22,806
TOTAL	$38,848	$662	$482	$1,382	$23,500	$64,875

BASE

SUMMARY / DIESEL / CNG / LNG / FUEL CELL / HYBRID / GLOSSARY / GO HOME

Table 7-16L. Valuation of Losses by Stage & Category (LNG)

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VALUATION OF LOSSES BY STAGE & CATEGORY ? Home

PER BUS-YEAR	Operation	Fueling	Prev. Maint.	Corr. Maint.	Parking	TOTAL
Workers	$3	$1	$1	$2	$2	$9
Public	$144					$144
Property	$39	$7	$3	$8	$271	$328
TOTAL	$186	$8	$3	$10	$273	$480

PER FLEET-YEAR	Operation	Fueling	Prev. Maint.	Corr. Maint.	Parking	TOTAL
Workers	$697	$129	$107	$338	$451	$1,721
Public	$28,751					$28,751
Property	$7,791	$1,482	$586	$1,563	$54,120	$65,542
TOTAL	$37,239	$1,611	$692	$1,901	$54,571	$96,015

BASE

SUMMARY / DIESEL / CNG / LNG / FUEL CELL / HYBRID / GLOSSARY / GO HOME

Table 7-17C. Valuation of Losses by Stage & Hazard (CNG)

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VALUATION OF LOSSES BY STAGE & HAZARD

? Home

RELEASE	Operation	Fueling	Prev. Maint.	Corr. Maint.	Parking	TOTAL
Injury	$139	$1	$1	$4	$10	$155
Fatality	$50	$0	$0	$1	$2	$54
Property	$4	$1	$1	$2	$104	$112
Subtotal (per bus-yr.)	$194	$3	$2	$7	$116	$322
FIRE						
Injury	$0	$0	$0	$0	$0	$0
Fatality	$0	$0	$0	$0	$0	$0
Property	$0	$0	$0	$0	$2	$2
Subtotal (per bus-yr.)	$1	$0	$0	$0	$2	$3
TOTAL (per bus-yr.)	$194	$3	$2	$7	$118	$324
TOTAL (fleet)	$38,848	$662	$482	$1,382	$23,500	$64,874

BASE

SUMMARY / DIESEL / CNG / LNG / FUEL CELL / HYBRID / GLOSSARY / GO HOME

Table 7-17L. Valuation of Losses by Stage & Hazard (LNG)

File Edit View Insert Format Tools Data Window Help

VALUATION OF LOSSES BY STAGE & HAZARD

? Home

RELEASE	Operation	Fueling	Prev. Maint.	Corr. Maint.	Parking	TOTAL
Injury	$61	$0	$0	$1	$1	$62
Fatality	$85	$0	$0	$1	$1	$88
Property	$38	$7	$3	$8	$243	$299
Subtotal (per bus-yr.)	$184	$8	$3	$9	$245	$450
FIRE						
Injury	$1	$0	$0	$0	$0	$1
Fatality	$1	$0	$0	$0	$0	$1
Property	$1	$0	$0	$0	$27	$29
Subtotal (per bus-yr.)	$2	$0	$0	$0	$28	$30
TOTAL (per bus-yr.)	$186	$8	$3	$10	$273	$480
TOTAL (fleet)	$37,239	$1,611	$692	$1,901	$54,571	$96,014

BASE

SUMMARY / DIESEL / CNG / LNG / FUEL CELL / HYBRID / GLOSSARY / GO HOME

8.5 Valuation of Losses by Stage ($/bus-yr.)

Tables 7-18C and 7-18L show the screens for the valuation of losses by stage for CNG and LNG, respectively. The release points are displayed in their natural order (numbered 1-15). Clicking on a **Rank by:** button at the top of any column (each of the five operating stages and the total) ranks the release points from greatest loss to least loss according to that variable. You may click any Rank by: button in any order. To return the ranking to its natural order, click Go Home and select Valuation of Losses by Stage. The word BASE or INCREMENTAL at the lower left of the screen shows which case is active.

8.6 Valuation of Losses by Hazard / Type ($/bus-yr.)

Tables 7-19C and 7-19L show the screens for the valuation of losses by hazard (release and fire), type (injury, fatality, property), and total for CNG and LNG, respectively. Clicking on a **Rank by:** button at the top of any column (each of the hazards, types, or the total) ranks the release points from greatest loss to least loss according to that variable. You may click any Rank by: button in any order. To return the ranking to its natural order, click Go Home and select Valuation of Losses by Hazard / Type. The word BASE or INCREMENTAL at the lower left of the screen shows which case is active.

8.7 Benefits & Costs ($/bus-yr.)

Tables 7-20C and 7-20L show the screens for the benefits and costs of an **Incremental Case** by release point and overall (weighted average). The CNG case incorporates the selection of two incremental point mitigation measures: replacement of PRDs and pressure testing of cylinders every three years. It shows that the PRD replacement is cost-effective (benefit-cost ratio = 1.28) but that the pressure testing is not (benefit-cost ratio = 0.04). The effective benefit-cost ratio for PRD replacement in this example is actually slightly higher than 1.28 since replacement to mitigate fast releases also mitigates slow releases. The dollar benefit in the slow release case (not shown) is about $2 of the $4 Base Loss.

The LNG case incorporates the selection of two incremental point mitigation measures: replacement of PRDs every four years (PRD slow release) and tightening of fuel line fittings. It also incorporates two non-point mitigation measures: inspections and spark arresters. The LNG case shows that the two point mitigation measures are cost-effective even if the two non-point mitigation measures are selected. This cost-effectiveness is due to the low cost of the mitigation measures more than the large savings from mitigation. To see if non-point mitigation measures are cost-effective with or without the point mitigation measures, it is necessary to compare the costs of the measure per fleet-year with the savings from the measure on any of the summary valuation output screens. This comparison can be done in a step-wise fashion. For example, in the LNG case, the estimated value of the losses with the four mitigation measures noted above is $65,789. Rerunning the model with spark arresters removed from the mitigation scenario increases the loss estimate to $66,789, or about $1,000 per year. Since spark arresters are estimated to cost $2,000 per fleet per year, this mitigation is not cost-effective if the other mitigation measures are taken. In comparison, spark arresters alone are estimated to reduce the losses from the Base Case value of $96,015 per fleet-year to $93,233, or almost $2,800 per fleet-year versus the cost of $2,000 per fleet-year. Thus, spark arresters alone are estimated to be cost-effective.

To identify which mitigation measures are active in each case it is necessary to review the individual mitigation input screens. There is no summary screen showing all of the selected mitigation measures across all mitigation categories.

The columns on the table are described below.

- ***Base Loss*** -- The loss in the **Base Case**. This loss changes as the Base Case changes but does not change in the **Incremental Case**.

- ***Mit'd Loss*** -- The mitigated loss in the **Base Case** (equal to the Base Loss) or the **Incremental Case** (incremental to the Base Loss).

- ***Benefit* --** The benefit of mitigation is zero in the **Base Case** (since it is already reflected in the Base Loss) and equal to the change in losses in the **Incremental Case**.

- ***Cost*** -- The cost of mitigation is zero in the **Base Case** and equal to the cost of the mitigation measures in the **Incremental Case**.

- ***Benefit-Cost Ratio*** -- The ratio of the benefits of incremental mitigation to the costs of incremental mitigation by release point and overall.

Table 7-18C. Valuation of Losses by Stage (CNG)

File Edit View Insert Format Tools Data Window Help

VALUATION OF LOSSES BY STAGE ($/bus-yr)

? Home

RLEASE POINT	Operation	Fueling	Prev. Maint.	Corr. Maint.	Parking	Total
	Rank by:	Rank by:	Rank by:	Rank by:	Rank by:	Rank by:
1. Cylinder - slow	$0	$0	$0	$0	$5	$6
2. Cylinder - fast	$32	$1	$0	$1	$29	$64
3. PRD - fast	$155	$2	$2	$5	$63	$228
4. PRD - slow	$1	$0	$0	$0	$3	$4
5. Refueling device	$0	$0	$0	$0	$1	$1
6. Fuel line fittings	$0	$0	$0	$0	$1	$1
7. Fuel line	$5	$0	$0	$0	$2	$7
8. LP regulator	$0	$0	$0	$0	$2	$3
9. HP regulator	$0	$0	$0	$0	$4	$5
10. Solenoid valve	$0	$0	$0	$0	$3	$4
11. 1/4 turn valve	$0	$0	$0	$0	$2	$3
12. Other valve	$0	$0	$0	$0	$0	$1
13. Other	$0	$0	$0	$0	$0	$0
14. Open	$0	$0	$0	$0	$0	$0
15. Open	$0	$0	$0	$0	$0	$0
TOTAL	$194	$3	$2	$7	$118	$324

BASE

SUMMARY / DIESEL / CNG / LNG / FUEL CELL / HYBRID / GLOSSARY / GO HOME

Table 7-18L. Valuation of Losses by Stage (LNG)

File Edit View Insert Format Tools Data Window Help

VALUATION OF LOSSES BY STAGE ($/bus-yr)

? Home

RLEASE POINT	Rank by: Operation	Rank by: Fueling	Rank by: Prev. Maint.	Rank by: Corr. Maint.	Rank by: Parking	Rank by: Total
1. Fuel tank (Vac. Loss)	$11	$2	$1	$2	$57	$73
2. Fuel Tank Rupture	$81	$1	$0	$1	$7	$90
3. PRD - fast (2/tank)	$10	$0	$0	$0	$0	$10
4. PRD - slow (2/tank)	$16	$1	$1	$1	$52	$71
5. Refueling receptacle	$22	$3	$1	$3	$84	$112
6. Fuel line fittings	$20	$1	$0	$1	$38	$61
7. Fuel line	$17	$0	$0	$0	$1	$19
8. Regulator	$2	$0	$0	$0	$7	$10
9. Vaporizer	$4	$1	$0	$1	$20	$25
10. Solenoid valve	$1	$0	$0	$0	$2	$3
11. 1/4 turn valve	$0	$0	$0	$0	$0	$0
12. Injector (Fuel Valve)	$0	$0	$0	$0	$0	$0
13. Cryo Pump	$0	$0	$0	$0	$0	$0
14. Gauges	$2	$0	$0	$0	$4	$6
15. Couplings	$0	$0	$0	$0	$0	$1
TOTAL	$186	$8	$3	$10	$273	$480

BASE

SUMMARY / DIESEL / CNG / LNG / FUEL CELL / HYBRID / GLOSSARY / GO HOME

Table 7-19C. Valuation of Losses by Hazard / Type (CNG)

File Edit View Insert Format Tools Data Window Help

VALUATION OF LOSSES BY HAZARD / TYPE ($/bus-yr) ? Home

	Rank by:	Rank by:	Rank by:	Rank by:	Rank by:	Rank by:
RELEASE POINT	Fire (All)	Release (All)	Injury	Fatality	Property	Total
1. Cylinder - slow	$0	$6	$0	$0	$6	$6
2. Cylinder - fast	$0	$64	$1	$32	$31	$64
3. PRD - fast	$1	$226	$149	$22	$57	$228
4. PRD - slow	$0	$3	$0	$0	$3	$4
5. Refueling device	$0	$1	$0	$0	$1	$1
6. Fuel line fittings	$0	$1	$0	$0	$1	$1
7. Fuel line	$0	$7	$5	$1	$2	$7
8. LP regulator	$0	$2	$0	$0	$2	$3
9. HP regulator	$0	$4	$0	$0	$5	$5
10. Solenoid valve	$0	$3	$0	$0	$4	$4
11. 1/4 turn valve	$0	$3	$0	$0	$3	$3
12. Other valve	$0	$1	$0	$0	$1	$1
13. Other	$0	$0	$0	$0	$0	$0
14. Open	$0	$0	$0	$0	$0	$0
15. Open	$0	$0	$0	$0	$0	$0
TOTAL	$3	$322	$156	$55	$114	$324

BASE

SUMMARY / DIESEL / CNG / LNG / FUEL CELL / HYBRID / GLOSSARY / GO HOME

Table 7-19L. Valuation of Losses by Hazard / Type (LNG)

File Edit View Insert Format Tools Data Window Help

VALUATION OF LOSSES BY HAZARD / TYPE ($/bus-yr) ? Home

RELEASE POINT	Rank by: Fire (All)	Rank by: Release (All)	Rank by: Injury	Rank by: Fatality	Rank by: Property	Rank by: Total
1. Fuel tank (Vac. Loss)	$5	$68	$2	$1	$70	$73
2. Fuel Tank Rupture	$1	$89	$17	$66	$7	$90
3. PRD - fast (2/tank)	$0	$10	$4	$6	$0	$10
4. PRD - slow (2/tank)	$22	$49	$9	$2	$60	$71
5. Refueling receptacle	$1	$111	$8	$2	$103	$112
6. Fuel line fittings	$1	$60	$12	$3	$46	$61
7. Fuel line	$0	$19	$8	$10	$2	$19
8. Regulator	$0	$9	$0	$0	$9	$10
9. Vaporizer	$0	$25	$1	$0	$24	$25
10. Solenoid valve	$0	$2	$1	$0	$2	$3
11. 1/4 turn valve	$0	$0	$0	$0	$0	$0
12. Injector (Fuel Valve)	$0	$0	$0	$0	$0	$0
13. Cryo Pump	$0	$0	$0	$0	$0	$0
14. Gauges	$0	$5	$1	$0	$4	$6
15. Couplings	$0	$1	$0	$0	$0	$1
TOTAL	$30	$450	$63	$89	$328	$480

BASE

SUMMARY / DIESEL / CNG / LNG / FUEL CELL / HYBRID / GLOSSARY / GO HOME

Table 7-20C. Benefits & Costs (CNG)

File Edit View Insert Format Tools Data Window Help

BENEFITS & COSTS ($/bus-yr.)

? Home

RELEASE POINT	Base Loss	Mit'd Loss	Benefit	Cost	Benefit-Cost
	Rank by:	Rank by:	Rank by:	Rank by:	Rank by:
1. Cylinder - slow	$6	$6	$0	$0	0.00
2. Cylinder - fast	$64	$6	$57	$1,500	0.04
3. PRD - fast	$228	$23	$205	$160	1.28
4. PRD - slow	$4	$4	$0	$0	0.00
5. Refueling device	$1	$1	$0	$0	0.00
6. Fuel line fittings	$1	$1	$0	$0	0.00
7. Fuel line	$7	$7	$0	$0	0.00
8. LP regulator	$3	$3	$0	$0	0.00
9. HP regulator	$5	$5	$0	$0	0.00
10. Solenoid valve	$4	$4	$0	$0	0.00
11. 1/4 turn valve	$3	$3	$0	$0	0.00
12. Other valve	$1	$1	$0	$0	0.00
13. Other	$0	$0	$0	$0	0.00
14. Open	$0	$0	$0	$0	0.00
15. Open	$0	$0	$0	$0	0.00
TOTAL	$324	$62	$262	$1,660	0.16

INCREMENTAL

SUMMARY / DIESEL / CNG / LNG / FUEL CELL / HYBRID / GLOSSARY / GO HOME

Table 7-20L. Benefits & Costs (LNG)

File Edit View Insert Format Tools Data Window Help

BENEFITS & COSTS ($/bus-yr.)

? Home

RELEASE POINT	Base Loss	Mit'd Loss	Benefit	Cost	Benefit-Cost
	Rank by:	Rank by:	Rank by:	Rank by:	Rank by:
1. Fuel tank (Vac. Loss)	$73	$63	$9	$0	N/M
2. Fuel Tank Rupture	$90	$81	$10	$0	N/M
3. PRD - fast (2/tank)	$10	$9	$1	$0	N/M
4. PRD - slow (2/tank)	$71	$13	$57	$50	1.14
5. Refueling receptacle	$112	$100	$12	$0	N/M
6. Fuel line fittings	$61	$5	$55	$50	1.11
7. Fuel line	$19	$17	$2	$0	N/M
8. Regulator	$10	$9	$1	$0	N/M
9. Vaporizer	$25	$23	$3	$0	N/M
10. Solenoid valve	$3	$2	$0	$0	N/M
11. 1/4 turn valve	$0	$0	$0	$0	N/M
12. Injector (Fuel Valve)	$0	$0	$0	$0	0.00
13. Cryo Pump	$0	$0	$0	$0	0.00
14. Gauges	$6	$5	$1	$0	N/M
15. Couplings	$1	$1	$0	$0	N/M
TOTAL	$480	$329	$151	$100	1.51

INCREMENTAL

SUMMARY / DIESEL / CNG / LNG / FUEL CELL / HYBRID / GLOSSARY / GO HOME

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9.0 ANALYSIS OF ALTERNATIVE-FUEL HAZARDS

This section analyzes the base losses and identifies cost-effective mitigation measures for CNG and LNG. It also discusses the approach to identifying cost-effective mitigation measures in the broader context of the model and the industry.

9.1 CNG Base Losses

Losses in the CNG Reference Case are estimated at $324 per bus per year. Roughly 90 percent of these losses are attributable to fast releases from PRDs ($228 per bus-year) and fast releases from cylinders ($64 per bus-year). The remaining ten percent of the base losses ($32) are attributable to all other components. This observation suggests that the first place to look for cost-effective point mitigation measures would be PRDs and cylinders, rather than other components or broadly-defined non-point mitigation measures. This is a significant observation since it confirms the importance of the industry's current focus on PRDs and cylinders and the relative unimportance of additional effort addressing all other components and systems. The PRD issues are particularly significant in climates where freezing takes place.

The estimated loss of $324 per bus-year is highly sensitive to the release frequencies used in the analysis. Switching from the 1998-99 release frequencies to the 1996-97 frequencies increases the base loss to $601 per bus-year. Most of the losses, however, are still attributable to fast PRD releases and fast cylinder releases. This also confirms the importance of continuing to address PRD and cylinder issues.

In terms of events and injuries, the Reference Case estimates 0.14 worker injuries per fleet-year, 0.44 public injuries per fleet-year, and 12.1 release events causing property damage per fleet-year. Most of the injuries and property damage take place in operation or in parking. Parking contributes significantly to losses because the bus is fully fueled and the cylinders are at maximum pressure.

9.2 CNG Loss Mitigation Measures

Using the Reference Case and 1998-99 release frequencies as a basis, the only cost-effective mitigation measure is the replacement of PRDs. The observation that only one mitigation measure appears cost-effective on average, across the industry is important. It suggests that there are no systemic deficiencies in components (except PRDs) or industry practices. Rather, there are individual deficiencies in components, systems, practices, etc. that must be addressed. Point mitigation measures directed at components other than fast releases from PRDs are not cost-effective in the model. Non-point and post-event mitigation measures are also not cost-effective. Like LNG, however, this inference is sensitive to the release probabilities used in the model and the event database behind it. Relatively modest changes in release probabilities in key areas, or in the consequences of key release categories, would significantly change the relationships. The user should verify that the release frequencies are appropriate for his or her situation.

It is also important to stress that the overall cost-effective level of systems, operations, and safety practices depends on a relatively high degree of compliance with established safety practices. SAIC has observed substantial occurrences of off-specification safety activities, equipment, facilities, etc. This degraded adherence to safety standards figures into the losses estimated in the base case in the model. Strict adherence to safety standards would lower the base losses and make fewer itemized mitigation measures cost-effective.

Note also that selection of multiple mitigation measures has an interactive effect. For example, the base loss in the model from fast PRD releases in the Reference Case is \$228 per bus-year. If inspection (pre-event non-point mitigation) is added to the Reference Case, the base loss from fast PRD releases declines to \$204. If inspection and increased maintenance (also a pre-event non-point mitigation) are *both* added to the Reference Case, the base loss from fast PRD releases declines to \$163. This base loss is about the same as the estimated cost for PRD replacements (\$160 per bus-year), indicating that PRD replacement would be only marginally cost-effective if inspection and increased maintenance were both part of the transit agency's standard practices. Two other points are important in this regard: PRD replacement (at \$160 per bus-year or \$32,000 per fleet-year) would be more cost-effective than increased inspections and maintenance (a total of \$95,000 per fleet-year) in reducing losses from fast PRD releases and second, although increased inspections and maintenance (at \$95,000 per fleet-year) would reduce losses in all areas, not just fast PRD releases, it would not be cost-effective overall. The model shows that the base loss in the Reference Case would decline to \$233 per bus-year (\$46,566 per fleet-year) from \$324 per bus-year (\$64,875 per fleet year) with the addition of the two non-point mitigation measures. Since these measures are estimated to cost \$95,000 per fleet-year (\$20,000 for inspections and \$75,000 for maintenance), the costs exceed the gains by about 5:1 (\$95,000 versus roughly \$18,000, i.e., the difference in the base loss in the two cases). This observation is important since it indicates that issues specific to PRDs are critical in cost-effective risk-reduction, not general increases in inspection and maintenance that also affect PRD risks.

9.3 LNG Base Losses

Losses in the LNG Reference Case are estimated at \$480 per bus per year. Most of the losses are attributable to the following five release points: refueling receptacle (\$112), fuel tank rupture (\$90), fuel tank vacuum loss (\$73), PRD slow release (\$71), and fuel line fittings (\$61). The remaining \$75 of losses are attributable to eight other release points. This observation suggests that point mitigation measures aimed at the five major release points are the most likely ones to be cost-beneficial. The PRD issues are particularly significant in climates where freezing takes place.

The estimated loss of \$480 per bus-year is highly sensitive to the release frequencies used in the analysis. Switching from the 1998-99 release frequencies to the 1996-97 frequencies increases the base loss to \$9,810 per bus-year. Moreover, it changes the highest risk release points to fast PRD (\$4,124), fuel line (\$2,394), regulator (\$2,003), couplings (\$734), and fuel tank vacuum loss (\$457).

This radical change in both the overall total and the individual components driving the total suggests that the LNG systems and operational practices are exceedingly variable from fleet-to-fleet and over time. This is also an indicator of technical and operational immaturity. Note, for example, that fuel lines and regulators are major sources of loss in the 1996-97 data but that the refueling receptacle is not. In the 1998-99 data, the reverse is true. The 1998-99 release frequencies are based on recent experiences at a medium-size southwestern transit agency. The earlier frequencies are based on earlier experiences at a large southwestern transit agency. LNG operators should also be aware that the variations over time and across components and fleets are based on a relatively small database of buses and events. This observation suggests caution in directly translating the values in the model to individual fleets.

In terms of events and injuries, the Reference Case estimates 0.06 worker injuries per fleet-year, 0.83 public injuries per fleet-year, and 173 release events causing property damage per fleet-year. Most of the injuries and property damage take place in operation or in parking. Parking contributes significantly to losses because the bus is fully fueled.

9.4 LNG Loss Mitigation Measures

Using the Reference Case in the model and the 1998-99 release frequencies as a basis, the only cost-effective point mitigation measures are replacing all the PRDs and tightening the fuel line fittings. Installation of spark arresters is a highly cost-effective non-point mitigation measure, costing $2,000 per fleet-year but reducing losses in the Reference Case by about $2,800 per fleet year. Increasing inspections reduces losses by about $10,000 per fleet-year but costs about $20,000 per fleet-year, making it cost-ineffective. The observation that only a small number of mitigation measures appear cost-effective on average is important. It suggests that there are few systemic deficiencies in components (except PRDs) or industry practices. Rather, there are individual deficiencies in components, systems, practices, etc. that must be addressed. This observation is tied directly to the estimated frequency of releases, however. Fleets with characteristics like those forming the 1996-97 release estimates, have much larger estimated losses and many more cost-effective mitigation options. The user should verify that the release frequencies are appropriate for his or her situation.

It is also important to stress that the overall cost-effective level of systems, operations, and safety practices depends on a relatively high degree of compliance with established safety practices. SAIC has observed substantial occurrences of off-specification safety activities, equipment, facilities, etc. This degraded adherence to safety standards figures into the losses estimated in the base case in the model. Strict adherence to safety standards would lower the base losses and make fewer itemized mitigation measures cost-effective.

Note also that selection of multiple mitigation measures has an interactive effect. For example, the base loss from the refueling receptacle in the Reference Case is $112 per bus-year. If spark arresters are used, the loss is reduced only to $111. The loss reduction is small because spark arresters primarily affect parking and corrective maintenance, while releases from the refueling receptacle take place during refueling. Inspection, which covers release probabilities equally by stage of operation, reduces losses at the refueling receptacle release point to $100 per bus-year. These observations are important since they indicate that issues specific to the refueling receptacle (and the other release points) are more important to cost-effective risk-reduction than most general increases in non-point mitigation measures that also affect refueling receptacle risks. As noted earlier, spark arresters are cost-effective overall, with most of the gain occurring in the parking stage of the daily operating cycle.

APPENDIX A. Valuation of Injuries and Fatalities

This appendix provides monetary values for injuries and fatalities from fuel-related events on transit buses. In each case, the monetary value is the Willingness-to-Pay (WTP) of the individual (i.e., the operator, maintenance worker, rider, transit company, etc.) to avoid the specified impacts. References to the cited valuation studies are included.

A.1 Valuing a Life

Table A-1 summarizes a sample of value of life studies based on willingness-to-pay. It shows a two order-of-magnitude range of WTP valuation, from hundreds of thousands to tens of millions. Other surveys show similarly broad ranges but essentially the same mean and median values (e.g., low to middle single-digit millions of dollars) (Morrall, 1986). Valuations used in Federal agencies from about $2.7 million at the Department of Transportation to $5 million at the Consumer Products Safety Commission and the Environmental Protection Agency.

Based on these analyses, it is apparent that at least two important splits exist in the valuation of a life: (1) the type of life, i.e., worker or non-worker; and (2) the method of death, i.e., common or uncommon. In general, a higher valuation is placed on non-workers than on workers (due to the assumption of risk by workers) and a higher valuation is placed on avoidance of uncommon fatalities than on common fatalities (due to a variety of issues relating to control, fear, etc.). Most of the fatalities associated with fires and fires or explosions aboard or around transit buses would be part of the uncommon fatality category. This would distinguish them from traffic accidents, for example. Avoidance would thus have a higher valuation (e.g., $5 million) than would avoidance of an ordinary fatality (e.g., $3 million).

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Table A-1. Representative Sample of Value of Life Studies

1. Labor Market Studies

Author and Year	Sample	Basis	Implicit Value of Life ($M)
R.S. Smith, 1974	Census of manufacturers, U.S. Census	Bureau of Labor Statistics	7.20
W. Kip Viscusi, 1978-79	Survey of working conditions, 1969-70	Bureau of Labor Statistics	4.10
Richard Arnould and Len Nichols, 1983	U.S. Census	Society of Actuaries	0.90
John Garen, 1988	Panel Study of Income Dynamics, 1981-82	Bureau of Labor Statistics	13.50
W. Kip Viscusi and Moore, 1989	Panel Study of Income Dynamics, 1982	NIOSH National Traumatic Occupational Fatality Survey	7.80
Henry Herzog and Alan Schlottman, 1987	U.S. Census	Bureau of Labor Statistics	9.10
Douglas Gegax, Gerking, and Schulze, 1991	Authors' mail survey, 1984	Workers' assessed fatality risk at work	1.60

2. Studies Based on Tradeoffs Outside the Labor Market

Author and Year	Nature of Risk	Basis	Implicit Value of Life ($M)
Debapriya Ghosh, Dennis Lees, & William Seal, 1975	Highway speed-related accident risk, 1973	Value of driver time based on wage rates	0.07
Rachel Dardis, 1980	Fire fatality risks without smoke detectors, 1974-79	Purchase price of smoke detectors	0.60
Paul R. Portney, 1981	Mortality effects of air pollution, 1978	Property values in Allegheny County, PA	0.80
Pauline Ippolito & Richard Ippolito, 1984	Cigarette smoking, 1980	Estimated monetary equivalent of effect of risk information	0.70
Christopher Garbacz, 1989	Fire fatality risks without smoke detectors, 1968-85	Purchase price of smoke detector	2.00

3. Studies Based on Survey Evidence

Author and Year	Nature of Risk	Basis	Implicit Value of Life ($M)
Jones Lee, 1989	Motor vehicle accidents	Willingness to pay for risk reduction, U.K.1982	3.80
W. Kip Viscusi, Magat, & Huber, 1991	Automobile accident risks	Pair-wise auto risk-living cost tradeoffs, 1987	2.70

4. Averages

	Implicit Value of Life ($M)
1. Labor market studies	6.31
2. Studies based on tradeoffs outside the labor market	1.36
3. Studies based on survey evidence	3.25
Average from all studies	3.92

Source: Viscusi, 1993, as tabulated by SAIC, in 1990 dollars

A.2 Valuing Public Safety

Table A-2 summarizes the results of a well-known 1989 study on the monetary costs of injuries. Monetary costs include medical and rehabilitation costs and foregone earnings (including an imputed value for household labor) but do not include values for pain and suffering or other factors that people would be willing to pay to avoid. Related property damage and administrative costs were also excluded. These monetary costs should be considered as minimum values from which WTP-based estimates can be developed.

Table A-2. Monetary Cost of Injuries

Type of Injury	Monetary Cost (1985$)
Motor vehicle accident	$9,062
Falls	$3,033
Firearm injuries	$53,831
Poisonings	$5,015
Fire injuries and burns	$2,619
Drownings and near-drownings	$64,993
Other	$1,187
All fatalities (including injuries that lead to fatalities)	$317,189
Injuries requiring hospitalization	$34,116
Injuries not requiring hospitalization	$518

Source: Rice, 1989 as cited in Boardman, 1996, pp. 380-81.

The results in Table A-2 are expressed in 1985 dollars, as in the original. Adjusted for inflation, the results summarized in Table A-2 suggest that the monetary cost of fatalities is in the range of $500,000 and the monetary cost of injuries requiring hospitalization is in the range of $50,000. Of the types of injuries likely to result from bus accidents, fire injuries and burns are in the $4,000 range and motor vehicle accidents are in the $14,000 range.

Note that these are direct costs for treating and indemnifying the injured party. One study estimated pain and suffering at ten times the financial cost of an injury (Bordley, 1994). This valuation estimate appears reasonable since it equates the monetary cost of fatal injuries (estimated at $500,000) with the WTP for avoiding an uncommon fatality (estimated at $5 million). Extending this analogy suggests that the WTP would be in the $40,000 range to avoid fire and burn injuries and the $140,000 range to avoid motor vehicle accidents.

It is difficult to estimate the WTP to avoid the most severe injuries, e.g., paralysis. One study of motor vehicle accidents (using an all-encompassing valuation for direct and indirect costs, lost quality of life, legal and administrative costs, etc.) supported valuations for most severe accidents and fatalities consistent with the idea that WTP exceeds direct monetary costs by a factor of ten. Table A-3 shows the results from this study, with crash injuries ranked in decreasing order of severity. Adjusted for inflation from 1988$, the data show that fatalities have a valuation in the range of $3 million (1998$). This all-inclusive, WTP-like cost-estimate is consistent with the estimate for the $3 million value for avoiding common fatalities. For very severe injuries but excluding the most severe injury (placed in the spinal cord category on Table A-3), the all-inclusive costs are roughly in the range of $100,000 to $200,000 (1998$). Again, this is consistent with the factor of ten WTP valuation placed on the direct monetary costs of the more severe injuries.

For the most severe injuries (classified as spinal cord) a valuation in the range of $2 million (1998$) suggests such a large loss in the quality of life that the WTP approaches that for the WTP for avoiding a fatality. This is consistent with a ratio of WTP to direct monetary costs of perhaps 30 rather than ten. It reflects the disproportionate weight society places on avoiding the most severe, permanent, non-fatal injuries.

Table A-3. All-inclusive Costs of Motor Vehicle Crashes

Type of Injury (decreasing order of severity)	Cost (1988$)
Spinal cord	$1.5 million
Lower extremity	$142,000
Brain	$85,000
Upper extremity	$55,000
Trunk/abdomen	$42,000
Face, other head	$16,000
Minor external	$4,000
Non-fatal injuries, average	$40,000
Fatal injuries, average	$2.4 million

Source: Miller, 1993 cited in Boardman, 1996 pp. 382-383.

A.3 Valuing Worker Safety

The value of worker safety begins with the value of avoiding a lost-time workers' compensation claim. According to the National Council on Compensation Insurance, Inc. (NCCI), costs per workers' compensation claim increased rapidly to the period ending around 1990 but have since leveled off or declined. From 1980 to 1990 the average indemnity cost per lost time claim increased at an eight percent annual rate, reaching $9,500 in 1990. From 1990 to 1995, however, the growth rate was negative-one percent per year, producing an average indemnity cost of $9,200 per lost time claim. From 1980 to 1990, the average medical cost per lost time claim increased at a twelve percent annual rate, reaching $7,100 in 1990. From 1990 to 1995, the growth rate was four percent per year, producing an average medical cost of $8,700 per lost time claim. The total cost is almost $18,000 (NCCI, 1997). NCCI attributes this moderation in costs to systems reforms, medical fee schedules, lower overall medical inflation, enhanced safety measures, improved case management, and the use of managed care programs. Assuming the continuation of these trends, this report estimates workers' compensation costs to be stable in the $18,000 range (1998$) over the near-term.

Table A-4 shows the average total workers' compensation claim costs for 10 major injury categories for the period 1991-1993. Two important inferences can be drawn from the Table. First, the average costs for different injury categories are much more tightly grouped than the severity of the injury might suggest. Total costs (including indemnification) for extremely severe accidents, such as amputations, are much lower than most people would expect. This narrow grouping is one of the functions of the workers' compensation program. In return for prompt payment of medical costs and lost wages and a small payment for functional losses (e.g., amputations) the worker is excluded from most types of litigation. The second important inference from the Table is that the standard deviation in costs for most of the injury categories is several times the average cost for the category. This indicates a significant risk of a cost far above the average. The combination of high variability in costs and a very large gap between direct costs and WTP, especially for the more severe injuries, indicates substantial public value for avoiding lost time workers' compensation claims. Although not shown on the Table, back claims account for about one-third of workers' compensation claims and generate average costs of about $16,000. This cost is consistent with those of the other moderately severe and incapacitating injuries shown on Table A-4.

To determine the WTP, it is appropriate to refer to estimates of the tradeoff between wages and the risk of injury. Viscusi (1993) found that regardless of severity, most injury valuation estimates are in the $25,000 - $50,000 range. Excluding less severe injuries that do not result in lost workdays, the estimates cluster around $50,000. The combination of WTP in the range of $50,000 and direct costs of moderately severe to severe accidents of $15-20,000, suggests a WTP multiplier for pain and suffering, legal costs, reduced quality of life, etc. of about three.

The reason the WTP ratio for workers is less than the WTP ratio for the public relates to the assumption of risk and the compensation for risk. It is widely accepted that workers in hazardous occupations accept the risks of those occupations in return for greater compensation, e.g., wages or benefits. To the extent certain transit bus operations are deemed disproportionately hazardous, we would expect them to provide greater compensation to attract workers. It is not accepted that the public accepts significantly greater risks from these same activities. For example, workers and the public would accept that working on a transit bus fueled by natural gas carries some risk of death due to fire, explosion, or asphyxiation. Neither would accept that riding on the same bus ought to carry the same degree of risk. Thus, the public's valuation on avoiding industrial injuries or injuries deriving from the standard use of industrial products should be greater (in relation to treatment cost) than the workers' valuation. On the other hand, it is unlikely that transit bus workers perceive their profession disproportionately hazardous and would place a significant valuation on avoiding severe injuries. The Reference Case in the model estimates the valuation for minor and moderate injuries consistently with the valuations in the literature but increases the valuation for severe injuries to address this perception.

Table A-4. Average Workers' Compensation Claim Costs ($), 1991-1993

Injury	Average Cost	Standard Deviation
Amputation	19,726	64,511
Fracture/Crushing/Dislocation	15,979	52,285
Other Trauma	15,278	66,249
Occupational Diseases and Cumulative Injuries	14,173	37,676
Carpal Tunnel	14,039	20,537
Burn	11,875	54,743
Sprain/Strain	11,859	23,587
Contusion/Concussion	10,850	36,257
Laceration/Puncture	10,453	24,077
Infection/Inflammation	10,207	21,538

Source: NCCI, 1997, p. 51.

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APPENDIX B. SAIC Surveys of Gas Releases from CNG Bus Part Failures

In 1997, SAIC surveyed 13 CNG bus facilities throughout the U.S. Unlike a similar survey completed in 1994, the 1997 survey population only included the largest facilities. Facilities excluded from the 1997 survey were mostly those with fewer than 10 CNG buses at each site. SAIC estimates that the 1997 survey included owners of at least 70% of the CNG buses operating in the U.S. during the period. The total number of buses in the survey was 703.

The 1994 and 1997 surveys (covering 1989 through late-1994 and late-1994 through 1997, respectively) showed wide variations in the frequency of gas releases from facility to facility. In 1994, the exclusion of one facility (with eight buses) reduced the overall failure rate by about 40%. In 1997, the exclusion of one west coast facility (with 95 buses) also reduced the overall failure rate by about 40%. Regardless of whether the cause for this large variance in failure rates among facilities is due to reporting differences or actual differences, the inference is that risk estimation is highly uncertain without a better understanding of the variance among facilities. While 1997 failure rates are numerically lower than 1994 rates by a factor of about 2.5, data quality issues preclude confident statements as to whether or not failure rates have truly decreased.

B.1 Survey Methods

A survey/questionnaire was sent to 19 CNG bus facilities. The questionnaire requested information on the number and type of buses in operation during the survey period, along with information on part failures that resulted in the release of natural gas. Returned questionnaires were examined for internal consistency, and data were entered into a spreadsheet for analysis. Bus-years were calculated for each respondent by multiplying the number of operational buses at the facility by the number of years each bus was operational within the survey period. Failure rates were calculated by dividing the number of failure events by the total number of bus-years.

In 1994, greater weight was given to larger fleets under the theory that larger fleets were less likely to be in the experimental, training, or start-up stages. In 1997, small fleets were mostly not included (7% of the total buses surveyed, versus 25% in 1994), and the small fleets that were included had several more years of experience with CNG. Thus, in 1997, the use of weighted data was not necessary.

Because of the obvious differences in 1997 failure rates at the west coast facility versus the rest of the industry and because of uncertainty over the underlying reality implied by these differences, failure rates were calculated in three ways: 1) all respondents, 2) all respondents except the west coast facility, 3) only the west coast facility.

An important observation is that the west coast facility data were based upon daily maintenance logs. Many of the other facilities in the survey based their response on the recollections of supervisors at the end of the survey period. Survey data derived from daily logs is much more likely to accurately and inclusively represent gas release events than information based on long-term memories. Thus, outlier failure rates could have been high because their records were more complete or due to other, unknown factors.

B.2 Survey Results

The 703 buses in the survey were reported to have had 132 gas releases events and one fire due to part failures over the survey period. The fire resulted from the failure of an inadequately designed PRD on a bus in an indoor maintenance facility. Table B-1 provides basic information on the surveyed population, including the number of facilities, buses, bus-years, and minimum mileage of the survey population by fleet size categories. Not all respondents provided fleet mileage information, thus the mileage provided in Table B-1 does not include all buses in the survey population.

Table B-1. 1997 Survey Respondent Population Statistics

	Small Fleets (5 to 20 buses)	Large Fleets (20+ buses)	Total
# buses	48	655	703
# fleets	6	7	13
bus-years	80.53	567.22	647.75
minimum mileage	>3,500,000	>20,000,000	>23,500,000

Table B-2 shows failure rates for each of the listed parts. Rates are provided for the entire 1997 survey population; all facilities excluding the west coast facility; and the west coast facility alone. As in 1994, PRDs failed most often with a release of fuel. Cylinder O-ring pop-off valves, PRD O-rings, and non-specified O-ring failures were only reported by the west coast facility. Failure rates for quarter-turn valves and high-pressure regulators were also disproportionately higher at the west coast facility.

Table B-3 provides part failure rates, shown in Table B-2, by the approximate volume of gas released. In general, releases >10,000 scf were the entire on-board fuel capacity; releases of 4,000 to 9,999 scf were at least one full bank of cylinders; 1,000 to 3,999 scf were one full cylinder to one bank; and <1,000 scf was typically less than one full cylinder.

Table B-4 displays the number of release events that occurred while buses were inside, outside, parked, in maintenance, or in operation. This information was provided for 56 of the 132 reported events. Multiple locations were given for some events if the bus was moved. When multiple locations were listed, all listed locations were reported in Table B-4. In both 1994 and 1997, the most common location and activity when the failure and release occurred was outside and parked, followed by outside and refueling.[14]

Table B-5 shows the number of part failures for each of the listed causes. This information was reported for 27 of the 132 reported events. When more than one cause was listed for a failure, all causes are reported in Table B-5. In 1997, the most frequently listed cause was wear, followed by design defect and material defect, both of which were often listed as the cause for PRD failures. This is in contrast to 1994, when the most commonly listed cause was faulty installation, followed by design defect and impact.

Table B-2. Failure Rates of Surveyed Parts

Failed Part		All Events	Excluding the west coast facility (wcf)	Only the west coast facility (wcf)
Cylinder	A. Line between cylinders	0.0013	0.0015	0
	B. Cylinder burst	0.0013	0.0015	0
	B3. Other -- cylinder	0.0089	0.0046	0.0297
	B2. PRD	0.0358	0.0309	0.0593
	Q1. PRD o-ring	0.0128	0	0.0742
	Q2. O-ring pop off valve	0.0038	0	0.0223
	D. Quart. turn valve	0.0192	0.0062	0.0816
Main Supply	B1. Main Shut-off valve	0.0051	0.0046	0.0074
	C. Main supply line	0.0013	0.0015	0
Refueling	G. Filler manifold	0.0026	0.0031	0
	H. Fast fill receptacle	0.0153	0.0185	0
	R. Fueler door	0.0013	0	0.0074
Regulator	J. Low pressure regulator	0.0077	0.0077	0.0074
	K. High pressure regulator	0.023	0.0077	0.0964
Other	E. Solenoid shut-off valve	0.0077	0.0062	0.0148
	N. Dual fuel P-switch	0.0013	0.0015	0
	O. Mixer	0.0013	0.0015	0
	Q. O-ring	0.0166	0	0.0964
	Z. Not listed	0.0026	0	0.0148
Total		0.1687	0.0973	0.5118

[14] Failure during parking is common because buses are parked immediately after being fueled.

Table B-3. Gas Release Events per Bus-year for Failed Components

Failed Part / Range of Release Rates		> 10,000 scf			4,000 to 9,999 scf			1,000 to 3,999 scf			>1,000 scf		
		All	No wcf	only wcf	All	No wcf	only wcf	All	No wcf	only wcf	All	No Sacr.	only Sacr.
Cylinder Related	A. Line between cylinders	0	0	0	0	0	0	0	0	0	0.0013	0.0015	0
	B. Cylinder burst	0.0013	0.0015	0	0	0	0	0	0	0	0	0	0
	B3. Other -- cylinder	0	0	0	0	0	0	0.0077	0.0046	0.0223	0.0013	0	0.0074
	B2. PRD	0.0089	0.0108	0	0.0077	0.0077	0.0074	0.0141	0.0077	0.0445	0.0051	0.0046	0.0074
	Q1. PRD o-ring	0	0	0	0.0013	0	0.0074	0.0051	0	0.0297	0.0064	0	0.0371
	Q2. O-ring pop off valve	0	0	0	0	0	0	0.0026	0	0.0148	0.0013	0	0.0074
	D. Quart. turn valve	0	0	0	0.0026	0	0.0148	0.0051	0	0.0297	0.0115	0.0062	0.0371
Main Supply	B1. Main Shut-off valve	0	0	0	0	0	0	0.0051	0.0046	0.0074	0	0	0
	C. Main supply line	0	0	0	0	0	0	0	0	0	0.0013	0.0015	0
Refueling related	G. Filler manifold	0	0	0	0	0	0	0	0	0	0.0026	0.0031	0

		> 10,000 scf			4,000 to 9,999 scf			1,000 to 3,999 scf			>1,000 scf		
	H. Fast fill receptacle	0	0	0	0	0	0	0	0	0	0.0153	0.0185	0
	R. Fueler door	0	0	0	0	0	0	0.0013	0	0.0074	0	0	0
Regulator	J. Low pressure regulator	0	0	0	0	0	0	0.0013	0	0.0074	0.0064	0.0077	0
	K. High pressure regulator	0	0	0	0.0026	0	0.0148	0.0077	0	0.0445	0.0128	0.0077	0.0371
Other	E. Solenoid shut-off valve	0.0038	0.0046	0	0.0013	0.0015	0	0.0026	0	0.0148	0	0	0
	N. Dual fuel P-switch	0	0	0	0	0	0	0	0	0	0.0013	0.0015	0
	O. Mixer	0	0	0	0	0	0	0	0	0	0.0013	0.0015	0
	Q. O-ring	0.0013	0	0.0074	0.0026	0	0.0148	0.0102	0	0.0593	0.0026	0	0.0148
	Z. Not listed	0	0	0	0	0	0	0.0026	0	0.0148	0	0	0
	Total	0.0153	0.017	0.0074	0.0179	0.0093	0.0593	0.0652	0.017	0.2967	0.0703	0.054	0.1483

Table B-4. Number of Gas Release Events By Location and Activity

Failed Part		Indoor Maint.	Indoor Refuel	Indoor Parked	Operation	Outdoor Maint.	Outdoor Refuel	Outdoor Parked
Cylinder Related	A. Line between cylinders							1
	B. Cylinder burst						1	
	B3. Other -- cylinder	3				3		
	B2. PRD		2	1	1	1		8
	Q1. PRD o-ring							
	Q2. O-ring pop off valve							
	D. Quart. turn valve						4	
Main Supply	B1. Main Shut-off valve	1			1			3
	C. Main supply line							
Refueling	G. Filler manifold			2				
	H. Fast fill receptacle						8	4
	R. Fueler door							
Regulator	J. Low pressure regulator						1	4
	K. High pressure						1	4
Other	E. Solenoid shut-off							4
	N. Dual fuel P-switch							
	O. Mixer							
	Q. O-ring							
	Z. Not listed							
	Total	4	2	3	2	4	15	29

Table B-5. Number of Part Failures By Cause

Failed Part		Corrosion./ Chafing/ Pitting	Impact	Wear	Misuse	Faulty Install.	Design Defect	Material Defect	Ice in water vent	Refuel station malfunct.
Cylinder Related	A. Line between cylinders					1				
	B. Cylinder burst		1							
	B3. Other -- cylinder						3			
	B2. PRD			4	1		11	7	2	1
	Q1. PRD o-ring									
	Q2. O-ring pop off valve									
	D. Quart. turn valve						4			
Main Supply	B1. Main Shut-off valve			3				3		
	C. Main supply line					1				
Refueling related	G. Filler manifold					2				
	H. Fast fill receptacle			12						

	R. Fueler door									
Regulator	J. Low pressure regulator			4				1		
	K. High pressure regulator			4		1				
Other	E. Solenoid shut-off valve					4				
	N. Dual fuel P-switch							1		
	O. Mixer									
	Q. O-ring									
	Z. Not listed									
	Total	0	1	27	1	9	18	12	2	1

APPENDIX C. Statistical and Data Quality Issues

The model and this document rely on the best and most comprehensive data on releases of fuel from CNG and LNG buses and associated fires, injuries, property damage, clean-up costs, etc. The key alternative-fuel data comes from two comprehensive surveys of CNG facilities (1994 and 1997), visits to numerous facilities (e.g., Sacramento RT, Pierce Transit (Tacoma, Washington), LACMTA, Baltimore MTA, Houston Metro, and Phoenix Transit), and in-depth interviews and data acquisition programs with numerous additional transit agencies. Data on diesel bus buses was generated by AEGIR Systems as a member of the project team.

C.1 CNG and LNG

- In each of the two CNG bus surveys, a single agency accounted for a disproportionate share of the releases (one with eight buses in 1994 and a different agency (the "west coast facility") in 1997). Excluding each of these agencies from the survey sample reduced the release rate by 40 percent. For a variety of reasons, as described in this section, it is not possible to know precisely how much of this deviation is attributable to actual releases and how much is attributable to different types of record keeping and reporting.

- In the 1997 survey, the data from the west coast facility were supplied from daily maintenance logs while the data from most of the other agencies were supplied from the recollections of the maintenance managers and partial records. It is reasonable to expect that the data reporting of the latter group understated the actual incidence of releases and the complete costs of rectifying the problems.

- In both surveys, data on the costs associated with releases vary by several orders of magnitude for similar types of releases. It is all but certain that different transit agencies are reporting differently and may be keeping records differently with respect to indirect and consequential damages, e.g., cleaning-up a facility after a fire or after water sprinklers are used. The project team has compared certain survey data with costs known from other sources and found the survey costs to be significantly understated.

- In both surveys and in all discussions, it is clear that a majority of the releases are attributable to a small number of components and, more important, a small number of types or brands of these components. To the extent the survey respondents used these poorer performing components during the survey period and have since replaced them, the statistics presented in the model overstate the likelihood of a release.

- Excluding the problem components mentioned in the previous bullet and excluding the transit agencies reporting outlying release rates, the distribution of releases by component, stage of operation, transit agency, etc. is both random and sparse. There are very few concentrations of releases by any single factor, possibly excluding cold weather. Thus, there is little or no statistical basis to estimate the long-run or overall frequency of releases on as disaggregated a basis as presented in the model (e.g., by release point, stage of operation, and severity of release). Because this degree of disaggregation is of some interest to the industry, however, the project team used engineering judgment to conservatively estimate it.

- Release rates and repair and maintenance requirements and costs have varied dramatically from year to year. Usage of LNG release frequencies for the mid-1990s at an early implementation, for example, would result in loss estimates at least two orders of magnitude higher than those for that same agency only a few years later. Similar variations in year-to-year performance have been observed at other facilities for CNG. These variations within an agency over a period of years are at least as great as those across most agencies during a common time period. The user is encouraged to consider the reasonableness of the release frequencies as presented in the model in assessing the likelihood of losses in his or her facility.

- The limited statistical basis and highly variable data quality discussed above combines with the rapid state of change in the industry (e.g., replacement of poorer performing valves and fuel tanks or cylinders) to make an assessment of standardized mitigation measures difficult. The mitigation measures suggested in the model are based on expert judgment for a conceptual facility that is nominally but not fully in compliance with codes and standards. The project team has observed widespread non-compliance with codes and standards at numerous facilities and has used these observations to suggest mitigation measures that might not be appropriate if the facility were fully complying with the standards but are appropriate because many facilities are not fully complying.

- Costs for releases, fires, injuries, property damage, etc. will vary widely depending on many factors. There is no way to develop a single value that reflects the cost of high-pressure cylinder rupture on a bus when the bus could be in operation on a suburban highway, a crowed urban street, or a central bus terminal. The user is strongly encouraged to consider the reasonableness of the estimates for his or her operation.

C.2 Diesel

The data used for diesel fuel-related losses in the Reference Case (per bus-year) are based on a sample survey conducted by AEGIR Systems for this project. The $48 figure is a weighted average loss incurred by five west-coast transit agencies over the past seven years. It represents more than 16,000 bus years of service and includes clean-up costs associated with major spills, but does not include costs associated with environmental compliance of fuel tanks or other storage tank expenses.

The diesel fuel loss data obtained from the five respondents have a very large variance between and across agencies, bus-years, and years. This may imply that some agencies reported only major losses (reportable losses) and perhaps omitted lesser losses, such as injuries from a minor spill (injuries from slipping on spilled fuel, fuel-induced eye injuries, etc.), and that others were more thorough and included these lesser losses. However, it may also imply that diesel-related losses are highly site-specific. Therefore, the project team, with the concurrence from the TRB Advisory Panel (C-11), decided not to pursue more accurate diesel-related data and strongly encourages the use of site-specific loss data. It may also be appropriate to review the structure of the CNG and LNG data prior to the development of site-specific diesel data.

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APPENDIX D. Recent Cylinder and Bus Incidents

This appendix provides details on cylinder ruptures in North America in the 1990s (Section D.1) and recent notable releases and fires on CNG buses (Section D.2). Table D-1 in Section D.2 provides details on recent CNG bus incidents. The well-known cylinder rupture at a southwest transit agency is described on that table rather than in Section D.1. The table is intended to be representative of the types of major incidents involving component failures, relatively large releases or fires, and non-compliant safety or operational practices. It is not intended as a comprehensive review of all CNG incidents.

D.1 North American Cylinder Ruptures in the 1990s

- Type I (steel) -- One cylinder ruptured while refueling by a slow-fill fueling appliance. Cause was over-pressure from a failed control system on the refueling appliance. No damage estimates are available.

- Type II (hoop-wrapped) -- Two cylinders burst as a result of a combination of possible damage and over-pressure.

- Type II (steel, hoop wrapped) -- One cylinder burst during cylinder system testing. Theorized cause is ignition of a combustible mixture of natural gas and air that remained in the cylinder from testing. There were three deaths and significant property damage. Exact cause is under investigation.

- Type III (fully wrapped, glass fiber) -- Four cylinders ruptured on trucks, resulting in several major and minor injuries. Also resulted in the recall of CNG truck lines, and the suspension of CNG vehicle manufacturing by two of the three U.S. auto manufacturers. Likely cause of rupture was stress corrosion cracking of fibers from acid exposure.

- Type III (glass wrapped) -- One cylinder ruptured due to unspecified damage to the fiber over-wrap.

D.2 Recent Notable CNG Bus Releases and Fires

Table D-1 summarizes recent notable CNG bus releases and fires. Most of the releases and fires described on the table have resulted in changes in product design, operational practices, safety regulations, or some similar factor.

Table D-1. Recent Notable CNG Bus Releases and Fires

~DATE	EVENT SUMMARY	INJURY	~ $s/ PROPERTY DAMAGE	OTHER COMMENTS
Jan '95	With bus in the maintenance facility, a PRD activated, releasing gas. The gas ignited when it contacted the propane-fired open-flame heater.	Minor, to a fire fighter	About $5k to facility and $80K in clean-up costs.	Result: open-flame heaters in CNG facilities were disallowed by NFPA-88B
Aug '96	Carbon-fiber cylinder burst during refueling. The force of the rupture caused the rupture of an adjacent cylinder and destroyed the transit bus. The rupture was caused by either road debris or post-manufacturing impact.	None	Destroyed bus $300K, approx. $300K to the agency.	The integrity of the cylinders was questioned, resulting in the replacements of hundreds, if not thousands, of cylinders made by the manufacturer.
Aug '99	Airport parking shuttle bus had a fire in engine compartment, which led to a CNG fire and other property damage.	None	Entire bus, plus partial damage to 19 vehicles	
Oct. '99	Filter housing element burst while refueling, resulted in dispenser damage. Automatic shut-off system cut the gas supply.	None	Dispenser, fueling operations	Unofficially attributed to over-tightening
Oct. '99	Fuel pipe leading to dispenser burst.	3, minor	Loss of fueling capacity. Total $ losses are not known.	
Nov. '99	During repair of above incident, wrong valve was installed and burst.	1 or 2	No fueling capacity.	
Dec. '99	Burst PRD filled the facility with gas. Emergency shut-off failed to engage and gas ignited. An open-flame heater may have facilitated ignition.	1 moderate	Not yet determined.	Removed half of the CNG fleet from service.
Jan '00	PRD failed, releasing natural gas from cylinders. No ignition.	None	<$250.00	
May '00	CNG tank on roof of the bus hit a bridge overpass, resulting in gas leak and fire.	5, minor	Not yet determined.	Significant damage to the fuel system and bus.

Source: SAIC

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