APPENDICES

These appendices include additional technical information related to the material discussed in Volume 1 and Volume 2 of the Protocol. It provides additional background to aid the user in expanding his or her knowledge of issues related to pipeline risk analysis beyond the Protocol, and has value when additional issues might need to be addressed in Stage 3 analyses. Of necessity, these additional materials are limited. The vast literature related to risk analysis, pipelines, and potential impacts does not allow inclusion of many other informative materials. Users of the Protocol are encouraged to seek additional resources according to their needs. The references already cited in the Protocol provide a gateway through their own reference citations to even more information related to the subject than could be covered here.

The Appendices are:

Appendix A

Technical Literature Excerpts Related to Fire and Explosion Effects

Fire and Explosion Notes from Work by Others

Lee's well known book, already cited in the reference list of both Volumes of the Protocol, discusses flammable vapor and gas fire and explosion effects. Some notes from that work are listed below:

Lee's Chapter 17, p. 157

Lee's cites a statistical study on 165 Gas Cloud ignitions. Conclusions from the study included:

- Of the 87 incidents where the ignition location was known, 60% of these Gas Clouds ignited within 100 m (380 ft) of the release source.
- In 150 of the 165 incidents, it was known whether an explosion or flash fire occurred, in nearly 60% of these cases, the ignition resulted in an explosion. Flash fires occurred in the other cases.
- Explosions occurred only in semi-confined situations and never in unconfined situations.
- A short delay time to ignition enhanced the probability of an explosion.
- For delay times greater than 30 minutes, only flash fires occurred.
- Outside the combustible cloud, no one was killed due to the primary blast effects.

Lee's Chapter 17, p. 175

"There is considerable evidence that Gas Clouds of methane at normal temperatures burn, but do not readily explode."

"There have been no cases of an unconfined Gas Cloud explosion with natural gas."

Lee's Chapter 17, p. 237

50% probability of eardrum rupture at peak overpressure of 6.3 psi
90% probability of eardrum rupture at peak overpressure of 12.2 psi

Lee's Chapter 17, p. 238

Probability of death from lung hemorrhage due to peak overpressure:
1 % probability of death at peak overpressure of 14.5 psi.
10 % probability of death at peak overpressure of 17.5 psi.
50 % probability of death at peak overpressure of 20.5 psi.
90 % probability of death at peak overpressure of 25.5 psi.
99 % probability of death at peak overpressure of 29 psi.

Lee's Chapter 9, p. 98

Effects of explosion overpressure:
5% fatalities at 5 psi
injury due to flying glass at 1 psi
injury but very unlikely to be serious at 0.7 psi.

The Center for Chemical Process Safety also addresses the issue in the book: CCPS, *Guidelines for Evaluating Process Plant Buildings for External Explosions and Fires*, 1996:

Overpressure and Consequences, p. 40, and 44-45.

Peak Side-On Overpressure, psi	Consequences to building	Consequences to Building Occupants
0.2	Threshold of glass breakage	No injury to occupants
> 0.5	Significant repairable cosmetic damage is possible	Possible occupant injury from glass breakage and falling overhead fixtures.
>1	Possible minor structural damage to buildings and severe damage to un-reinforced masonry load-bearing wall buildings	Personnel injury from debris is likely
>2	Local failure of isolated parts of buildings and collapse of un-reinforced masonry load-bearing wall buildings	Possible serious injury or fatality of some occupants
>3	Collapse of buildings	Probable serious injury or fatality of some occupants
>10	Probable total destruction of non-blast-resistant buildings	Probable 100% fatalities

Building Type	Peak Side-On Overpressure, psi	Consequences to buildings	Vulnerability of Occupants
Wood frame	1	Isolated buildings overturn. Roofs and walls collapse	0.1
	2	Bear total collapse	0.4
	5	Building completely destroyed	1.0
Steel frame/metal siding pre-engineered building	1.25	Metal siding anchorage failure	0.1
	1.5	Sheeting ripped off and internal walls damaged. Danger from falling objects.	0.2
	2.5	Building frame stands, but cladding and internal walls destroyed as frame distorts	0.6
	5	Building completely destroyed	1.0
Un-reinforced masonry bearing wall building	1.0	Partial collapse of walls that have no breakable windows	0.1
	1.25	Walls and roof partially collapse	0.2
	1.5	Complete collapse	0.6
	3	Building completely destroyed	1.0
Steel or concrete frame with un-reinforced masonry infill or cladding	1	Failure of incident face	0.1
	1.5	Walls blow in.	0.2
	2	Roof slab collapses	0.4
	2.5	Complete frame collapse	0.6
	5	Building completely destroyed	1.0
Reinforced concrete of masonry shear wall building	4	Roof and wall deflect under loading. Internal walls damaged.	0.1
	6	Building has major damage and collapses.	0.4
	12	Building completely destroyed	1.0

A consultant to various school districts provided CDE with an internal letter that noted the following:

In a flat, open area (without confinement or obstacles), normal hydrocarbon deflagrations (ignition and burning of a flammable vapor cloud) do not produce substantial overpressures.

For example, Hirst and Eyre[1] make the following comments about the overpressures generated following ignition of vapor clouds in an open area.

"On the evidence of the trials performed at Maplin Sands, the deflagration [explosion] of truly unconfined flat clouds of natural gas or propane does not constitute a blast hazard."

…only the portion of the flammable cloud that is contained within the confined or congested area can contribute to the explosion overpressures.

In order to generate significant overpressures, some type of confinement or congestion is required.

If, under specific circumstances, a flammable vapor cloud reaches a residential area, or a parking lot, or any other location that provides repeated obstacles, moderate overpressures could be produced if the vapor cloud is ignited. The peak overpressure in the immediate vicinity of the obstacles is expected to be about 1.09 psig, which can result in minor damage to buildings.

For a significant vapor cloud explosion to occur, a release from the pipeline must occur, AND the vapor cloud must disperse downwind and close to grade, AND the vapor cloud must reach a sufficiently confined or congested area, AND the vapor cloud must be ignited.

[1] Hirst, W. 1. S., and 1. A. Eyre (1982), "Maplin Sands Experiments 1980: Combustion of Large LNG and Refrigerated Liquid Propane Spills on the Sea." *Proceedings of the Second Symposium on Heavy Gases and Risk Assessment*, Frankfurt am Main, May 25-26, 1982: pp. 221-224.

Appendix B

Example Risk Estimate Calculation by A Detailed Incremental Method

Detailed Incremental Method

This appendix contains the details of an incremental IR calculation method discussed in Section 4. It shows a particular Excel spreadsheet layout that was used to carry out the example calculations with the resulting numbers. The Excel worksheets copies show the: 1) input values for each variable; 2) equations where these values were used to calculate the corresponding probability values; results of the incremental calculations for the for each hazard scenario:

- Vertical leak jet fire
- Vertical rupture jet fire
- Vertical leak flash fire
- Vertical rupture flash fire
- Vertical leak explosion
- Vertical rupture explosion
- Horizontal leak jet fire
- Horizontal rupture jet fire
- Horizontal leak flash fire
- Horizontal rupture flash fire
- Horizontal leak explosion
- Horizontal rupture explosion

The incremental method is based on dividing the pipeline segment of concern into computational increments. These calculations are based on a calculation increment length of 50 ft. The steps in the calculation process reflected in each table are:

1. Beginning with the center increment closest to the receptor location, determine the distance from the center of the increment to the receptor location.
2. Determine the potential impact severity of the specified hazard impact for that distance.
3. Determine the fatality probability (mortality % divided by 100) for the specified impact severity.
4. Calculate the IR by multiplying the conditional probability of that hazard scenario, P(i,j,X), for the 50-ft increment length by the fatality probability, PF(i,j,X) to yield the local individual risk associated with hazard X, IR(i,j,X).
5. Repeat the process for each increment moving away from the center until the increment is reached where the impact is zero. Because of symmetry on each side of the center increment, the IR value shown in the tables for increments other than the center is twice the value of the IR for an individual increment.
6. Add up the IR values for all the increments to yield the estimate IR for each hazard for the subject pipeline segment.
7. The Total IR (TIR) for the segment of concern is the sum of the twelve individual hazard IRs, in two sets of six; one for vertical gas releases and the other for horizontal gas releases.

The values shown hear are from an earlier Protocol draft that used different consequence models so the values are for illustrative purposes only.

Conditional Probability Factors Calculations - Vertical Releases								
Base		**Leak**		**Rupture**		**Both**		
F	1.2E-04	**PC(L)**	0.8	**PC(R)**	0.2	**PC(OCC)**	0.16	
P0	1.2E-04	**PC(LIG)**	0.3	**PC(RIG)**	0.45	**PC(OUT)**	0.25	
PAF	**0.9**	**PC(FIG)**	0.99	**PC(FIG)**	0.99			
PA	1.1E-04	**PC(JF)**	0.98	**PC(JF)**	0.98			
L(j), ft	50	**PC(FF)**	0.01	**PC(FF)**	0.01			
P(j)	**1.0E-06**	**PC(EIG)**	0.01	**PC(EIG)**	0.01			

PC(LJF)	**=**	**P(j) x**	**PC(L) x**	**PC(LIG) x**	**PC(FIG) x**	**PC(JF) x**	**PC(OCC) x**	**PC(OUT)**	**= PC(j,X)**
		1.0E-06	0.8	0.3	0.99	0.98	0.16	0.25	9.5E-09
PC(RJF)	**=**	**P(j) x**	**PC(R) x**	**PC(RIG) x**	**PC(FIG) x**	**PC(JF) x**	**PC(OCC) x**	**PC(OUT)**	
		1.0E-06	0.2	0.45	0.99	0.98	0.16	0.25	3.6E-09
PC(LFF)	**=**	**P(j) x**	**PC(L) x**	**PC(LIG) x**	**PC(FIG) x**	**PC(FF) x**	**PC(OCC) x**	**PC(OUT)**	
		1.0E-06	0.8	0.3	0.99	0.01	0.16	0.25	9.7E-11
PC(RFF)	**=**	**P(j) x**	**PC(R) x**	**PC(RIG) x**	**PC(FIG) x**	**PC(FF) x**	**PC(OCC) x**	**PC(OUT)**	
		1.0E-06	0.2	0.45	0.99	0.01	0.16	0.25	3.6E-11
PC(LEX)	**=**	**P(j) x**	**PC(L) x**	**PC(LIG) x**	**PC(EIG) x**		**PC(OCC) x**	**PC(OUT)**	
		1.0E-06	0.8	0.3	0.01		0.16	0.25	9.8E-11
PC(REX)	**=**	**P(j) x**	**PC(R) x**	**PC(RIG) x**	**PC(EIG) x**		**PC(OCC) x**	**PC(OUT)**	
		1.0E-06	0.2	0.45	0.01		0.16	0.25	3.7E-11

All Release Scenario Summary								
Vertical Releases			**Horizontal Releases**					
IR(LJF)	**=**	0.0E+00	**IR(LJF)**	**=**	0.0E+00			
IR(RJF)	**=**	**3.0E-08**	**IR(RJF)**	**=**	**4.5E-08**			
IR(LFF)	**=**	0.0E+00	**IR(LFF)**	**=**	0.0E+00			
IR(RFF)	**=**	**2.7E-09**	**IR(RFF)**	**=**	**3.0E-10**			
IR(LEX)	**=**	0.0E+00	**IR(LEX)**	**=**	0.0E+00			
IR(REX)	**=**	0.0E+00	**IR(REX)**	**=**	**3.7E-10**			
TIR (V)	**=**	**3.3E-08**	**TIR(H)**	**=**	**4.6E-08**			
						TIR	**=**	**7.8E-08**

Leak Jet Fire

Pipe Diameter (inches)	Pressure (psig)	Distance to Receptor Location (ft)	Distance along Line from Release Point (ft)	R(j,i) Impact Distance (ft)	I_{th} (j,i) Impact (Btu/hr-ft2)	Mortality %	P(i,j,X)	PF(i,j,X)	IR(i,j,X)
1	400	250	0	250	15	0	9.5E-09	0.0E+00	**0.0E+00**
		250	50	255	14	0	9.5E-09	0.0E+00	**0.0E+00**
							IR (LJF)	**=**	**0.0E+00**

Rupture Jet Fire

Pipe Diameter (inches)	Pressure (psig)	Distance to Receptor Location (ft)	Distance along Line from Release Point (ft)	R(j,i) Impact Distance (ft)	I_{th} (j,i) Impact (Btu/hr-ft2)	Mortality %	P(i,j,X)	PF(i,j,X)	IR(i,j,X)
30	400	250	0	250	13524	100	3.6E-09	1.0E+00	**3.6E-09**
		250	50	255	13004	100	3.6E-09	1.0E+00	**7.1E-09**
		250	100	269	11659	97	3.6E-09	9.7E-01	**6.9E-09**
		250	150	292	9944	77	3.6E-09	7.7E-01	**5.5E-09**
		250	200	320	8247	54	3.6E-09	5.4E-01	**3.8E-09**
		250	250	354	6762	31	3.6E-09	3.1E-01	**2.2E-09**
		250	300	391	5543	11	3.6E-09	1.1E-01	**7.7E-10**
		250	326	411	5008	1	3.6E-09	1.3E-02	**9.1E-11**
		250	376	452	4146	0	3.6E-09	0.0E+00	**0.0E+00**
							IR (RJF)	**=**	**3.0E-08**

Leak Flash Fire

Pipe Diameter (inches)	Pressure (psig)	Distance to Receptor Location (ft)	Distance along Line from Release Point (ft)	R(j,i) Impact Distance (ft)	LFL(j,i) Impact (ft)	Mortality %	P(i,j,X)	PF(i,j,X)	IR(i,j,X)
1	400	250	0	250	95	0	9.7E-11	0.0E+00	**0.0E+00**
		250	50	255	95	0	9.7E-11	0.0E+00	**0.0E+00**
							IR (LFF)	**=**	**0.0E+00**

Rupture Flash Fire

Pipe Diameter (inches)	Pressure (psig)	Distance to Receptor Location (ft)	Distance along Line from Release Point (ft)	R(j,i) Impact Distance (ft)	LFL(j,i) Impact (ft)	Mortality %	P(i,j,X)	PF(i,j,X)	IR(i,j,X)
30	400	250	0	250	1900	100	3.6E-11	1.0E+00	**3.6E-11**
		250	50	255	1900	100	3.6E-11	1.0E+00	**7.3E-11**
		250	100	269	1900	100	3.6E-11	1.0E+00	**7.3E-11**
		250	150	292	1900	100	3.6E-11	1.0E+00	**7.3E-11**
		250	200	320	1900	100	3.6E-11	1.0E+00	**7.3E-11**
		250	250	354	1900	100	3.6E-11	1.0E+00	**7.3E-11**
		250	300	391	1900	100	3.6E-11	1.0E+00	**7.3E-11**
		250	350	430	1900	100	3.6E-11	1.0E+00	**7.3E-11**
		250	400	472	1900	100	3.6E-11	1.0E+00	**7.3E-11**
		250	450	515	1900	100	3.6E-11	1.0E+00	**7.3E-11**
		250	500	559	1900	100	3.6E-11	1.0E+00	**7.3E-11**
		250	550	604	1900	100	3.6E-11	1.0E+00	**7.3E-11**
		250	600	650	1900	100	3.6E-11	1.0E+00	**7.3E-11**
		250	650	696	1900	100	3.6E-11	1.0E+00	**7.3E-11**
		250	700	743	1900	100	3.6E-11	1.0E+00	**7.3E-11**
		250	750	791	1900	100	3.6E-11	1.0E+00	**7.3E-11**
		250	800	838	1900	100	3.6E-11	1.0E+00	**7.3E-11**
		250	850	886	1900	100	3.6E-11	1.0E+00	**7.3E-11**
		250	900	934	1900	100	3.6E-11	1.0E+00	**7.3E-11**
		250	950	982	1900	100	3.6E-11	1.0E+00	**7.3E-11**
		250	1000	1031	1900	100	3.6E-11	1.0E+00	**7.3E-11**
		250	1050	1079	1900	100	3.6E-11	1.0E+00	**7.3E-11**
		250	1100	1128	1900	100	3.6E-11	1.0E+00	**7.3E-11**
		250	1150	1177	1900	100	3.6E-11	1.0E+00	**7.3E-11**
		250	1200	1226	1900	100	3.6E-11	1.0E+00	**7.3E-11**
		250	1250	1275	1900	100	3.6E-11	1.0E+00	**7.3E-11**
		250	1300	1324	1900	100	3.6E-11	1.0E+00	**7.3E-11**
		250	1350	1373	1900	100	3.6E-11	1.0E+00	**7.3E-11**
		250	1400	1422	1900	100	3.6E-11	1.0E+00	**7.3E-11**
		250	1450	1471	1900	100	3.6E-11	1.0E+00	**7.3E-11**
		250	1500	1521	1900	100	3.6E-11	1.0E+00	**7.3E-11**
		250	1550	1570	1900	100	3.6E-11	1.0E+00	**7.3E-11**
		250	1600	1619	1900	100	3.6E-11	1.0E+00	**7.3E-11**
		250	1650	1669	1900	100	3.6E-11	1.0E+00	**7.3E-11**
		250	1700	1718	1900	100	3.6E-11	1.0E+00	**7.3E-11**
		250	1750	1768	1900	100	3.6E-11	1.0E+00	**7.3E-11**
		250	1800	1817	1900	100	3.6E-11	1.0E+00	**7.3E-11**
		250	1850	1867	1900	100	3.6E-11	1.0E+00	**7.3E-11**
		250	1900	1916	1900	0	3.6E-11	0.0E+00	**0.0E+00**
							IR (RFF)	**=**	**2.7E-09**

Leak Explosion

Pipe Diameter (inches)	Pressure (psig)	Distance to Receptor Location (ft)	Distance along Line from Release Point (ft)	R(j,i) Impact Distance (ft)	OP(j,i) Impact (psi)	Mortality %	P(i,j,X)	PF(i,j,X)	IR(i,j,X)
30	400	250	0	250	0	0	9.8E-11	0.0E+00	**0.0E+00**
		250	50	255	0	0	9.8E-11	0.0E+00	**0.0E+00**
							IR (LEX)	**=**	**0.0E+00**

Rupture Explosion

Pipe Diameter (inches)	Pressure (psig)	Distance to Receptor Location (ft)	Distance along Line from Release Point (ft)	R(j,i) Impact Distance (ft)	OP(j,i) Impact (psi)	Mortality %	P(i,j,X)	PF(i,j,X)	IR(i,j,X)
30	400	250	0	250	0	0	3.7E-11	0.0E+00	**0.0E+00**
		250	50	255	0	0	3.7E-11	0.0E+00	**0.0E+00**
							IR (REX)	**=**	**0.0E+00**

Conditional Probability Factors Calculations - Horizontal Releases								
Base		**Leak**		**Rupture**		**Both**		
F	1.2E-04	**PC(L)**	0.8	**PC(R)**	0.2	**PC(OCC)**	0.16	
P0	1.2E-04	**PC(LIG)**	0.3	**PC(RIG)**	0.45	**PC(OUT)**	0.25	
PAF	**0.1**	**PC(FIG)**	0.99	**PC(FIG)**	0.99			
PA	1.2E-05	**PC(LF)**	0.98	**PC(JF)**	0.98			
L(j), ft	50	**PC(FF)**	0.01	**PC(FF)**	0.01			
P(j)	**1.1E-07**	**PC(EIG)**	0.01	**PC(EIG)**	0.01			

PC(LJF)	**=**	**P(j) x**	**PC(L) x**	**PC(LIG) x**	**PC(FIG) x**	**PC(JF) x**	**PC(OCC) x**	**PC(OUT)**	**= PC(j,X)**
		1.1E-07	0.8	0.3	0.99	0.98	0.16	0.25	1.1E-09
PC(RJF)	**=**	**P(j) x**	**PC(R) x**	**PC(RIG) x**	**PC(FIG) x**	**PC(JF) x**	**PC(OCC) x**	**PC(OUT)**	
		1.1E-07	0.2	0.45	0.99	0.98	0.16	0.25	4.0E-10
PC(LFF)	**=**	**P(j) x**	**PC(L) x**	**PC(LIG) x**	**PC(FIG) x**	**PC(FF) x**	**PC(OCC) x**	**PC(OUT)**	
		1.1E-07	0.8	0.3	0.99	0.01	0.16	0.25	1.1E-11
PC(RFF)	**=**	**P(j) x**	**PC(R) x**	**PC(RIG) x**	**PC(FIG) x**	**PC(FF) x**	**PC(OCC) x**	**PC(OUT)**	
		1.1E-07	0.2	0.45	0.99	0.01	0.16	0.25	4.1E-12
PC(LEX)	**=**	**P(j) x**	**PC(L) x**	**PC(LIG) x**	**PC(EIG) x**		**PC(OCC) x**	**PC(OUT)**	
		1.1E-07	0.8	0.3	0.01		0.16	0.25	1.1E-11
PC(REX)	**=**	**P(j) x**	**PC(R) x**	**PC(RIG) x**	**PC(EIG) x**		**PC(OCC) x**	**PC(OUT)**	
		1.1E-07	0.2	0.45	0.01		0.16	0.25	4.1E-12

IR(LJF)	**=**	0.0E+00
IR(RJF)	**=**	**4.5E-08**
IR(LFF)	**=**	0.0E+00
IR(RFF)	**=**	**3.0E-10**
IR(LEX)	**=**	0.0E+00
IR(REX)	**=**	**3.7E-10**
TIR (H)	**=**	**4.6E-08**

Leak Jet Fire

Pipe Diameter (inches)	Pressure (psig)	Distance to Receptor Location (ft)	Distance along Line from Release Point (ft)	R(j,i) Impact Distance (ft)	Flame Impact Distance (ft)	Mortality %	HP(i,j,X)	PF(i,j,X)	IR(i,j,X)
1	400	250	0	250	93	0	1.1E-09	0.0E+00	**0.0E+00**
		250	50	255	93	0	1.1E-09	0.0E+00	**0.0E+00**
							IR (LJF)	**=**	**0.0E+00**

Rupture Jet Fire

Pipe Diameter (inches)	Pressure (psig)	Distance to Receptor Location (ft)	Distance along Line from Release Point (ft)	R(j,i) Impact Distance (ft)	Flame Impact Distance (ft)	Mortality %	P(i,j,X)	PF(i,j,X)	IR(i,j,X)
30	400	250	0	250	2770	100	4.0E-10	1.0E+00	**4.0E-10**
		250	50	255	2770	100	4.0E-10	1.0E+00	**7.9E-10**
		250	100	269	2770	100	4.0E-10	1.0E+00	**7.9E-10**
		250	150	292	2770	100	4.0E-10	1.0E+00	**7.9E-10**
		250	200	320	2770	100	4.0E-10	1.0E+00	**7.9E-10**
		250	250	354	2770	100	4.0E-10	1.0E+00	**7.9E-10**
		250	300	391	2770	100	4.0E-10	1.0E+00	**7.9E-10**
		250	326	411	2770	100	4.0E-10	1.0E+00	**7.9E-10**
		250	376	452	2770	100	4.0E-10	1.0E+00	**7.9E-10**
		250	426	494	2770	100	4.0E-10	1.0E+00	**7.9E-10**
		250	476	538	2770	100	4.0E-10	1.0E+00	**7.9E-10**
		250	526	582	2770	100	4.0E-10	1.0E+00	**7.9E-10**
		250	576	628	2770	100	4.0E-10	1.0E+00	**7.9E-10**
		250	626	674	2770	100	4.0E-10	1.0E+00	**7.9E-10**
		250	676	721	2770	100	4.0E-10	1.0E+00	**7.9E-10**
		250	726	768	2770	100	4.0E-10	1.0E+00	**7.9E-10**
		250	776	815	2770	100	4.0E-10	1.0E+00	**7.9E-10**
		250	826	863	2770	100	4.0E-10	1.0E+00	**7.9E-10**
		250	876	911	2770	100	4.0E-10	1.0E+00	**7.9E-10**
		250	926	959	2770	100	4.0E-10	1.0E+00	**7.9E-10**
		250	976	1008	2770	100	4.0E-10	1.0E+00	**7.9E-10**
		250	1026	1056	2770	100	4.0E-10	1.0E+00	**7.9E-10**
		250	1076	1105	2770	100	4.0E-10	1.0E+00	**7.9E-10**
		250	1126	1153	2770	100	4.0E-10	1.0E+00	**7.9E-10**
		250	1176	1202	2770	100	4.0E-10	1.0E+00	**7.9E-10**
		250	1226	1251	2770	100	4.0E-10	1.0E+00	**7.9E-10**
		250	1276	1300	2770	100	4.0E-10	1.0E+00	**7.9E-10**
		250	1326	1349	2770	100	4.0E-10	1.0E+00	**7.9E-10**
		250	1376	1399	2770	100	4.0E-10	1.0E+00	**7.9E-10**
		250	1426	1448	2770	100	4.0E-10	1.0E+00	**7.9E-10**
		250	1476	1497	2770	100	4.0E-10	1.0E+00	**7.9E-10**
		250	1526	1546	2770	100	4.0E-10	1.0E+00	**7.9E-10**
		250	1576	1596	2770	100	4.0E-10	1.0E+00	**7.9E-10**
		250	1626	1645	2770	100	4.0E-10	1.0E+00	**7.9E-10**
		250	1676	1695	2770	100	4.0E-10	1.0E+00	**7.9E-10**
		250	1726	1744	2770	100	4.0E-10	1.0E+00	**7.9E-10**
		250	1776	1794	2770	100	4.0E-10	1.0E+00	**7.9E-10**
		250	1826	1843	2770	100	4.0E-10	1.0E+00	**7.9E-10**
		250	1876	1893	2770	100	4.0E-10	1.0E+00	**7.9E-10**
		250	1926	1942	2770	100	4.0E-10	1.0E+00	**7.9E-10**
		250	1976	1992	2770	100	4.0E-10	1.0E+00	**7.9E-10**
		250	2026	2041	2770	100	4.0E-10	1.0E+00	**7.9E-10**
		250	2076	2091	2770	100	4.0E-10	1.0E+00	**7.9E-10**
		250	2126	2141	2770	100	4.0E-10	1.0E+00	**7.9E-10**
		250	2176	2190	2770	100	4.0E-10	1.0E+00	**7.9E-10**
		250	2226	2240	2770	100	4.0E-10	1.0E+00	**7.9E-10**
		250	2276	2290	2770	100	4.0E-10	1.0E+00	**7.9E-10**
		250	2326	2339	2770	100	4.0E-10	1.0E+00	**7.9E-10**
		250	2376	2389	2770	100	4.0E-10	1.0E+00	**7.9E-10**
		250	2426	2439	2770	100	4.0E-10	1.0E+00	**7.9E-10**
		250	2476	2489	2770	100	4.0E-10	1.0E+00	**7.9E-10**
		250	2526	2538	2770	100	4.0E-10	1.0E+00	**7.9E-10**
		250	2576	2588	2770	100	4.0E-10	1.0E+00	**7.9E-10**
		250	2626	2638	2770	100	4.0E-10	1.0E+00	**7.9E-10**
		250	2676	2688	2770	100	4.0E-10	1.0E+00	**7.9E-10**
		250	2726	2737	2770	100	4.0E-10	1.0E+00	**7.9E-10**
		250	2776	2787	2770	100	4.0E-10	1.0E+00	**7.9E-10**
		250	2826	2837	2770	0	4.0E-10	0.0E+00	**0.0E+00**
							IR (RJF)	**=**	**4.5E-08**

Leak Flash Fire

Pipe Diameter (inches)	Pressure (psig)	Distance to Receptor Location (ft)	Distance along Line from Release Point (ft)	R(j,i) Impact Distance (ft)	LFL(j,i) Impact (ft)	Mortality %	P(i,j,X)	PF(i,j,X)	IR(i,j,X)
1	400	250	0	250	95	0	1.1E-11	0.0E+00	**0.0E+00**
		250	50	255	95	0	1.1E-11	0.0E+00	**0.0E+00**
							IR (LFF)	=	**0.0E+00**

Rupture Flash Fire

Pipe Diameter (inches)	Pressure (psig)	Distance to Receptor Location (ft)	Distance along Line from Release Point (ft)	R(j,i) Impact Distance (ft)	LFL(j,i) Impact (ft)	Mortality %	P(i,j,X)	PF(i,j,X)	IR(i,j,X)
30	400	250	0	250	1900	100	4.1E-12	1.0E+00	**4.1E-12**
		250	50	255	1900	100	4.1E-12	1.0E+00	**8.1E-12**
		250	100	269	1900	100	4.1E-12	1.0E+00	**8.1E-12**
		250	150	292	1900	100	4.1E-12	1.0E+00	**8.1E-12**
		250	200	320	1900	100	4.1E-12	1.0E+00	**8.1E-12**
		250	250	354	1900	100	4.1E-12	1.0E+00	**8.1E-12**
		250	300	391	1900	100	4.1E-12	1.0E+00	**8.1E-12**
		250	350	430	1900	100	4.1E-12	1.0E+00	**8.1E-12**
		250	400	472	1900	100	4.1E-12	1.0E+00	**8.1E-12**
		250	450	515	1900	100	4.1E-12	1.0E+00	**8.1E-12**
		250	500	559	1900	100	4.1E-12	1.0E+00	**8.1E-12**
		250	550	604	1900	100	4.1E-12	1.0E+00	**8.1E-12**
		250	600	650	1900	100	4.1E-12	1.0E+00	**8.1E-12**
		250	650	696	1900	100	4.1E-12	1.0E+00	**8.1E-12**
		250	700	743	1900	100	4.1E-12	1.0E+00	**8.1E-12**
		250	750	791	1900	100	4.1E-12	1.0E+00	**8.1E-12**
		250	800	838	1900	100	4.1E-12	1.0E+00	**8.1E-12**
		250	850	886	1900	100	4.1E-12	1.0E+00	**8.1E-12**
		250	900	934	1900	100	4.1E-12	1.0E+00	**8.1E-12**
		250	950	982	1900	100	4.1E-12	1.0E+00	**8.1E-12**
		250	1000	1031	1900	100	4.1E-12	1.0E+00	**8.1E-12**
		250	1050	1079	1900	100	4.1E-12	1.0E+00	**8.1E-12**
		250	1100	1128	1900	100	4.1E-12	1.0E+00	**8.1E-12**
		250	1150	1177	1900	100	4.1E-12	1.0E+00	**8.1E-12**
		250	1200	1226	1900	100	4.1E-12	1.0E+00	**8.1E-12**
		250	1250	1275	1900	100	4.1E-12	1.0E+00	**8.1E-12**
		250	1300	1324	1900	100	4.1E-12	1.0E+00	**8.1E-12**
		250	1350	1373	1900	100	4.1E-12	1.0E+00	**8.1E-12**
		250	1400	1422	1900	100	4.1E-12	1.0E+00	**8.1E-12**
		250	1450	1471	1900	100	4.1E-12	1.0E+00	**8.1E-12**
		250	1500	1521	1900	100	4.1E-12	1.0E+00	**8.1E-12**
		250	1550	1570	1900	100	4.1E-12	1.0E+00	**8.1E-12**
		250	1600	1619	1900	100	4.1E-12	1.0E+00	**8.1E-12**
		250	1650	1669	1900	100	4.1E-12	1.0E+00	**8.1E-12**
		250	1700	1718	1900	100	4.1E-12	1.0E+00	**8.1E-12**
		250	1750	1768	1900	100	4.1E-12	1.0E+00	**8.1E-12**
		250	1800	1817	1900	100	4.1E-12	1.0E+00	**8.1E-12**
		250	1850	1867	1900	100	4.1E-12	1.0E+00	**8.1E-12**
		250	1900	1916	1900	0	4.1E-12	0.0E+00	**0.0E+00**
							IR (RFF)	=	**3.0E-10**

Leak Explosion

Pipe Diameter (inches)	Pressure (psig)	Distance to Receptor Location (ft)	Distance along Line from Release Point (ft)	R(j,i) Impact Distance (ft)	OP(j,i) Impact (psi)	Mortality %	P(i,j,X)	PF(i,j,X)	IR(i,j,X)
30	400	250	0	250	0	0	1.1E-11	0.0E+00	**0.0E+00**
		250	50	255	0	0	1.1E-11	0.0E+00	**0.0E+00**
							IR (LEX)	**=**	**0.0E+00**

Rupture Explosion

Pipe Diameter (inches)	Pressure (psig)	Distance to Receptor Location (ft)	Distance along Line from Release Point (ft)	R(j,i) Impact Distance (ft)	OP(j,i) Impact (psi)	Mortality %	P(i,j,X)	PF(i,j,X)	IR(i,j,X)
30	400	250	0	250	13	100	4.1E-12	1.0E+00	**4.1E-12**
		250	50	255	13	100	4.1E-12	1.0E+00	**8.2E-12**
		250	100	269	13	100	4.1E-12	1.0E+00	**8.2E-12**
		250	150	292	13	100	4.1E-12	1.0E+00	**8.2E-12**
		250	200	320	13	100	4.1E-12	1.0E+00	**8.2E-12**
		250	250	354	13	100	4.1E-12	1.0E+00	**8.2E-12**
		250	300	391	13	100	4.1E-12	1.0E+00	**8.2E-12**
		250	350	430	13	100	4.1E-12	1.0E+00	**8.2E-12**
		250	400	472	13	100	4.1E-12	1.0E+00	**8.2E-12**
		250	450	515	13	100	4.1E-12	1.0E+00	**8.2E-12**
		250	500	559	13	100	4.1E-12	1.0E+00	**8.2E-12**
		250	550	604	13	100	4.1E-12	1.0E+00	**8.2E-12**
		250	600	650	13	100	4.1E-12	1.0E+00	**8.2E-12**
		250	650	696	13	100	4.1E-12	1.0E+00	**8.2E-12**
		250	700	743	13	100	4.1E-12	1.0E+00	**8.2E-12**
		250	750	791	13	100	4.1E-12	1.0E+00	**8.2E-12**
		250	800	838	13	100	4.1E-12	1.0E+00	**8.2E-12**
		250	850	886	13	100	4.1E-12	1.0E+00	**8.2E-12**
		250	900	934	13	100	4.1E-12	1.0E+00	**8.2E-12**
		250	950	982	13	100	4.1E-12	1.0E+00	**8.2E-12**
		250	1000	1031	13	100	4.1E-12	1.0E+00	**8.2E-12**
		250	1050	1079	13	100	4.1E-12	1.0E+00	**8.2E-12**
		250	1100	1128	13	100	4.1E-12	1.0E+00	**8.2E-12**
		250	1150	1177	13	100	4.1E-12	1.0E+00	**8.2E-12**
		250	1200	1226	13	100	4.1E-12	1.0E+00	**8.2E-12**
		250	1250	1275	13	100	4.1E-12	1.0E+00	**8.2E-12**
		250	1300	1324	13	100	4.1E-12	1.0E+00	**8.2E-12**
		250	1350	1373	13	100	4.1E-12	1.0E+00	**8.2E-12**
		250	1400	1422	13	100	4.1E-12	1.0E+00	**8.2E-12**
		250	1450	1471	13	100	4.1E-12	1.0E+00	**8.2E-12**
		250	1500	1521	13	100	4.1E-12	1.0E+00	**8.2E-12**
		250	1550	1570	13	100	4.1E-12	1.0E+00	**8.2E-12**
		250	1600	1619	13	100	4.1E-12	1.0E+00	**8.2E-12**
		250	1650	1669	13	100	4.1E-12	1.0E+00	**8.2E-12**
		250	1700	1718	13	100	4.1E-12	1.0E+00	**8.2E-12**
		250	1750	1768	13	100	4.1E-12	1.0E+00	**8.2E-12**
		250	1800	1817	6	51	4.1E-12	5.1E-01	**4.2E-12**
		250	1850	1867	6	51	4.1E-12	5.1E-01	**4.2E-12**
		250	1900	1916	6	51	4.1E-12	5.1E-01	**4.2E-12**
		250	1950	1966	6	51	4.1E-12	5.1E-01	**4.2E-12**
		250	2000	2016	6	51	4.1E-12	5.1E-01	**4.2E-12**
		250	2050	2065	6	51	4.1E-12	5.1E-01	**4.2E-12**
		250	2100	2115	6	51	4.1E-12	5.1E-01	**4.2E-12**
		250	2150	2164	6	51	4.1E-12	5.1E-01	**4.2E-12**
		250	2200	2214	6	51	4.1E-12	5.1E-01	**4.2E-12**
		250	2250	2264	6	51	4.1E-12	5.1E-01	**4.2E-12**
		250	2300	2314	6	51	4.1E-12	5.1E-01	**4.2E-12**
		250	2350	2363	6	51	4.1E-12	5.1E-01	**4.2E-12**
		250	2400	2413	6	51	4.1E-12	5.1E-01	**4.2E-12**
		250	2450	2463	6	51	4.1E-12	5.1E-01	**4.2E-12**
		250	2500	2512	6	51	4.1E-12	5.1E-01	**4.2E-12**
		250	2550	2562	6	51	4.1E-12	5.1E-01	**4.2E-12**
		250	2600	2612	6	51	4.1E-12	5.1E-01	**4.2E-12**
		250	2650	2662	6	51	4.1E-12	5.1E-01	**4.2E-12**
		250	2700	2712	6	51	4.1E-12	5.1E-01	**4.2E-12**
		250	2750	2761	1	0	4.1E-12	0.0E+00	**0.0E+00**
							IR (REX)	**=**	**3.7E-10**

Appendix C

Additional Notes on Natural Gas Releases

Additional commentary on the effects of gas pipeline releases is given in the GRI report cited in the main body of the Protocol (GRI 2000):

"For gas pipelines, the possibility of a significant flash fire resulting from delayed remote ignition is extremely low due to the buoyant nature of the vapor, which generally precludes the formation of a persistent flammable vapor cloud at ground level. The dominant hazard is, therefore, heat radiation from a sustained jet or trench fire, which may be preceded by a short-lived fireball.

In the event of line rupture, a mushroom-shaped gas cloud will form and then grow in size and rise due to discharge momentum and buoyancy. This cloud will, however, disperse rapidly and a quasi-steady gas jet or plume will establish itself. If ignition occurs before the initial cloud disperses, the flammable vapor will burn as a rising and expanding fireball before it decays into a sustained jet or trench fire. If ignition is slightly delayed, only a jet or trench fire will develop.

Note that the added effect on people and property of an initial transient fireball can be accounted for by overestimating the intensity of the sustained jet or trench fire that remains following the dissipation of the fireball.

A trench fire is essentially a jet fire in which the discharging gas jet impinges upon an opposing jet and/or the side of the crater formed in the ground. Impingement dissipates some of the momentum in the escaping gas and redirects the jet upward, thereby producing a fire with a horizontal profile that is generally wider, shorter and more vertical in orientation, than would be the case for a randomly directed and unobstructed jet. The total ground area affected can, therefore, be greater for a trench fire than an unobstructed jet fire because more of the heat radiating flame surface will typically be concentrated near the ground surface.

An estimate of the ground area affected by a credible worst-case failure event can, therefore, be obtained from a model that characterizes the heat intensity associated with rupture failure of the pipe, where the escaping gas is assumed to feed a sustained trench fire that ignites very soon after line failure. Because the size of the fire will depend on the rate at which fuel is fed to the fire, it follows that the fire intensity and the corresponding size of the affected area will depend on the effective rate of gas release. The release rate can be shown to depend on the pressure differential and the hole-size. For guillotine-type failures, where the effective hole-size is equal to the line diameter, the governing parameters are, therefore, the line diameter and the pressure at the time of failure."

Further commentary is provided in the preamble to the final rule on Gas Pipeline Integrity Management (49 CFR Part 192, Subpart O). (Department Of Transportation, Research and Special Programs Administration, 49 CFR Part 192, [Docket No. RSPA-00-7666; Amendment 192-95] RIN 2137-AD54, Pipeline Safety: Pipeline Integrity Management in High Consequence Areas (Gas Transmission Pipelines), ACTION: Final rule.)

The DOT response to questions on the GRI-CFER model (GRI 2000) for jet fire impacts from gas pipeline failures stated the following:

"The appropriateness of the C-FER model was the subject of considerable discussion at the public meetings held during the comment period on the proposed rule. As a result of these discussions and comments to the docket, RSPA/OPS has concluded that the C-FER model is sufficiently conservative for use in the screening process to identify HCAs. RSPA/OPS believes the model adequately reflects the distance, lateral to the pipeline, at which significant effects of accidents will occur. In the final rule, we have adopted the model as the basis for calculating Potential Impact Circles under the bifurcated option

for defining HCAs (discussed in prior section) with the addition of the one radius at either end (discussed below). Discussion at the public meetings and with the advisory committee, and analysis of recent pipeline accidents, also identified that pipeline accidents have sometimes affected an elliptical area, with the long axis of the ellipse along the pipeline. The NTSB noted that this likely results from horizontal jetting in the direction of the pipeline. The elliptical nature of the burn pattern means that the C-FER radius is not always conservative in identifying the maximum distance from a potential pipe rupture, measured along the pipeline, at which the effects from the rupture will be felt. Following careful analysis of the burn patterns near pipeline ruptures, RSPA/OPS determined that it is appropriate to add an additional length of pipeline equal to the C-FER radius on either side of a high consequence area, i.e., increase its extent along the pipeline, rather than increase the lateral distance. INGAA concurred with this approach. We have incorporated this approach into the final rule. Where Potential Impact Circle(s) are used to define HCAs, the pipeline segment in the high consequence area extends from the outermost edge of the first circlet the outermost edge of the last contiguous circle. This is illustrated in Appendix, Figure E.I.A to the final rule. Under the proposed rule, the segment would have been limited to the pipe between the centers of these circles.

This appears to recognize a potential horizontal component in the axial direction to the otherwise vertical release but does not deem consideration of a horizontal release lateral to the pipeline as a necessary consideration for the identification of HCAs. This is a policy decision for defining a standard method for identifying potential impact areas for HCAs in the context of the regulation but does not exclude the possibility that there would be situations where a pipeline could have a release with a significant lateral, horizontal component.

Appendix D

Uncertainty

Probability Estimation Uncertainty

The probability analysis relies on combining various individual probability values for various events to estimate the individual risk. The events include the probability of release, ignition, fire or explosion, fatality if exposed to the release, and occupancy or exposure. Thus, uncertainties in each of these root conditional probabilities will propagate through the calculation to the final Individual Risk value.

This guidance assumes that if a pipeline release occurs, it will be a full break 20% of the time and a 1-inch hole 80% of the time based on suggestions provided in FEMA, EPA, and DOT (FEMA, 1989). However, FEMA points out that very few studies have detailed hole-size data. They state a number of studies that indicate that ruptures occur 10 to 20% of the time. One study that FEMA references indicates 14% of releases are ruptures while another study reports 36% of releases are ruptures, but this latter study uses many definitions of rupture. Thus, using the lower and upper bounds of full-rupture probability data could result in event probabilities of 0.5 to 1.8 times the FEMA recommended probability of 20%.

This Protocol assumes that 30% of pipeline releases ignite (the FEMA document states about one-third of natural gas pipelines ignite, with this estimate increasing to 45% for very large ruptures). In addition to size, the probability will vary with features of the location such as housing density. FEMA guidance also suggests that 30% of the releases that ignite result in explosions. However, experienced judgment suggests that this figure might be high and other sources suggest that the likelihood might be under 10% or even at 1% or less (Lees 1996). This also can vary.

Fatality probability data for heat radiation and explosion impacts are inherently uncertain due to the limited data available. Individual susceptibility varies. The vulnerability of people also varies with their exact location at the time of exposure. The heat radiation fatality impacts were based on data correlations from nuclear weapons testing, and are presented in CCPS (1994). CCPS provides no further information on the uncertainties inherent in these data.

The overpressure fatality or serious injury probabilities were based on studies of earthquake damage to buildings referenced in CCPS (1996), which CCPS related to comparable overpressure building damage and presented in a graph. CCPS notes that probabilities greater than 60% should be used with caution because of the lack of available data or direct impacts of overpressures. This limited data and the fact that the fatality data are derived results rather than direct studies of explosion overpressure are sources of uncertainty. In addition, the overpressure graph presented in CCPS does not distinguish between serious injuries and fatalities; thus, the fatality probability calculations presented in this Protocol conservatively treat the CCPS probability data as fatality data, which adds to the uncertainty.

Consequence Modeling Uncertainty

There is also uncertainty associated with consequence modeling for gas and vapor dispersion, fire heat effects, and explosion overpressures. The renewed emphasis on the better prevention of catastrophic chemical accidents beginning in the mid-1980s spurred additional development for the modeling of accidental chemical releases. Two key sources of information on modeling methods include the U.S. EPA and Center for Chemical Process Safety (CCPS). The U.S. EPA provides guidance for modeling accidental releases of toxic and flammable substances in their "Risk Management Program Guidance for Offsite Consequence Analysis," commonly referred to as "OCAG" (EPA, 1999).

The CCPS also provides information, equations and graphs for estimating impacts from fires and explosions (CCPS, 1994 and 1996). The classic work on Loss Prevention in the Process Industries is another source of useful information (Lees, 1996).

In conducting a risk analysis, results will vary within certain bounds according to the model and the assumptions used. There are a variety of consequence models available in both the literature as well as computer software media form, including publicly available and proprietary models. Depending on the model algorithms and assumptions used, the models can vary quite a bit, and as actual consequence, data are not readily available, particularly for explosion events. These models can also vary in complexity concerning both the input parameters needed as well as the estimation algorithms.

An EPA report compared several consequence models for dense gas releases (EPA, 1990). Table 3-1 shows a comparison of modeled results with actual measured data for liquefied natural gas (LNG) releases. The actual measured or observed data were based on experiments conducted involving spills of LNG onto water. Concentrations were measured at radii of 57, 140, 400, and 800 meters from the source.

Consequence modeling is also highly sensitive to the input parameters used and any assumptions made to establish these parameters. Often the input data are not available or assumptions must be made because a predicted event that has not occurred yet is being evaluated.

Table D-1. Model Comparison of Airborne Methane Concentrations for Liquefied Natural Gas Experiment[a]

Parameter	Measured	Modeled Predicted Results [a, b]					
		TRACE	AIRTOX	DEGADIS	SLAB	SAFEMODE	Modeled Average
Model Type	N/A	Proprietary	Proprietary	Public	Public	Proprietary	-
Concentration (ppm)	58,508	96,379	134,432	253,425	83,430	211,758	155,885
% Difference from Measured	N/A	64.7%	130%	333%	42.6%	262%	166%

[a] The measured and modeled results presented are based on 10 test cases with measured and predicted concentrations at 57, 140, 400, and 800 meters from the source. The table above presents the average maximum concentration for these 10 test cases (presented in Table 5-5 of the 1990 EPA report).

[b] The proprietary models CHARM® and FOCUS were also evaluated in the EPA study but are not included in the summary table above because results were not obtained for CHARM® at 57 and 140 meters and for FOCUS at 57 m because meaningful modeled results in the near field regime were not obtained. However, results were obtained for CHARM® at 400 and 800 m, and the percent difference from the measured concentration was 26.5 % (based on averaging results at 400 and 800 m). For the FOCUS model, the percent difference from the measured concentration was 1213 % (based on averaging results at 140, 400 and 800 m).

The source term that defines the physical characteristics of the release and the type of dispersion model used strongly influences dispersion modeling results, which in turn affects the fire and explosion impact estimates.

The Protocol is based on vertically oriented releases for natural gas and vapor evaporation from pools. Horizontal gas discharges are possible under some conditions, but are relegated to a Stage 3 analysis. The conditions under which such an analysis would be required would be if the pipeline axis pointed directly at the campus site property line.

This guidance assumes that the hole-size for releases are either 1-inch diameter leak or full diameter rupture based on data from FEMA, EPA, and DOT (FEMA, 1989), which indicates that a full diameter rupture occurs 20% of the time and a 1-inch hole occurs 80% of the time. The hole-size can have a profound effect on the modeled results, as the release rate is dependent on the hole-size. For instance, for the natural gas releases, the difference in the flash fire impact distance (LFL impact) for a full diameter rupture versus a 1-inch leak is roughly 3 to 37 times greater depending on the pipe diameter considered (4 to 36 inches in this Protocol). Hole-sizes smaller than a 1-inch hole would be expected to yield smaller flash fire distances. Similar differences are also observed in the jet fire impacts for the full bore and 1-inch diameter releases. Thus, uncertainty in the hole-size results in uncertainty of the modeled flash and jet fire impacts.

A recent comparison was made for natural gas fire heat radiation between a fire model and available data from accident reports (GRI, 2001). The American Society of Mechanical Engineers (ASME) recently adopted results in the GRI report (ASME, 2002). Another study by the New Jersey Institute of Technology (NJIT) also examined natural gas fires (Haklar, 1999).

Studies have also been done on the effects of simulated releases and ignition of natural gas at the Stanford Research Institute under private contract (Acton, 1999). However, these results are proprietary (SRI, 2002).

For this Protocol, jet fire radiation impacts for natural gas pipelines were estimated by modeling using ALOHA ® consequence software, as explained in the body of the Protocol. Sources of uncertainty arise when different models use different parameters for the amount of heat emitted from a fire. This is sometimes referred to as emissivity, fraction of combustion heat emitted, or radiation efficiency. This value was not located in the ALOHA user's manual.

It is reported for some other models. The calculated "radiation efficiency" is 0.2 in CHARM®, a commercial model. In the (GRI 2000) report two parameters are used, which when taken together, represent the radiation efficiency. The two are referred to as the combustion efficiency factor (0.35) and the emissivity factor (0.2). Thus, the GRI effective "radiation efficiency" is 0.07 (0.35 times 0.2). It has been determined that if CHARM® uses a radiation efficiency of 0.07 instead of 0.2, then it predicts approximately the same results as the GRI study. Thus, assumptions in a key model parameter result in different impacts for two different consequence models.

The time to flammable cloud explosion ignition is also another source of uncertainty. This guidance assumes that the cloud will ignite within up to 15 minutes or less based on data from Lees (1996). For natural gas, ignition is assumed to be 2 minutes, based on information in the GRI report (GRI 2000). The sooner ignition occurs the less the potential impacts for potential flash fire, explosion, and to a lesser extent pool fire scenarios. It would not have as bug an impact on jet fire scenarios. Actually ALOHA does not provide an ignition time option so that results in the Protocol could conservative, with larger estimated impact distances than would occur, in some cases.

Liquid pipeline modeling has potential uncertainties due to the varied nature of the pools formed as a result of the released liquid. Questions about the pool geometry prevail, as well as the pool depth, which has a direct impact on the area of the pool formed. Doubling the pool area causes the pool fire radiation impacts to double for circular pools. Increasing the length of a rectangular channel pool (keeping the width constant) increases the radiation impact by 1.1 to 2 times. Thus, the uncertainty of the pool area, which is related to the pool depth dictated by site topography, relates to uncertainty in the modeled impacts. In addition, uncertainties regarding migration of the pool will also lead to uncertainties in the location of impacts. The effects of topography were discussed previously.

Examples of Uncertainty Impacts on Risk Values

The greatest uncertainty with the greatest impact on the estimated risks, is the modeling of and probability of large flash fires and explosions. The values used for estimates in this Protocol were based on U.S. government agency suggested default values in a procedure manual specifically developed for estimating event frequencies from hazardous materials' releases (FEMA 1989). However, there is relatively little discussion in the general technical literature about natural gas explosions from high pressure gas pipeline releases. In some quarters, such explosions are discounted as a threat. The low probability combined with the properties of natural gas itself and the properties of high-pressure releases, experienced to date, suggest that such explosions are highly unlikely. The NJI T paper on natural gas fires, in the reference list of the Protocol, mentions the potential for such explosions, but an examination of the issue was outside the scope of the NJIT study.

In order to further evaluate the potential uncertainty in the probability of an explosion, consider another approach for estimating the probability based on historical experience. There are now and have been approximately 295,000 miles of high-pressure gas transmission pipeline in the U.S. for the past 34 years. A record of "reportable incidents" has been kept for this period by the OPS. During that time, to the authors' knowledge, there have not been any unconfined gas explosions, with significant overpressures, of the type examined in this Protocol. Therefore, an upper bound estimate of the probability of such event can be calculated by assuming one event during that period.

The result is,

Estimated upper bound probability of explosion = 1.0 / (295,000 x 34) = 1.0E-07 / mi-yr

If the FEMA-based conditional probability of 0.09 for an explosion from a gas release is applied to the average probability of reportable pipeline failures for California, the result is,

Estimated probability of explosion (FEMA based) = 1.2E-05 x 0.09 = 1.1E-06 / mi-yr

In order to match the result of the historical calculation, the effective default probability of 0.09 for an explosion would have to be reduced by about 91% to 0.008 to achieve a comparable result. This means that the chance of explosion, upon ignition of a gas release, would be 2.7% rather than FEMA value of 30%.

To further examine the impacts of specific uncertainties, consider the numerical example computation of IR. Table D-2 summarizes the impacts of several key variables on the final IR. Three key variables were selected to illustrate effects: the base failure frequency, F0, reflected in the base probability P1; jet fire fatality probability; and the rupture explosion probability. In each case, the impact was examined for changes in the designated variable only. All other variables remained unchanged.

Table D-2. Example Effects of Uncertainty of Risk Values

Variable	Change in Designated Variable	Change in Individual Risk Result
Base failure frequency, F0	from 4.6E-05 to 1.0E-05 (from 0.000046 to 0.000010)	from 1.6E-07 to 3.5 E-08 (from 0.00000016 to 0.000000035)
Rupture jet fire fatality probability	from 0.52 to 0.052	from 1.6E-07 to 5.7E-08 (from 0.00000016 to 0.000000057)
Explosion conditional probability	from 0.09 to 0.008	from 1.6E-07 to 1.2E-07 (from 0.00000016 to 0.00000012)

Appendix E

Some Comparisons of Other Pipeline Risk Analyses

A sampling of results from other risk analyses of pipelines is summarized in the following table. Some reflect studies done on the context of the CDE requirements for pipeline risk analyses as well as other studies done for other purposes, not related to the CDE analyses. They include some early work that predates the first draft CDE Protocol. References are not identified in full but are on files at the CDE Facilities Services Division for the studies done in the CDE context.

Pipeline	Distance to Campus Site or Receptor	Annual Pipeline Failure Probability	Specific Consequences Probability	Individual Risk (IR)
34-inch natural gas	Property line 216 ft Buildings 925 ft	1.6 E-04	Stated by analysts as "Lower than 1.6 E-04"	Stated by analysts as "Lower than 1.6 E-04"
36-inch natural gas	Property line 250 ft Buildings 270 ft	Low probability	Not addressed	Not addressed
30-inch natural gas, 562 psig	Property line 900 ft	1.8 E-05	Jet fire	3.16 E-06
36-inch natural gas (2 lines) Line 1 – 693 psig Line 2 – 693 psig	Property line 650 ft (averages farther – not parallel to property line)	8.72 E-04	Full rupture with fire	3.8 E-08
30-inch natural gas, 1000 psig	Property line 900 ft	1.21 E-03	Fire and explosion	4.0 E-08 to 3.3 E-07 (Ref. 2)
30-inch gasoline	200 ft	N.A.	Fire	3.0 E-07 (Ref.1)

(Ref. 1) A.D. Little, Inc., "An Approach to the Risk Assessment of Gasoline Pipelines," Proceedings for the 1996 Pipeline Reliability Conference, Houston, TX. Gulf Publishing Co. Houston, TX. 1996.

(Ref. 2) Cornwell, J.B., and Marx, J.D., Quest Consultants, Inc. 908 26th Avenue N.W., Norman Oklahoma 73069. "Application of Quantitative Risk Analysis to Code-Required Siting Studies Involving Hazardous Material Transportation Routes," 2003.

Appendix F

Some Example ALOHA® Software Data Screens

The following table is and example of a typical ALOHA text report for an ALOHA run. This example is for a gas jet fire. ALOHA also shows a graphic display of each run's impact contours. Data up to "Source Strength" apply to all sizes and pressures for gas lines for the Protocol Basis Scenarios. Individual pipeline data inputs are in the "Source Strength" input where the line diameter and pressure vary between runs. Impact distance results for a run are presented for specified levels of heat radiation and are under the "Threat Zone" heading. ALOHA uses metric units for heat radiation intensities. The values shown correspond to 12,000, 8,000, and 5,000 Btu/hr-ft^2 values from highest to lowest. Impact distances in yards were converted to feet for preparing the Protocol figures of Section 4. Also to simulate the double-ended (each side of a broken pipe) releases of a ruptured pipeline, an equivalent diameter was used for a stated pipeline diameter. It is the diameter that gives twice the flow rate of a single-end release. In the example table the 17-inch input equivalent diameter applies to a 12-inch pipe size. The ratio is about 1.4 times the actual diameter of the pipe.

Example Text Report for ALOHA Run for – Gas Jet Fire

SITE DATA:
Location: SACRAMENTO, CALIFORNIA
Building Air Exchanges Per Hour: 0.66 (unsheltered single storied)
Time: February 15, 2007 1652 hours PST (using computer's clock)

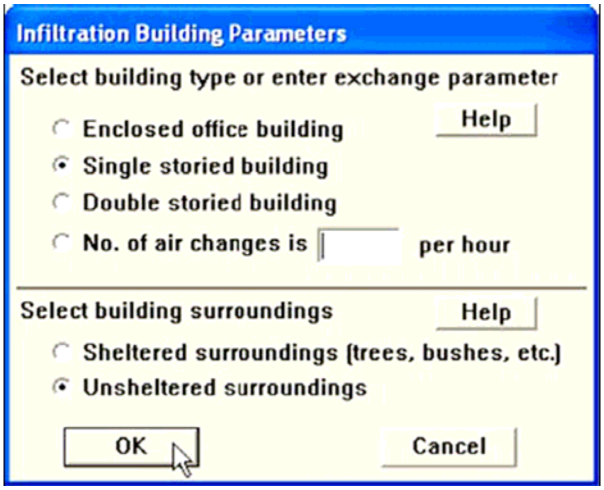
CHEMICAL DATA:
Chemical Name: METHANE Molecular Weight: 16.04 g/mol
TEEL-1: 15000 ppm TEEL-2: 25000 ppm TEEL-3: 50000 ppm
LEL: 44000 ppm UEL: 165000 ppm
Ambient Boiling Point: -258.7° F
Vapor Pressure at Ambient Temperature: greater than 1 atm
Ambient Saturation Concentration: 1,000,000 ppm or 100.0%

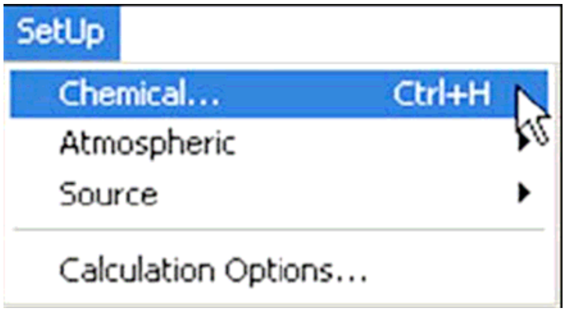
ATMOSPHERIC DATA: (MANUAL INPUT OF DATA)
Wind: 6.7 miles/hour from S at 3 meters
Ground Roughness: open country Cloud Cover: 5 tenths
Air Temperature: 77° F
Stability Class: D (user override)
No Inversion Height Relative Humidity: 50%

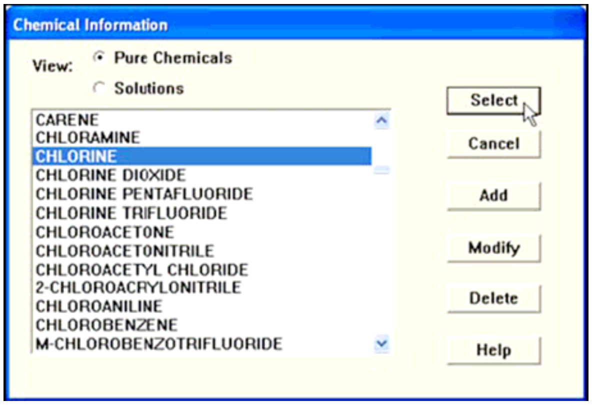
SOURCE STRENGTH:
Flammable gas is burning as it escapes from pipe
Pipe Diameter: 17 inches Pipe Length: 26400 feet
Unbroken end of the pipe is connected to an infinite source
Pipe Roughness: smooth Hole Area: 227 sq in
Pipe Press: 94.7 psia Pipe Temperature: 77° F
Max Flame Length: 39 yards
Burn Duration: ALOHA limited the duration to 1 hour
Max Burn Rate: 18,100 pounds/min
Total Amount Burned: 117,886 pounds (continued on next page)

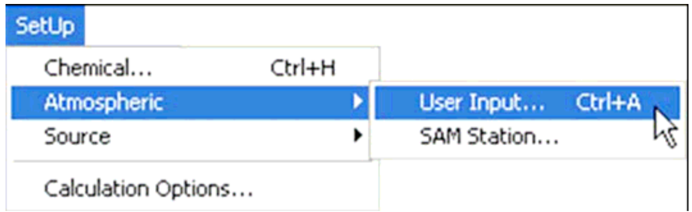
THREAT ZONE:
Threat Modeled: Thermal radiation from jet fire
Red : 11 yards --- (37.86 kW/(sq m))
Orange: 16 yards --- (25.24 kW/(sq m))
Yellow: 36 yards --- (15.77 kW/(sq m))

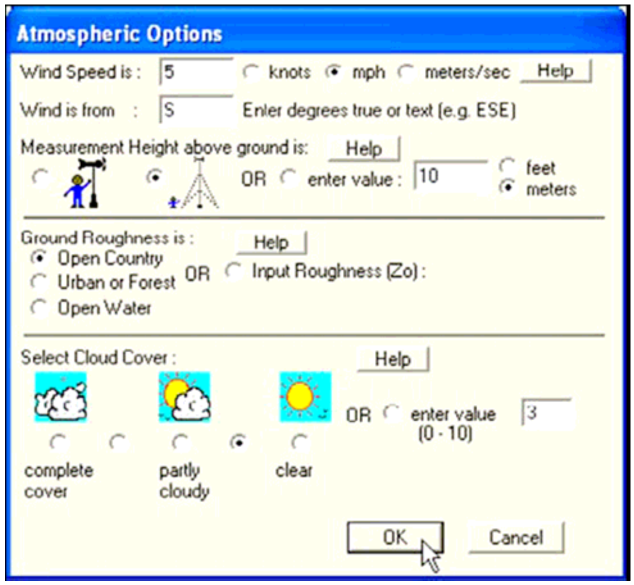
The following screens are included to show Protocol users a sampling of input and output data screens found in ALOHA. These appear in the ALOHA User's Manual/February 2006 of the U.S. Environmental Protection Agency, Office Of Emergency Management, Washington, D.C. and the National Oceanic And Atmospheric Administration, Office of Response and Restoration/ Hazardous Materials Response Division, Seattle, Washington.

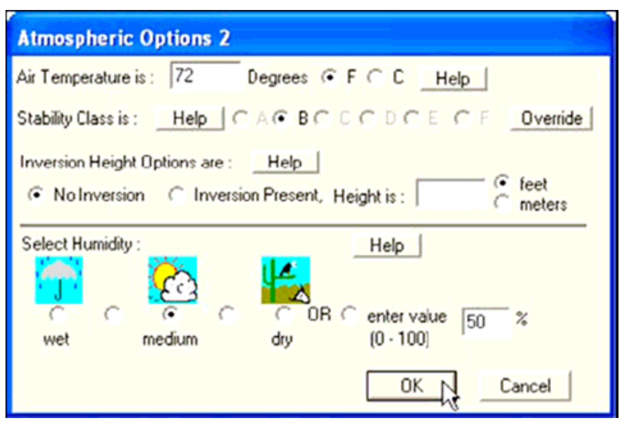


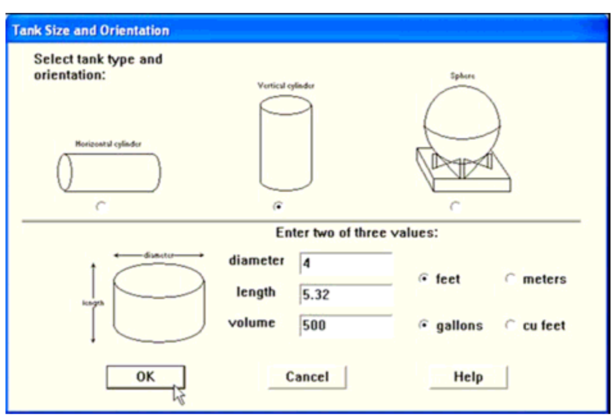


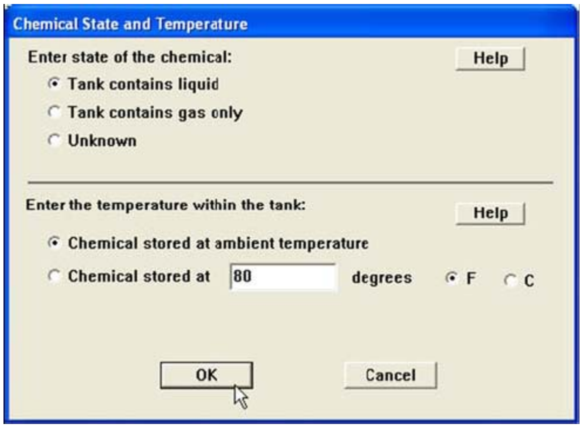


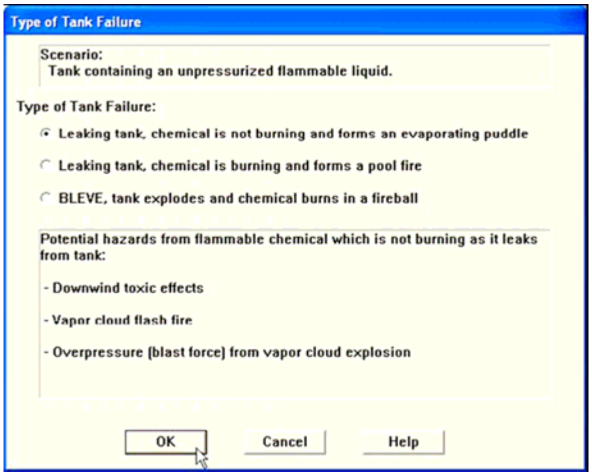

SetUp
Chemical... Ctrl+H
Atmospheric
Source
Calculation Options...
User Input... Ctrl+A
SAM Station...

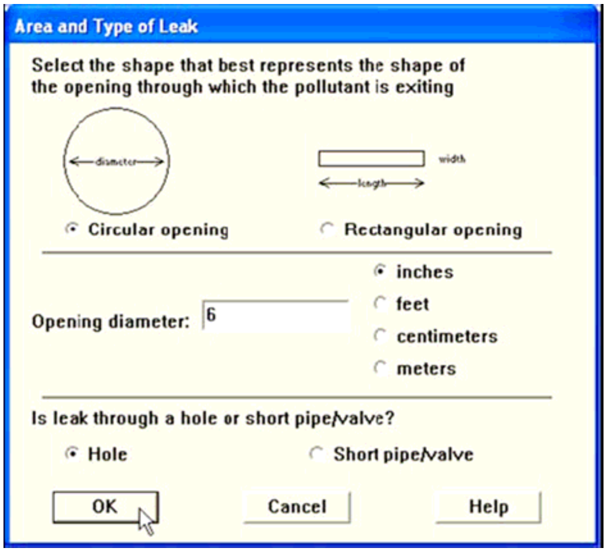

Atmospheric Options
Wind Speed is : 5 knots mph meters/sec Help
Wind is from : S Enter degrees true or text (e.g. ESE)
Measurement Height above ground is: Help
OR enter value : 10 feet meters
Ground Roughness is : Help
Open Country
Urban or Forest OR Input Roughness (Zo) :
Open Water
Select Cloud Cover : Help
OR enter value (0 - 10) 3
complete cover
partly cloudy
clear
OK
Cancel

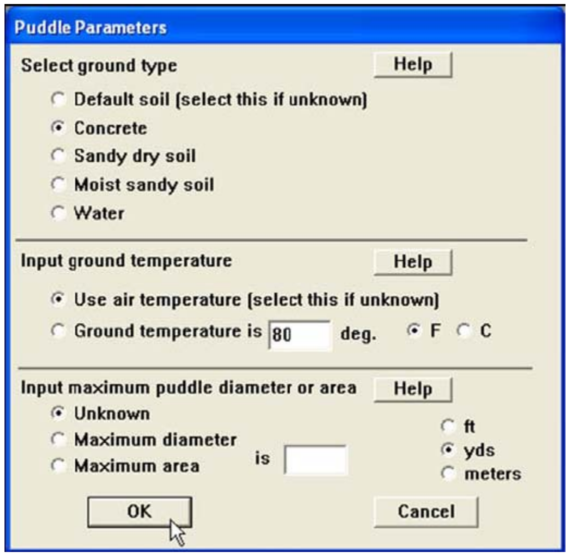

Atmospheric Options 2
Air Temperature is : 72 Degrees F C Help
Stability Class is : Help A B C D E F Override
Inversion Height Options are : Help
No Inversion Inversion Present, Height is : feet meters
Select Humidity : Help
OR enter value (0 - 100) 50 %
wet
medium
dry
OK
Cancel

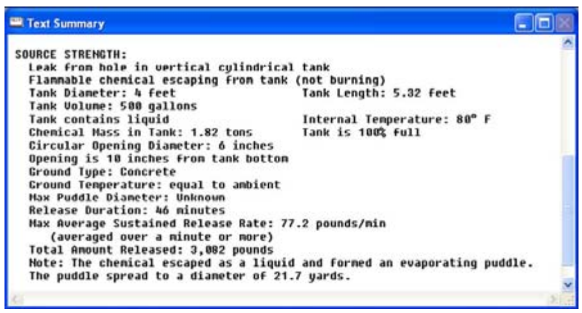

Tank Size and Orientation
Select tank type and orientation:
Enter two of three values:
diameter 4
length 5.32
volume 500
feet meters
gallons cu feet
OK
Cancel
Help

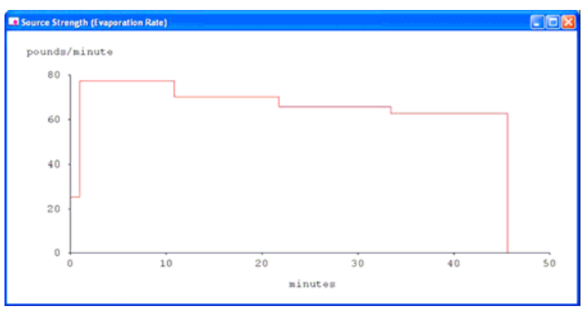

Chemical State and Temperature
Enter state of the chemical:
Help
Tank contains liquid
Tank contains gas only
Unknown
Enter the temperature within the tank:
Help
Chemical stored at ambient temperature
Chemical stored at
80
degrees
F
C
OK
Cancel

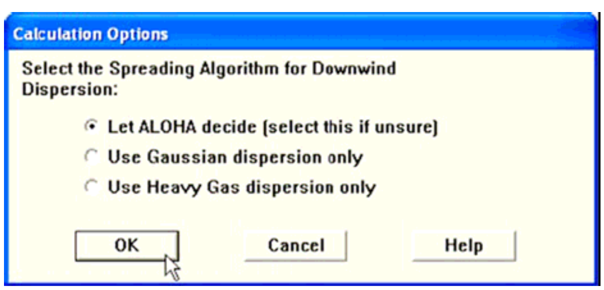

Type of Tank Failure
Scenario:
Tank containing an unpressurized flammable liquid.
Type of Tank Failure:
Leaking tank, chemical is not burning and forms an evaporating puddle
Leaking tank, chemical is burning and forms a pool fire
BLEVE, tank explodes and chemical burns in a fireball
Potential hazards from flammable chemical which is not burning as it leaks from tank:
- Downwind toxic effects
- Vapor cloud flash fire
- Overpressure (blast force) from vapor cloud explosion
OK
Cancel
Help

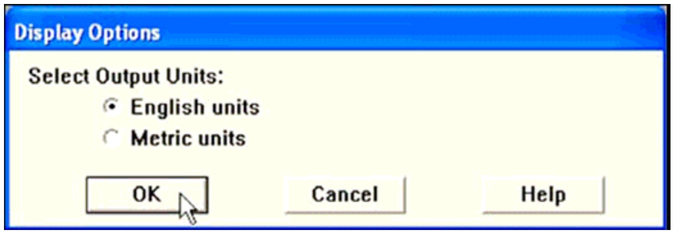

Area and Type of Leak
Select the shape that best represents the shape of the opening through which the pollutant is exiting
Circular opening
Rectangular opening
inches
feet
centimeters
meters
Opening diameter:
6
Is leak through a hole or short pipe/valve?
Hole
Short pipe/valve
OK
Cancel
Help

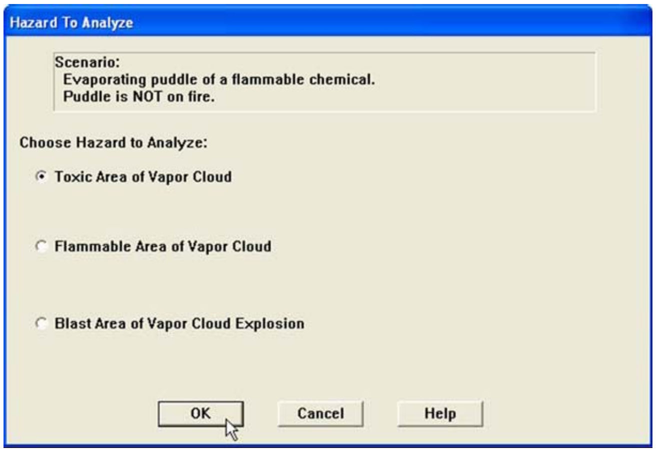

Puddle Parameters
Select ground type
Help
Default soil (select this if unknown)
Concrete
Sandy dry soil
Moist sandy soil
Water
Input ground temperature
Help
Use air temperature (select this if unknown)
Ground temperature is
80
deg.
F
C
Input maximum puddle diameter or area
Help
Unknown
Maximum diameter
Maximum area
is
ft
yds
meters
OK
Cancel

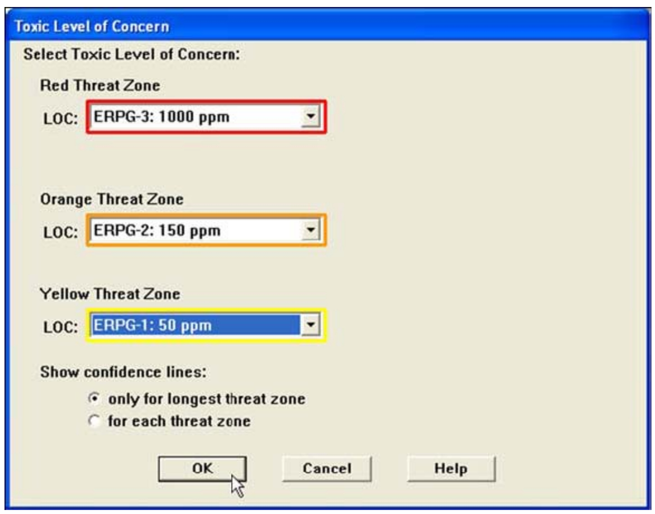

Text Summary
SOURCE STRENGTH:
Leak from hole in vertical cylindrical tank
Flammable chemical escaping from tank (not burning)
Tank Diameter: 4 feet
Tank Length: 5.32 feet
Tank Volume: 500 gallons
Tank contains liquid
Internal Temperature: 80° F
Chemical Mass in Tank: 1.82 tons
Tank is 100% full
Circular Opening Diameter: 6 inches
Opening is 10 inches from tank bottom
Ground Type: Concrete
Ground Temperature: equal to ambient
Max Puddle Diameter: Unknown
Release Duration: 46 minutes
Max Average Sustained Release Rate: 77.2 pounds/min
(averaged over a minute or more)
Total Amount Released: 3,082 pounds
Note: The chemical escaped as a liquid and formed an evaporating puddle.
The puddle spread to a diameter of 21.7 yards.

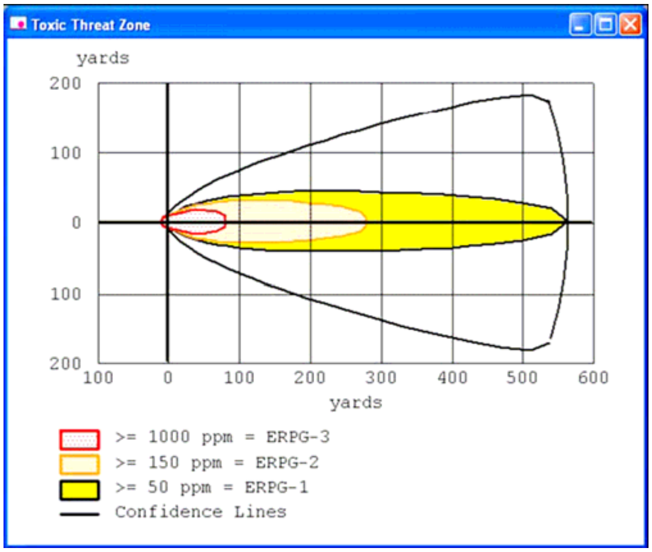

Source Strength (Evaporation Rate)
pounds/minute
80
60
40
20
0
0
10
20
30
40
50
minutes

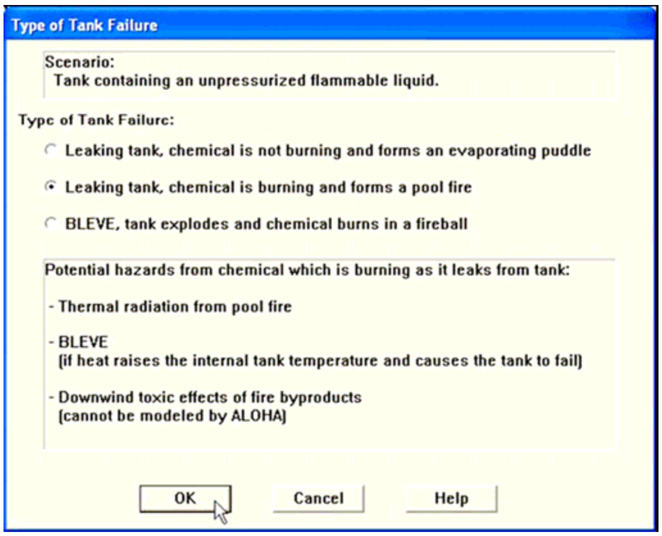

Calculation Options
Select the Spreading Algorithm for Downwind Dispersion:
Let ALOHA decide (select this if unsure)
Use Gaussian dispersion only
Use Heavy Gas dispersion only
OK
Cancel
Help

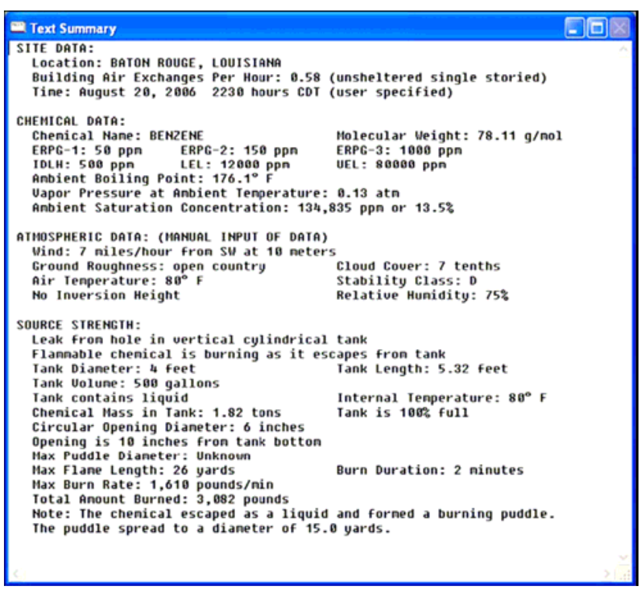

Display Options
Select Output Units:
English units
Metric units
OK
Cancel
Help


Hazard To Analyze
Scenario:
Evaporating puddle of a flammable chemical.
Puddle is NOT on fire.
Choose Hazard to Analyze:
Toxic Area of Vapor Cloud
Flammable Area of Vapor Cloud
Blast Area of Vapor Cloud Explosion
OK
Cancel
Help

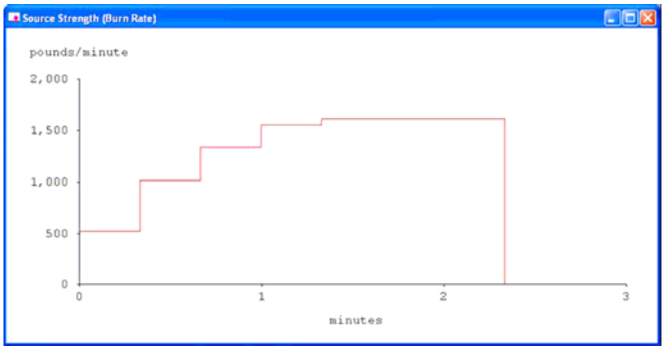

Toxic Level of Concern
Select Toxic Level of Concern:
Red Threat Zone
LOC: ERPG-3: 1000 ppm
Orange Threat Zone
LOC: ERPG-2: 150 ppm
Yellow Threat Zone
LOC: ERPG-1: 50 ppm
Show confidence lines:
only for longest threat zone
for each threat zone
OK
Cancel
Help

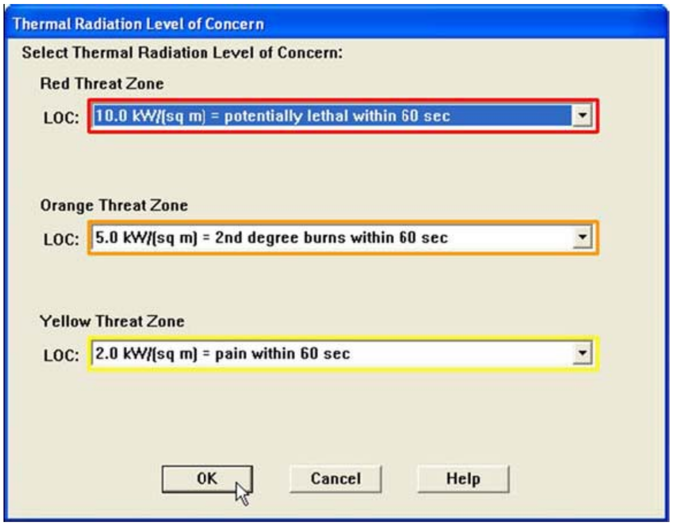


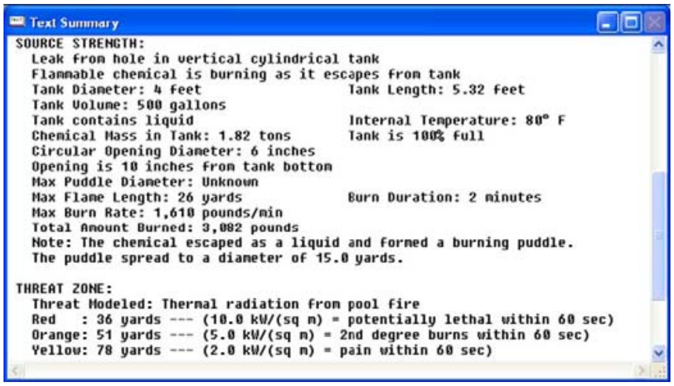



Text Summary

```
SITE DATA:
  Location: BATON ROUGE, LOUISIANA
  Building Air Exchanges Per Hour: 0.58 (unsheltered single storied)
  Time: August 20, 2006  2230 hours CDT (user specified)

CHEMICAL DATA:
  Chemical Name: BENZENE                    Molecular Weight: 78.11 g/mol
  ERPG-1: 50 ppm      ERPG-2: 150 ppm       ERPG-3: 1000 ppm
  IDLH: 500 ppm       LEL: 12000 ppm        UEL: 80000 ppm
  Ambient Boiling Point: 176.1° F
  Vapor Pressure at Ambient Temperature: 0.13 atm
  Ambient Saturation Concentration: 134,835 ppm or 13.5%

ATMOSPHERIC DATA: (MANUAL INPUT OF DATA)
  Wind: 7 miles/hour from SW at 10 meters
  Ground Roughness: open country            Cloud Cover: 7 tenths
  Air Temperature: 80° F                    Stability Class: D
  No Inversion Height                       Relative Humidity: 75%

SOURCE STRENGTH:
  Leak from hole in vertical cylindrical tank
  Flammable chemical is burning as it escapes from tank
  Tank Diameter: 4 feet                     Tank Length: 5.32 feet
  Tank Volume: 500 gallons
  Tank contains liquid                      Internal Temperature: 80° F
  Chemical Mass in Tank: 1.82 tons          Tank is 100% full
  Circular Opening Diameter: 6 inches
  Opening is 10 inches from tank bottom
  Max Puddle Diameter: Unknown
  Max Flame Length: 26 yards                Burn Duration: 2 minutes
  Max Burn Rate: 1,610 pounds/min
  Total Amount Burned: 3,082 pounds
  Note: The chemical escaped as a liquid and formed a burning puddle.
  The puddle spread to a diameter of 15.0 yards.
```








```
SOURCE STRENGTH:
  Leak from hole in vertical cylindrical tank
  Flammable chemical is burning as it escapes from tank
  Tank Diameter: 4 feet                Tank Length: 5.32 feet
  Tank Volume: 500 gallons
  Tank contains liquid                 Internal Temperature: 80° F
  Chemical Mass in Tank: 1.82 tons     Tank is 100% full
  Circular Opening Diameter: 6 inches
  Opening is 10 inches from tank bottom
  Max Puddle Diameter: Unknown
  Max Flame Length: 26 yards           Burn Duration: 2 minutes
  Max Burn Rate: 1,610 pounds/min
  Total Amount Burned: 3,082 pounds
  Note: The chemical escaped as a liquid and formed a burning puddle.
  The puddle spread to a diameter of 15.0 yards.

THREAT ZONE:
  Threat Modeled: Thermal radiation from pool fire
  Red   : 36 yards --- (10.0 kW/(sq m) = potentially lethal within 60 sec)
  Orange: 51 yards --- (5.0 kW/(sq m) = 2nd degree burns within 60 sec)
  Yellow: 78 yards --- (2.0 kW/(sq m) = pain within 60 sec)
```

Appendix G

Background Information on State of California Pipeline Regulatory Agencies

Hazardous Liquid Pipelines

California's Office of the State Fire Marshal (SFM) regulates the safety of approximately 5,500 miles of intrastate hazardous liquid transportation pipelines and acts as an agent of the federal Office of Pipeline Safety concerning the inspection of more than 2,000 miles of interstate pipelines. Pipeline Safety staff inspect, test, and investigate to ensure compliance with all federal and state pipeline safety laws and regulations. All spills, ruptures, fires, or similar incidents are responded to immediately and all such incidents are investigated for cause.

Hazardous liquid pipelines are also periodically tested for integrity using procedures approved by SFM. The program has been certified by the federal government since 1981. The SFM also maintains Geographic Information Systems (GIS)-based maps of all regulated pipelines and has been named as a state repository for pipeline data by the National Pipeline Mapping System (NPMS).

California Department of Forestry & Fire Protection
Office of State Fire Marshall
Pipeline Safety Division
Complete contacts at http://osfm.fire.ca.gov/pipestaff.html

Sacramento Office,
P.O. Box 944246
(916) 445-8477

Lakewood Office
3950 Paramount Blvd. #210
Lakewood, CA 90712
(562) 497-9100

Bakersfield Office
P.O. Box 20156
Bakersfield, CA 93390
(661) 587-1601

Northern California Office
P.O. Box 518
Middletown, CA 95461
(707) 987-2058

Inland Empire Office
P.O. Box County
Administrative Blvd.
82-675 Highway 111
Room 2190
Indio, CA 92201
(760) 342-1296

Natural Gas Pipelines

The California Public Utilities Commission (CPUC) regulates natural gas utility service for approximately 10.5 million customers that receive natural gas from Pacific Gas and Electric Company (PG&E), Southern California Gas (SoCalGas), San Diego Gas and Electric Company (SDG&E), Southwest Gas, and several smaller natural gas utilities. This includes in-state transportation over the utilities' transmission and distribution pipeline systems, storage, and procurement.

California Public Utilities Commission
Utilities Safety Branch
San Francisco Office (Headquarters)
505 Van Ness Avenue, Room 2201
San Francisco, CA 94102
(415) 703-1327

Complete Contacts are listed at http://www.cpuc.ca.gov/static/contactus/index.htm

Gas and Oil Exploration and Production

California Department of Conservation
Division of Oil, Gas and Geothermal Resources
Oil and Gas Section
Headquarters
801 K Street, MS 20-20
Sacramento, CA 95814-3530
Phone: (916) 445-9686

California's Division of Oil, Gas and Geothermal Resources oversees the drilling, operation, maintenance, and plugging and abandonment of oil, natural gas, and geothermal wells. The regulatory program emphasizes the wise development of oil, natural gas, and geothermal resources in the state through sound engineering practices that protect the environment, prevent pollution, and ensure public safety.

Complete contacts are listed at: http://www.consrv.ca.gov/DOG/contactUs.htm

Other

California Department of Fish and Game, Office of Spill Prevention and Response

1700 K Street
Sacramento, CA 95814
Phone: (916) 445-9338
Fax: (916) 324-8829

The mission of Office of Spill Prevention and Response (OSPR) is to provide best achievable protection of California=s natural resources by preventing, preparing for, and responding to spills of oil and other deleterious materials, and through restoring and enhancing affected resources.

Complete contacts are listed at: http://www.dfg.ca.gov/ospr/