GSX Pipeline Project
Joint Review Panel Hearing Order GH-4-2001

Undertaking for GSX Panel #7
As noted in paragraphs 20006 and 20136

Quantitative Risk Calculations for GSX Pipeline

This document presents preliminary estimates of risks to the public that might be created by the proposed operation of the GSX pipeline. The additional risk calculations build upon the worst case estimates provided in the NEB application and will be used for emergency response planning. This analysis is preliminary and requires verification and review before using in connection with emergency planning.

Normalized Frequency-based Probabilistic Risk Estimates

Risk is examined in two parts: probability of a pipeline failure and consequences of a failure. In order to produce failure probabilities for a specific pipeline that is not yet operational, a failure frequency estimate based on other pipeline experience is required. Four sets of calculations, each based on a different underlying failure frequency, have been performed to produce four risk estimates for the proposed GSX pipeline. The estimates rely upon frequencies of reportable incidents, fatalities, and injuries as recorded in the referenced databases. The incident rate is used to calculate the probability of failure and the fatality/injury rates are used to estimate consequences. The frequency estimates that underlie each of the four cases are generally described as follows:

Case 1
The subject pipeline is assumed to behave exactly like a hypothetical, statistically 'average' Williams-owned (WGP) gas transmission pipeline. For this case, WGP system leak experiences are used to predict future performance of the subject pipeline.

Case 2
The subject pipeline is assumed to behave exactly like a hypothetical, statistically 'average' Canadian gas transmission pipeline. In this case, the Transportation Safety Board historical leak frequency is used to predict future performance of the subject pipeline.

Case 3
The subject pipeline is assumed to behave exactly like a hypothetical, statistically 'average' U.S. gas transmission pipeline. In this case, the U.S. historical leak frequency is used to predict future performance of the subject pipeline.

Case 4
The subject pipeline is assumed to behave like some U.S. gas transmission pipelines; in particular, those with similar diameter, age, stress level, burial depth, and integrity verification protocols. In this case, the U.S. historical leak frequency is used as a starting point to predict future performance of the subject pipeline.

In all cases, failures are as defined by the respective regulations ('reportable accidents') using regulatory criteria for reportable incidents.

The calculation results for the four cases applied to the proposed 37.3 miles (60.0 km) of Canadian GSX Pipeline are shown in the following table:

Comparison Criteria	Failures per Year	Injuries per year	Fatalities per Year	Years to Fail	Years to Injury	Years to Fatality	Annual Probability of an Individual Fatality[5]
Case 1 WGP [1]	0.01055	0	0	100.4	never	never	0
Case 2 Canada [2]	0.01200	0	0	83.3	never	never	0
Case 3 U.S. [3]	0.01015	0.00167	0.00044	98.6	600.2	2,278.8	4.8E-06
Case 4 U.S. adj[4]	0.00507	0.00084	0.00022	197.2[6]	1,200.4	4,557.6	2.4E-06

Notes:
1. WGP, All Williams gas transmission systems 1986—2000
2. TSB, Canadian gas transmission pipelines 1994—1998; only one fatality (in 1985 third party excavation) reported for NEB jurisdictional pipelines since 1959; a significant change in definition of reportable incidents occurred in 1989.
3. OPS, US gas transmission pipelines 1986—2002
4. Adjusted by assuming failure rate of subject pipeline is ~50% of US gas transmission average, by rationale discussed
5. Assumes an individual is threatened by 2,000 ft of pipe (directly over pipeline, 1000 ft either side, 24-7 exposure). 2,000 ft is chosen as a conservative length based on hazard zone calculations.
6. This equates to 265 years to fail for the offshore portion only, as reported elsewhere.

Case 4 Discussion

Case 4 produces the best point estimate for risk for the GSX pipeline. Note that all estimates suggest that the GSX pipeline will experience no reportable failures during its design life. Probabilities of injuries and/or fatalities are extremely low in all cases.

The U.S. DOT database of pipeline failures provides the best set of pertinent data from which to infer a failure frequency. It is used to support calculations for Cases 3 and 4 above. Primarily basing failure calculations on U.S. statistics, rather than Canadian, is appropriate because:

- More complete data available (larger historical failure database and data is better characterized)
- Strong influence by a major U.S. operator on design, operations, and maintenance.
- Similar regulatory codes, pipeline environments, and failure experiences.
- Apparently similar failure experience between the countries.

Since the combined experience of all US pipelines cannot realistically represent this pipeline's future performance (it may 'encompass' this pipeline, but not represent it), a suitable comparison subset of the data is desired. Variables that tend to influence failure rates and hence are candidates for criteria by which to divide the data, include: time period, location, age, diameter, stress level, wall thickness, product type, depth of cover, etc. Unfortunately, no database can be found that is complete enough to allow such characterization of a subset. Therefore, it is reasonable to supplement the statistical data with adjustment factors to account for the more significant differences between the subject pipeline and the population of pipelines from which the statistics arise. Rationale supporting the adjustment factors is as follows:

- larger diameter is <10% of failures in the complete database (90+% benefit from higher diameter is implied by the database but only 25% reduction in failures is assumed)
- lower stress decreases failure rate by 10% (assumption based on the role of stress in many failure mechanisms)
- new coating decreases failure rate by 5% (assumption note the well-documented problem with PE tape coatings in Canada)
- New IMP procedures decreases failure rate 10% (assumption based on judgment of ability for IMP to interrupt incident event sequence)
- deeper cover (2ft of additional depth is estimated to be worth 30% reduction in third party damages according to one European study so a 10% reduction in overall failures is assumed)
- more challenging offshore environment leads to 10% increase in failures (somewhat arbitrary assumption, conservative since there are no known unresolved offshore design issues)

Combining these factors leads to the use of a ~50% reduction from the average U.S. gas transmission failure rate. This is conservative—accepting a bias on the side of over predicting the failure frequency. Additional conservatism comes from the omission of other factors that logically would suggest lower failure frequencies. Such factors include:

- initial failure frequency is derived from pipelines that are predominantly pre-1970 construction—there are more stringent practices in current pipe and coating manufacture and pipeline construction
- better one-call (more often mandated, better publicized, in more common use)
- better continuing public education
- designed and mostly operated to Class 3 requirements where Class 3 pipelines have lower failure rates compared to other classes from which baseline failure rates have been derived
- leaks versus ruptures (leaks less damaging, but counted if reporting criteria is triggered)
- company employee fatalities are included in frequency data, even though general public fatalities/injuries are being estimated
- knowledge that frequency data does not represent the event of "one or more fatalities", even though that is the event being estimated

Model-Based Failure Consequence Estimates

An analysis of consequence, beyond the use of the historical fatality/injury rate described above, has also been undertaken. The severity of consequences (solely from a public safety perspective) associated with a pipeline's failure depends on the extent of the product release; thermal effects from potential ignition of the released product; and the nature of any damage receptors within the affected area. The area affected is primarily a function of the pipeline's diameter, pressure, and weather conditions at the time of the event. Secondary considerations include characteristics of the area including topography, terrain, vegetation, and structures.

Failure Discussion

The potential consequences from a pipeline release will depend on the failure mode (e.g. leak vs. rupture), discharge configuration (e.g. vertical vs. inclined jet, obstructed vs. unobstructed), and the time to ignite (e.g. immediate vs. delayed). For natural gas pipelines, the possibility of a significant flash fire or vapor cloud explosion resulting from delayed remote ignition is extremely low due to the gas' buoyant nature which prevents the formation of a persistent flammable vapor cloud near common ignition sources.

Thermal radiation from a sustained jet fire, potentially preceded by a fireball, is the primary hazard to people and property in the immediate vicinity of a GSX Pipeline failure. In the event of a line rupture, a vapor cloud will form, grow in size as a function of release rate, and rise due to discharge momentum and buoyancy. This cloud will disperse rapidly and an ignited gas jet, or unignited plume, will be established. If ignition occurs before the initial cloud disperses, the gas may burn as a rising and expanding fireball.

A trench fire is a special type of jet fire. It can occur if a discharging gas jet impinges on the side of the rupture crater or some other obstacle. This impingement redirects the gas jet, reducing its momentum and length while increasing its width, and possibly producing a horizontal profile fire. The affected area of a trench fire can be greater than for an unobstructed jet fire because more of the heat-radiating flame surface may be concentrated near the ground surface[1].

Several credible high-pressure natural gas pipeline release models have been developed which characterize the heat intensity associated with worst-case ruptures. In these models, escaping gas is assumed to feed a fire that ignites shortly after pipe failure. Commonly used high-pressure natural release models yield conservative estimates of potentially affected areas. The affected ground area can be estimated by quantifying the radiant heat intensity associated with a sustained ignited trench fire[1].

GSX applied a "Model of Sizing High Consequence Areas (HCAs) Associated with Natural Gas Pipelines"[1], developed by C-FER Technologies in Canada, to determine the potential worst-case GSX Pipeline failure impacts on surrounding people and property. The Gas Research Institute (GRI) funded the development of this model for U.S. gas transmission lines in 2000, in association with the U.S. Office of Pipeline Safety (OPS), to help define and size HCAs as part of new integrity management regulations.

This model uses a conservative and simple equation that calculates the size of the affected worst-case failure release area based on the pipeline's diameter and operating pressure. This release impact model includes the following elements[1]:

1. Fire Model - The fire model relates rate of gas release to the heat intensity of the fire. This approach conservatively models releases as vertically-oriented jet flame or trench fire impact areas. The conservatism compensates for the possibility of a laterally-orientated jet, delayed ignition fireball, and/or the potential wind effect on actual fire position. Additional conservatism is employed since a significant portion of the radiant heat energy will actually be absorbed by the atmosphere.

2. Release Model - The release model assumes that the gas peak effective release rate feeds a steady-state trench fire even though the rate of gas released will immediately drop to a fraction of the initial peak rate. Therefore, the release model's calculated effective release rate is a maximum value which overestimates the actual rate for the full release duration of a typical gas pipeline rupture fire.

3. Heat Intensity Threshold - A heat intensity threshold establishes the sustained radiant heat intensity level above which the effects on people and property would be considered significant. The degree of harm to people caused by thermal radiation exposure is estimated by using an equation that relates the chance of burn injury or fatality to the thermal load received. The degree of damage to wooden structures through piloted ignition, and spontaneous ignition, is also estimated as a function of the thermal load received.

Combining the model's effective release rate equation with the radiant intensity versus distance equation gives a hazard area equation of [1]:

$$r = [(2348*p*d^{2})/I]^{1/2}$$

where r = radius from pipe release point for given radiant heat intensity (feet)
I = radiant heat intensity (BTU/hr/ft^{2})
p = maximum pipeline pressure (psi)
d = pipeline diameter (inches)

This release impact area equation is used to create five radiant heat intensity "hazard zones" representing various radii from the GSX Pipeline at the 15,305 kPa (2,220 psig) MAOP for the entire 16-inch onshore pipeline segment.

Failure Scenarios

There are an infinite number of possible failure scenarios encompassing all possible combinations of failure parameters. For evaluation purposes, nine different scenarios are examined involving permutations of three failure (hole) sizes and three possible pressures at the time of failure. These are used to represent the complete range of possibilities so that all probabilities sum to 100%. Probabilities of each hole size and pressure are assigned, as are probabilities for ignition in each case. For each of the nine cases, 4 possible damage ranges (resulting from thermal effects) are calculated.

Parameters used in the nine failure scenarios include:

Hole size	Probability of Occurrence	Comments
50% to Full Bore Rupture (8"-16")	20%	Possible result of third party damage or land movement
0.5" to 8"	40%	
< 0.5"	40%	Corrosion or material defect related

Pressure (psig)	Probability of Occurrence	Comments
1800-2220 (2220 psig is used)	20%	1800 psig is contract delivery pressure; current Centra connection pressures normally are ~800 psig. > 1800 psig would not be normal.
1500-1800 (1800 psig is used)	70%	
< 1500 (1500 psig is used)	10%	

For GSX Pipeline release modeling, a worst-case rupture is assumed to be guillotine-type failure, where the hole size is equal to the pipe diameter, at the pipeline's 15,305 kPa (2,220 psig) Maximum Allowable Operating Pressures (MAOP). This worst-case rupture is further assumed to include a double-ended gas release that is almost immediately ignited and becomes a trench fire.

It is important to note that the majority of the GSX Pipeline will normally operate well below its post-installation pressure tested MAOP in Canada. Anticipated normal operating pressures in Canada are in the range of 800 to 1100 psig, even though this range is given only a 40% probability and all other scenarios conservatively involve higher pressures. Therefore the worst case release modeling assumptions are very conservative and cover all operational scenarios up to the 15,305 kPa (2,220 psig) MAOP at any point along the pipeline.

Other parameters used in the failure scenarios cases are ignition probability and thermal radiation intensity.

Hole size	Ignition Probability, Given Failure has Occurred	Comments
50% to Full Bore Rupture (8” - 16”)	40%	Larger release rates, as driven by larger hole diameters, may find more ignition sources due to more violent nature of rupture and larger volumes of gas.
0.5” to 8”	20%	
< 0.5”	5%	

Ignition probability estimates usually fall in the range of 5% to 12% based on pipeline industry experience. 65% is conservatively used in this analysis.

The four potential damage ranges that are calculated for each of the nine failure scenarios are a function of thermal radiation intensity. The thresholds were chosen to represent specific potential damages that are of interest. They are generally described as follows:

Thermal Radiation Level (BTU/hr sq ft)	Description
12000	100% mortality in ~30 sec
5000	1% mortality in ~30 sec
4000	eventual wood ignition
1600	onset injury ~30 sec

These were chosen as being representative of the types of potential damages of interest. Reference 1 recommends the use of 5000 BTU/hr sq ft as a heat intensity threshold for defining a ‘high consequence area’. It is chosen because it corresponds to a level below which:

- “Property, as represented by a typical wooden structure would not be expected to burn
- People located indoors at the time of failure would likely be afforded indefinite protection and
- People located outdoors at the time of failure would be exposed to a finite but low chance of fatality”[1]

Note that these thermal radiation intensity levels only imply damage states. Actual damages are dependent upon the quantity and types of receptors that are potentially exposed to these levels. A preliminary assessment of structures has been performed, identifying the types of buildings and distances from the pipeline. This information is not yet included in these calculations but will be used in emergency planning.

Role of Leak Detection in Consequence Reduction

The nine failure scenarios analyzed represent the vast majority of all possible failure scenarios. Leak detection plays a relatively minor role in minimizing hazards to the public in most of these possible scenarios. Therefore, the analysis presented is not significantly impacted by any assumptions relative to leak detection capabilities. This is especially true since the damage states use an exposure time of ~30 seconds in the analysis.

Reference 1 (and others) illustrate that pipeline release hazards are dependent upon release rates which in turn are governed by pressure. In the case of larger releases, the pressure diminishes quickly—more quickly than would be affected by any actions that could be taken by a control center. In the case of smaller leaks, pressures decline more slowly but ignition probability is much lower and hazard areas are much smaller. In general, there are few opportunities to evacuate a pressurized gas pipeline more rapidly than occurs through the leak process itself, especially when the leak rate is significant.

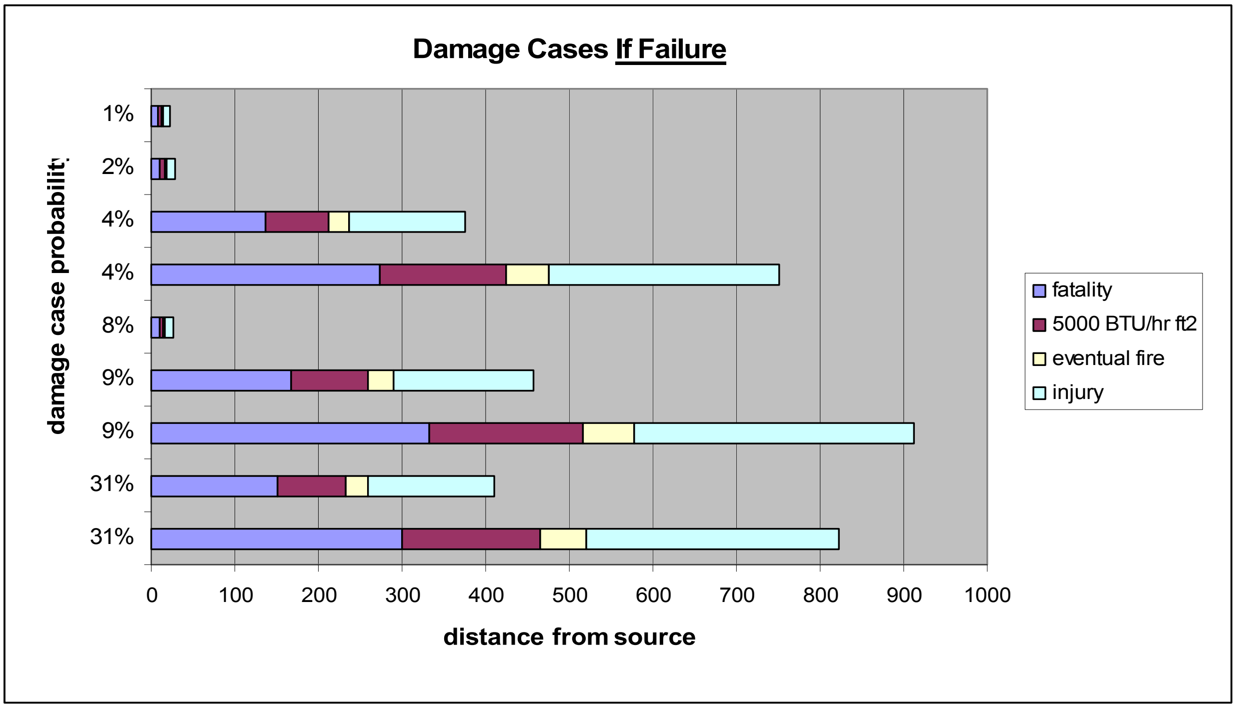
The ignition of a small leak which causes localized damages, perhaps igniting more combustible materials as the fire continues, is an unlikely scenario. In that unlikely case, leak detection might be more useful in minimizing potential impacts to the public. This is being further assessed as part of emergency planning.

Results of calculations involving nine failure scenarios and four damage (consequence) states.

			Impact Distances (ft) Effected by Specified BTU/hr sq ft Thermal Intensity				Probability					
damage state scenario	hole, in	press, psig	12000	5000	4000	1600	hole	pressure	ignition	damage state over project life[2]	damage state if failure	Individual experiencing a damage state[3]
1	16	1800	300 ft	465 ft	520 ft	822 ft	20%	70%	40%	3.23E-04	31%	7.65E-06
2	8	1800	150	232	260	411	40%	70%	20%	3.23E-04	31%	1.53E-05
3	16	2220	333	516	578	913	20%	20%	40%	9.24E-05	9%	2.19E-06
4	8	2220	167	258	289	457	40%	20%	20%	9.24E-05	9%	4.37E-06
5	0.5	1800	9	15	16	26	40%	70%	5%	8.08E-05	8%	1.53E-05
6	16	1500	274	424	475	751	20%	10%	40%	4.62E-05	4%	1.09E-06
7	8	1500	137	212	237	375	40%	10%	20%	4.62E-05	4%	2.19E-06
8	0.5	2220	10	16	18	29	40%	20%	5%	2.31E-05	2%	4.37E-06
9	0.5	1500	9	13	15	23	40%	10%	5%	1.15E-05	1%	2.19E-06
										1.04E-03*	100%	

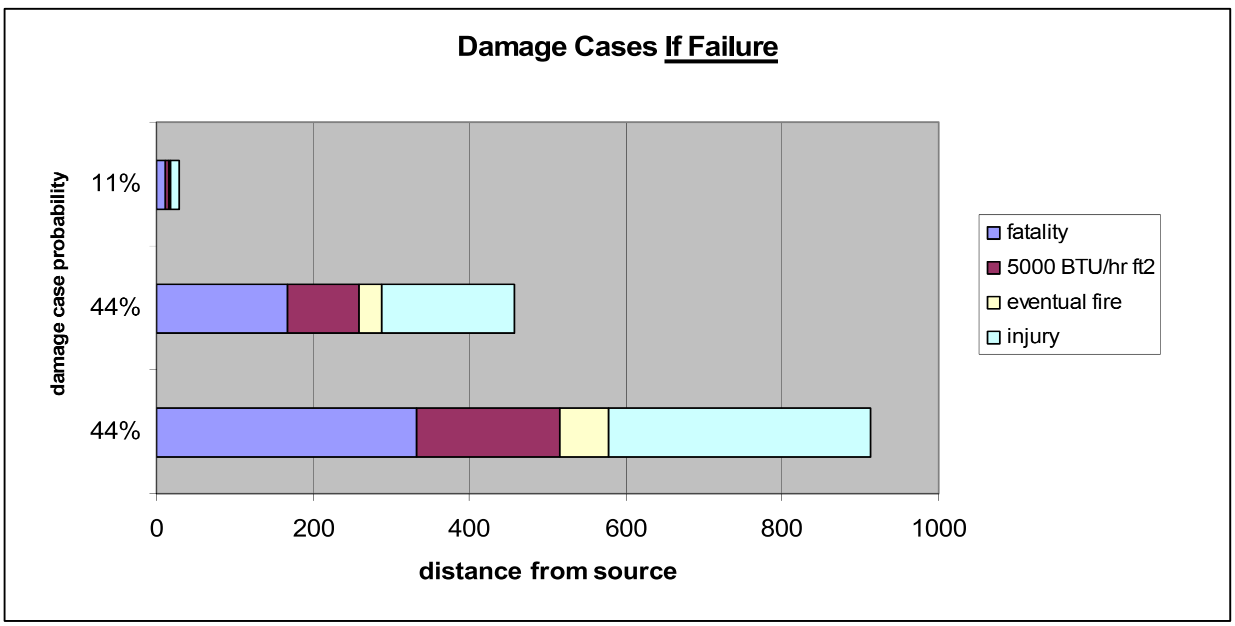
Table Notes
1 Failure rate used is 0.0005 failures per mile-yr as calculated in Case 4 of the normalize, frequency-based probabilistic calculations
2 Probabilities of one or more damage states over the life of the project is 1.04E-03
3 This calculation uses failure frequency for 2000 ft of pipe and assumes an individual is directly over the pipeline continuously (24/7) and therefore continuously exposed to the potential damage states for 40 years.

The nine cases are shown graphically as follows.



The right-most end of each bar represents the total distance of <u>any</u> consequence type. The farthest extent of each damage type is shown by the right-most end point of the consequence type's color.

These nine cases can be grouped into three categories as shown below.



This chart illustrates that 11% of all possible failure scenarios would not have any of the specified damages beyond 29 ft from the failure point. 56% (44% + 11%) of all possible failure scenarios would not have any specified damages beyond 457 ft. No failure scenario is envisioned that would produce the assessed damage states beyond 913 ft.

In these groupings, the worst case (largest distance) is displayed. For example, the specific damage types can be interpreted from the chart as follows:

> Given a pipeline failure, 100% (44% + 44% + 11%) of the possible damage scenarios have a fatality range of 333 ft or less (the longest bar). There is also a 56% chance that, given a pipeline failure, the fatality range would be 167 ft or less (the second longest bar).

In the NEB filing, the distance of 500 meters as a possible extent of damage was noted. This distance corresponds to a very low potential hazard, where even under the worst case scenario (full line rupture at MAOP) the thermal radiation levels would be on the order of 500 BTU/hr sq ft. At this thermal radiation level, no damage to structures is expected, sheltered individuals would not be harmed, and exposed individuals would only be injured after long exposure.

Emergency Planning Zones

Estimated potential impacts may be used to create hazard zone categories for purposes of development of the emergency response procedures. Such consequence analysis results can be used to delineate Emergency Planning Zones (EPZs) within GSX's Emergency Plan and Preparedness Manual, per OPR-99 and NEB's Memorandum of Guidance (MOG) provide Emergency Preparedness and Response program requirements and guidelines.

Under GSX's Continuing Education Program, information on specific types of structures and gathering sites (e.g. public, private, school, commercial, recreational) are identified within the established EPZ once the pipeline route has been approved. Structures designed for high occupancy and structures which contain people with restricted mobility are also identified.

Risk Comparisons

In the preceding analyses, the more conservative risk estimation is derived from the normalized, frequency-based probabilistic approach. These results are used for the following comparisons.

A comparison between the adjusted US Case 4 above and US hazardous liquid pipelines is shown below. U.S. hazardous liquids pipelines are expected to have a fatality rate of 2.3 times higher, an injury rate of 4.1 times higher, and a failure rate 8.6 times higher than a natural gas transmission pipeline similar to the proposed GSX Pipeline.

Comparison Criteria	Failures per Year	Injuries per year	Fatalities per Year	Years to Fail	Years to Injury	Years to Fatality	Annual Probability of an Individual Fatality[2]
Case 4 U.S. adj [1]	0.00507	0.00084	0.00022	197.2	1,200.4	4,557.6	2.4E-06
U.S. Liquid[3]	0.04344	0.00348	0.00050	23.0	287.4	1,987.6	4.7E-06

Notes

1. Adjusted by assuming failure rate of subject pipeline is ~50% of US gas transmission average, by rationale discussed above
2. Assumes an individual is threatened by 2000 ft of pipe (directly over pipeline, 1000 ft either side, 24-7 exposure)
3. OPS, US hazardous liquid pipelines 1986—2002

Compared to Other Modes of Transportation

Pipelines have fewer safety incidents than truck or rail transport. Truck transportation has a fire and explosion incident rate approximately 35 times higher and rail transportation 8.5 times higher than pipeline transportation accident rates. Fatality rates are correspondingly 85 and 2.5 times higher, respectively, and injury rates are 2 and 0.5 times higher.

Compared to Other Societal Risks

Statistical analysis is of limited usefulness, even if data were more complete than it is. Basic problems with historical data as predictive tool include:

- trying to predict an individual behavior from the behavior of the group
- situation must be unchanging if history is to be a good predictor of the future (assumption of static conditions is not normally appropriate)
- small data samples (leading to very high uncertainty)

Comparisons are often made among voluntary risks and among involuntary risks. Individuals have different risk tolerances when it comes to chosen risks—witness mountain climbers, parachutists, and even driving habits.

The following table is extracted from Table 6-18 of the Longhorn Pipeline Environmental Assessment, 2000. The complete table is included at the end of this document.

Event	Chance for One Individual in a 50-Year Period
Motor vehicle injury	1 in 2
Cancer fatality	1 in 10
Motor vehicle fatality	1 in 123
Fatality by fall (all locations)	1 in 380
Pedestrian fatality (by motor vehicle accident)	1 in 870
Fatality by fall (public places)	1 in 1,000
Recreational boating fatality	1 in 1,840
Fatality from GSX Pipeline	1 in 10,300
Fatality from firearms in public places	1 in 10,600

It is appropriate to compare risks of a pipeline introduced into a community with other non-voluntary risks to which that community might be exposed.

An NEB report, ***NEB Risk Analysis Study, Development of Risk Estimation Method, April 1992,*** lists some common individual and societal risk values for comparison. The following table, is extracted from the table labeled "Risks Associated with Common Activities and Natural Phenomena" in NEB study. The GSX pipeline risk estimate is inserted.

ACTIVITY OR EVENT	RISK (Fatalities per exposed person per year)
Smoking (20 cig/day)	5.0×10^{-3}
Mountaineering	2.0×10^{-3}
All Accidents	5.0×10^{-4}
Motor Vehicle Accidents	2.5×10^{-4}
All Industrial Accidents	1.7×10^{-4}
Unacceptable Risk Threshold (> 1.0×10^{-4})	
Falls	7.2×10^{-5}
Drowning	5.0×10^{-5}
Fires	3.1×10^{-5}
Air Travel	7.0×10^{-6}
GSX Pipeline	2.4×10^{-6}
Railway Travel	2.0×10^{-6}
Acceptable Risk Threshold (< 1.0×10^{-6})	
Lightening	8.0×10^{-7}
Meteorites	6.0×10^{-11}

In this NEB study, acceptable risk thresholds are defined. Pipeline risks generally fall between 'acceptable risk' (< 1.0×10^{-6}) and 'unacceptable risk' (> 1.0×10^{-4}) thresholds as used in this report. In this region, the report notes that actions to reduce risk may be warranted but should be justified on a cost-benefit basis.

The following is Table 6-18 of the Longhorn Pipeline Environmental Assessment, 2000.

Summary of Common Individual Risks

Event	Chance for One Individual in a 50-Year Period *	Source/Basis of Estimate
Motor vehicle deaths	1 in 123	Accident Facts, 1997, p.78. Estimated based on reported death rate of 16.3 deaths/year per 100,000 persons for 1996.
Motor vehicle injuries	1 in 2	Accident Facts, 1997, p.78. Estimated based on reported total injuries of 2,600,000 for 1996 and a 1996 US population of 265,229,000 persons. Assumes total population exposed each year and constant population.
Pedestrian deaths (by motor vehicle accident)	1 in 870	Accident Facts, 1997, p.100. Estimated based on reported total deaths of 6,100 for 1996 and a 1996 US population of 265,229,000 persons. Assumes the entire population has the potential to be a pedestrian.
Falling deaths (public places)	1 in 1,000	Accident Facts, 1997, p.100. Estimated based on 5,300 reported deaths for 1996 and a 1996 US population of 265,229,000 persons. Excludes fall-related deaths at home and work.
Falling deaths (all locations)	1 in 380	Accident Facts, 1997, p.8. Estimated based on 1996 death rate of 5.3 deaths/year per 100,000 population. Includes unintentional fall related deaths in all locations (public, home and work).
Deaths from firearms in public places	1 in 10,600	Accident Facts, 1997, p.117. Estimated based on 500 reported deaths for 1996 and a 1996 US population of 265,229,000 persons. Excludes firearm-related deaths at home and work. Unintentional deaths only, homicides/ suicides excluded.
Recreational boating deaths	1 in 1,840	Based on report from National Association of State Boating Law Administrators (NASBLA). Factors Related to Recreational Boating Participation in the United States: A Review of the Literature. August 17, 2000. Pp. 5 and 62. 815 total deaths in 1998. Recreational boating participants of 74,847,000 in 1998 (approx. 29 percent of the total US population).
Tornado deaths (1999, states with reported tornado deaths)	1 in 16,600	National Climatic Data Center web site. Based on tornado data from 1999. 94 tornado deaths in 13 states. Total population of these 13 states of 78,000,000 (29 percent of the US population) was taken from the US Census Bureau web site for 1999.

Tornado deaths (1999, entire US)	1 in 58,000	National Climatic Data Center web site. Tornado data from 1999. 94 tornado deaths in 13 states. Total US population of 272,690,813 was taken from the US Census Bureau web site for 1999.
Lightning deaths	1 in 119,000	National Climatic Data Center web site. Based on 46 lightning deaths in 1999. 1999 US population taken from Census Bureau (272,690,813).
Cancer deaths	1 in 10	American Cancer Society. Statistics taken from web site. Expected cancer deaths rate in 1999 of 563,100. Risk based on total 1999 US population.
Cancer deaths in males	1 in 9	American Cancer Society. Cancer Facts and Figures – 1997 from the ACS web site. Male: 219 deaths/year per 100,000 population.
Cancer deaths in females	1 in 14	American Cancer Society. Cancer Facts and Figures – 1997 from the ACS web site. Female: 142 deaths/year per 100,000 population.

[*] Chance for one individual in a 50-year period was calculated by multiplying the risk in one year by 50. For example, if the risk is one death/year per 100,000 population, then the risk for 50 years is 50 times the one-year risk or 50 deaths per 100,000 population (i.e., 1 in 2000 chance over a 50-year period).

References:

[1] C-FER Technologies. 2000. *A Model For Sizing High Consequence Areas Associated With Natural Gas Pipelines.* Gas Research Institute (GRI), Chicago, Illinois, USA.