International Pipeline Conference — Volume 1
ASME 1996

IPC1996-1819

PUBLIC SAFETY RISK ASSESSMENT OF NATURAL GAS LIQUIDS PIPELINES

Michael J. Zelensky, M.Sc., P.Eng.

W. Arthur J. Springer, M.Sc., P.Eng.

BOVAR Environmental
#1600, 555 Fourth Avenue S.W.
Calgary, Alberta, Canada
T2P 3E7
Phone - (403) 264-2140
Fax - (403) 237-7634

ABSTRACT

Public safety risks are becoming an important issue in the planning of new pipelines and the operation of existing pipelines. Pipelines are initially routed to avoid densely populated areas. However, new developments may encroach on existing pipelines. Risks to the public can be estimated to determine an adequate setback distance.

The methodology for risk assessment is described using a Canadian case study. Ethane, propane, butane and pentanes are commonly transported as liquids in pipelines. These compounds have a high vapour pressure, and when accidentally released, may form a flammable dense gas cloud. If the cloud is ignited, a flash fire or vapour cloud explosion may occur. Consequences and frequencies of the selected hazardous incidents are provided. Individual risk levels in rural and urban areas along the pipeline are presented and compared to the risk-based land use planning guidelines of the Major Industrial Accidents Council of Canada.

1. INTRODUCTION

The potential hazards of pressurized, flammable liquid pipelines are well known. Although efforts are made to reduce risks as much as possible, some level of risk will remain as in any undertaking. The determination of the level of risk, to which the public could be exposed by a pipeline, is important for several reasons:

- To check the safety standard specified in project planning and design as well as the proposed operating procedures used for the facility;
- To assist with emergency response planning by predicting the effect zone;
- To inform the public who either are, or may be, in a zone that could be affected by an accidental release from the installation;
- To compare the estimated level of risk with existing risks encountered and accepted in day-to-day activities;
- To provide a basis of assessment to assist regulatory authorities.

Risk can be reduced by careful routing, quality engineering, good preventive maintenance and well-designed emergency planning. However, risk is still present in spite of any reduction measures.

The objective of this study is to assess the risks to the public associated with a typical NGL pipeline. The risk estimates are the incremental risks to which the public would be exposed.

The consequences of an accidental release of NGL are assessed in terms of fatalities and injuries. It is also necessary to quantify how often the hazardous incidents are expected to occur (known as the frequency). Risk is determined by combining the consequence and frequency results.

A general risk management framework is shown in Figure 1. Risk assessment is the combined process of risk analysis and risk evaluation. The basic components of the assessment are described in the following sections:

- System Description (Section 2);
- Hazard Identification (Section 3);
- Consequence Analysis (Section 4);
- Frequency Analysis (Section 5); and
- Risk Estimation and Evaluation (Section 6).

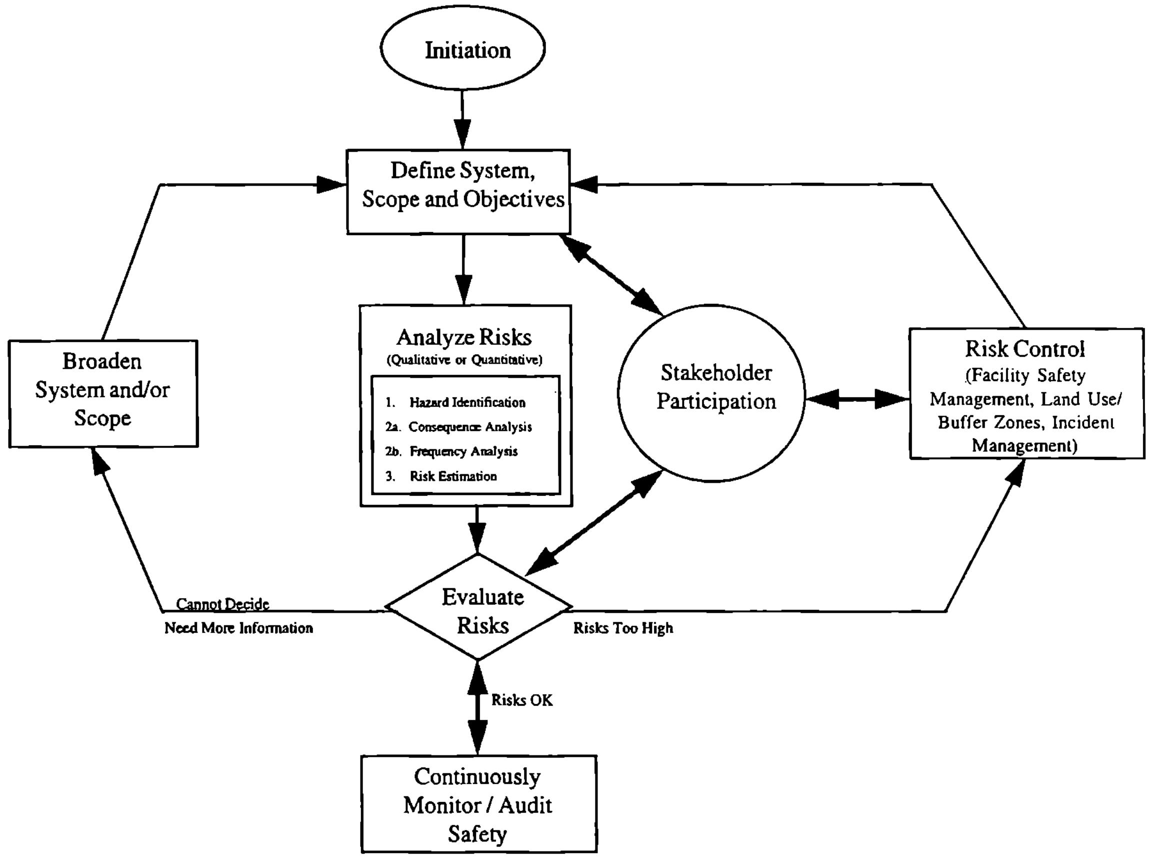

Figure 1. Risk Management Framework.

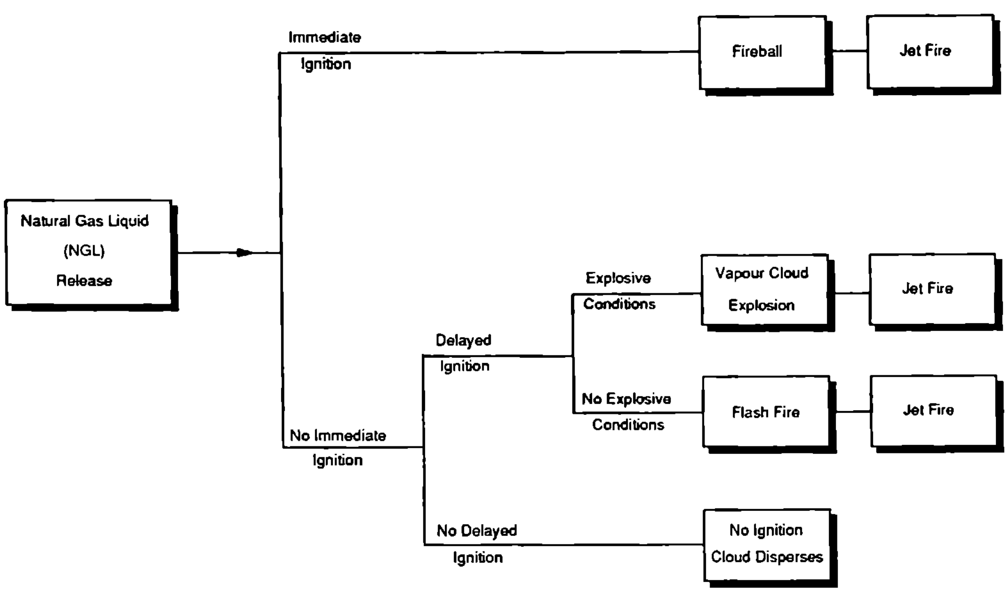

Figure 2. Event tree showing sequence of possible events following an NGL release.

2. SYSTEM DESCRIPTION

Natural gas liquids are a mixture of ethane, propane, butane and pentane. These compounds are gases at atmospheric conditions. Under the high pressure in the pipeline, the components are compressed to form a liquid. NGL's are referred to as high vapour pressure (HVP) liquids. NGL is a highly flammable, colourless, and nearly odourless gas at atmospheric conditions. A typical composition of NGL is given in Table 1.

HVP pipelines are constructed to meet or exceed all applicable codes and regulations. If a pipeline route crosses agricultural land with a low population density (designated as Zone 1 in the CAN/CSA Z662 code), it can be designed to meet less stringent design requirements than for more heavily populated areas (designated as Zone 2 in code). The more stringent measures required for pipelines in urban areas include:

- Pipe that has increased wall thickness.
- Pipeline buried with minimum 1.2 m (4 feet) of cover.
- Remote operation block valves must be installed a maximum of every 15 km.

The design pressure of NGL pipelines is about 10 000 kPa (1440 psi); the normal operating pressure range is from 3000 to 7000 kPa. The example pipeline has a capacity of 7000 m^3/day, through a 273.1 mm (10") diameter steel pipe with 6.35 mm (0.25") wall thickness and has block valves spaced every 15 km.

Table 1.
Typical NGL Composition

	Mol Fraction %
Ethane	57
Propane	23
Butane	16
Pentane	4
TOTAL	100

3. HAZARD IDENTIFICATION

Identification of hazardous incidents is undertaken at a level that addresses major threats from the materials handled, to all members of the public who reside near to or who may come into the vicinity of the pipeline. The selection of hazardous incidents is made on the basis that they are credible and that they can occur with measurable and significant frequency. Three release scenarios have been considered:

- **Full Rupture** where NGL is emitted from two complete cross sections of the pipe (worst possible release);
- **Partial Rupture** where NGL is emitted from a hole at a flow rate equivalent to the normal expected throughput of the pipeline (worst credible release);
- **Leak** where NGL is emitted from a hole at a flow rate equivalent to 10% of the normal expected throughput of the pipeline (most probable release).

This is a representative set of releases which will result in catastrophic, major and localized incidents, respectively.

The sequence of possible events following a pipeline release is presented in the event tree diagram in Figure 2. The hazardous incidents associated with a release are:

- **Fireball**, if the released material is ignited immediately after the release.
- **Jet fire** following immediate or delayed ignition of high pressure vapour/liquid releases.
- **Flash Fire** or **Vapour Cloud Explosion**, if delayed ignition takes place away from the source. A flash fire travels from the point of ignition through the cloud of flammable vapour. Under certain conditions, the flame speed may reach high velocities and produce pressure waves, resulting in a vapour cloud explosion. These events could result in a jet fire when the fire burns back to the release point.
- **No Ignition**, cloud disperses with no consequences to the public, except for the possibility of asphyxiation near the release point.

4. CONSEQUENCE ANALYSIS

Estimating the consequences of hazardous incidents requires the determination of the area around an accident site where the concentration of unignited vapours, thermal radiation or blast waves may have harmful effects on people. Mathematical models are used to estimate the size of the hazard zones by determining the intensity of the effect (concentration, thermal radiation, or overpressure) as a function of distance from the source. The models require as input the released material flow rate and properties and meteorological conditions. Sample results are presented for a full rupture.

4.1 NGL Release Rates

The initial portion of the release will be as a liquid until the pressure in the pipeline drops to the mixture vapour pressure of 1500 kPa. Upon flashing to atmospheric pressure the released material has a temperature of -67°C and has a vapour mass fraction of 0.71.

A simplified blowdown model was used to account for the two-phase and multi-component nature of the discharge. The pressure in the pipeline will be maintained at the NGL vapour pressure until all of the liquid is vapourized. During this time the two-phase flow rate is relatively constant (Fauske and Epstein, 1988). The following constant mass flow rates over the time to discharge the section were used:

- **Full Rupture** - The estimated NGL discharge rate from a full rupture is 432 kg/s. At this rate, it would take approximately 15 minutes to blowdown a 15 km section of pipe. Block valves would close within minutes as the pressure in the pipeline drops very quickly.
- **Partial Rupture** - The normal capacity of the NGL pipeline is 7000 m^3/day or 40 kg/s. This flow rate as a two-phase mixture requires a rupture diameter of about 112 mm. The block valves would normally close within minutes of sensing a release has occurred. At this rate, it would take about two and a half hours to blowdown a 15 km segment.
- **Leak** - A leak flow rate of 4 kg/s, equivalent to 10% of the normal capacity of the pipeline, was assumed. The hole size is about 10 mm in diameter, based on liquid flow. A typical leak detection system would detect a leak of this magnitude within 15 minutes, and close the block valves.

4.2 Meteorological Conditions

In the event of an NGL release, weather conditions determine the direction of the cloud and the amount of dilution in the cloud as it moves downwind. The direction is determined by the wind at the time of the release. The dilution is determined by the amount of turbulence in the atmosphere.

Atmospheric turbulence can be generated by thermal or mechanical processes. Heating and cooling of the ground by radiation contributes to the generation and suppression of turbulence, respectively. High wind speeds contribute to the generation of mechanical turbulence. Meteorologists frequently use the following classification scheme when evaluating the dilution capacity of the atmosphere.

- **Unstable** Classes A, B and C are primarily associated with daytime heating which produce increased turbulence levels.
- **Neutral** Class D is primarily associated with high wind speed conditions which result in mechanical turbulence.
- **Stable** Classes E and F are associated with night-time cooling conditions which result in suppressed turbulence levels.

Data from the Edmonton Namao Airport was used for this example (Environment Canada, 1988). For a given release scenario, the resulting cloud size is very sensitive to the prevailing atmospheric turbulence and wind speed. To avoid modelling each release scenario (3) for each combination of wind speed and stability class (18), four conditions were selected to represent the range of weather conditions.

An ambient temperature of 15°C was assumed for modelling purposes as this results in larger predicted cloud areas. An annual average relative humidity of 70% was used. Mechanical turbulence can be generated by surface roughness features such as vegetation and buildings. A surface roughness scaling height of 100 cm was used. This is representative of flat or rolling terrain covered with obstructions tens of metres in height (e.g., forests, cities).

4.3 Dispersion of NGL

SLAB (Ermak, 1990), a dense gas dispersion model developed by the Lawrence Livermore National Laboratory, was used to determine the concentration of NGL in the atmosphere. The model simulates the atmospheric dispersion of denser-than-air releases by accounting for air entrainment into, and gravity spreading of, the heavy gas cloud. The effects of NGL droplet evaporation, water droplet formation and ground heating on the cloud are included.

A vertical release from the crater formed by the release was assumed and the initial release height was set at ground level. Concentrations as a function of downwind distance, crosswind distance, elevation above ground and time are predicted by the model. A 10 second concentration averaging time was used to conservatively estimate the flammability range.

4.4 Fireballs and Jet Fires

Empirical models are used to estimate the size and duration of fireballs and the length of jet fires (Crocker and Napier, 1988). A stationary spherical cloud resting on the ground was assumed for a fireball. A vertical line source was assumed for the jet fire. The fraction of energy released as thermal radiation was taken as 30%.

The thermal radiation intensity received by a target normal to the source, accounting for the transmissivity of the atmosphere, was determined. The dose a receptor receives was determined from: (exposure time) times (thermal radiation) $^{4/3}$. A receptor is assumed to be exposed to the entire duration of a fireball. For a jet fire, a receptor is assumed to be stationary for five seconds and then flees from the source at a rate of 2.5 m/s. Probit parameters were used to determine the percentage of the population effected (Clay *et al.* 1988).

If immediate ignition does occur, the initial fireball rapidly decays to a jet. The fireball has a mass of about 11 tonnes of NGL, would last approximately 10 seconds and has a diameter of about 130 metres. The jet fire has a height of about 190 m and would last approximately 15 minutes. As shown in Figure 3, the effect zones for jet fires are less than for the fireball.

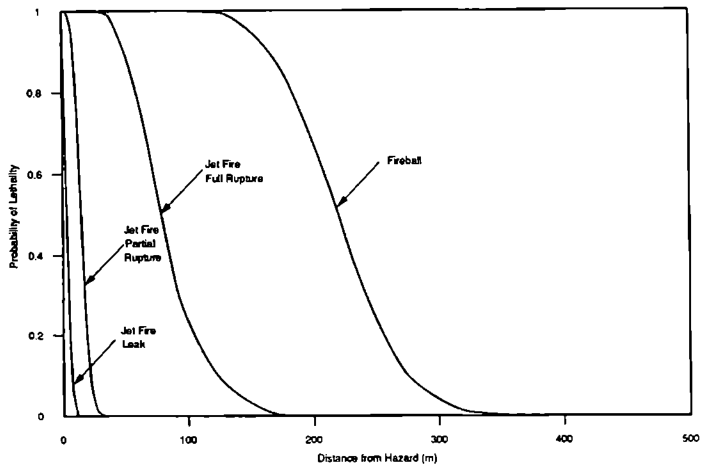

Figure 3. Probability of lethality from thermal effects in the vicinity of an NGL pipeline rupture.

4.5 Flash Fires

Output from the dispersion model was used to determine the extent of a flash fire. Combustion of the NGL - air mixture may occur if the concentration of NGL is between the lower flammable limit (LFL) and the upper flammable limit (UFL). For the NGL considered, the LFL concentration is 2.4% on a volume basis in air and the UFL concentration is 10.9%.

The size of the flammable cloud grows as the release progresses until the maximum size is reached. The maximum size of the cloud was used in the assessment. For the partial rupture and leak, the maximum cloud forms early in the release and is not sensitive to the release duration time. For the full rupture, the size of the cloud increases with increasing release duration and shorter pipeline segments would have smaller flammable clouds.

Figure 4 shows the effect zones for flash fires associated with a full rupture in a 15 km pipeline segment, under each of the four meteorological conditions considered. The black area is where the maximum concentration is above the UFL. The darker shaded area is where the predicted maximum NGL concentration is between the UFL and the LFL. The outermost contour represents one fifth of the LFL.

It is conservatively assumed that people and buildings within the LFL contour would be exposed to direct flame contact and would not survive (TNO, 1988). The largest effect zones are associated with low wind speeds and stable atmospheric conditions. For the higher wind speed conditions (C3, D5, E3) the predicted maximum downwind extent of the flammable area is reached while the release is occurring. At the lower wind speeds (F1), the maximum cloud size occurs after the release has stopped.

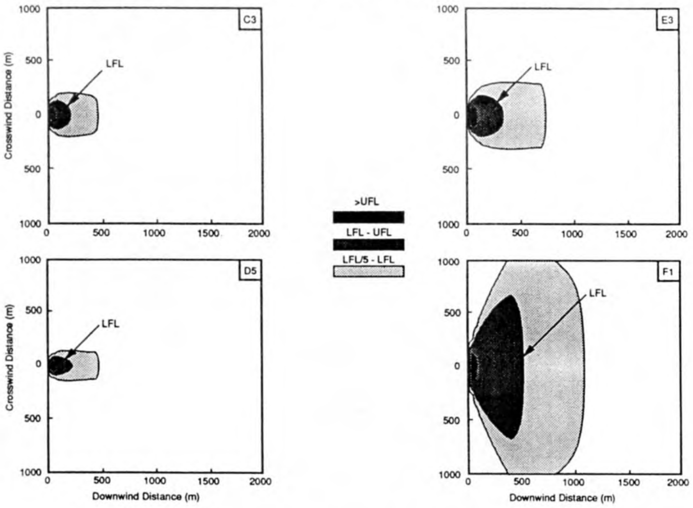

Figure 4. Predicted concentrations resulting from the full rupture of an NGL pipeline.

4.6 Vapour Cloud Explosions

In certain cases, flash fires propagate so quickly through the flammable mixture that a blast wave is created. The explosive mass of the cloud between the LFL and UFL concentrations was determined by integrating the output of the dispersion model. The centre of mass (epicentre) was also determined. The maximum explosive mass is used in the assessment.

The TNT model was used to determine the overpressure as a function of distance with 10% of the heat of combustion of the NGL converted into the production of blast waves. Peak overpressures within the vapour cloud are 100 kPa (AIChE, 1989). A probit approach was used to determine the probability of the given effect as a function of distance from the epicentre (Clay *et al.* 1988).

Table 2 provides the size of the cloud, the downwind distance to the epicentre and the explosive mass of the cloud. In the event of a vapour cloud explosion, it is assumed that no one survives if they are within the LFL contour (TNO, 1988) shown in Figure 4. The pressure wave created by the explosion can also cause damage to people and buildings.

Table 2.
Cloud Size and Overpressure Effect Zones for Full Rupture

		Meteorological Condition Code[a]			
		C3	D5	E3	F1
Cloud size to LFL					
Length	(m)	200	220	320	510
Half-width	(m)	140	90	200	720
Area	(ha)	4.1	2.6	9.2	49.7
Distance to Epicentre	(m)	90	90	130	240
Explosive Mass	(t)	14	9	27	124

a See Table 3 for description of conditions.

The least favourable meteorological condition is low wind speed stable class F1, as this results in the largest explosive mass of 124 t. The total mass of NGL released from a 15 km section is 366 t. The most favourable meteorological condition D5 results in the minimum explosive mass of 9 t. The effect zones increase with the explosive mass of the cloud, as can be seen in Figure 5.

The distance to a 50% chance of eardrum damage corresponds to nearly complete destruction of houses. People outdoors may experience eardrum damage; however, if they were indoors they could be seriously injured due to the building collapsing on them.

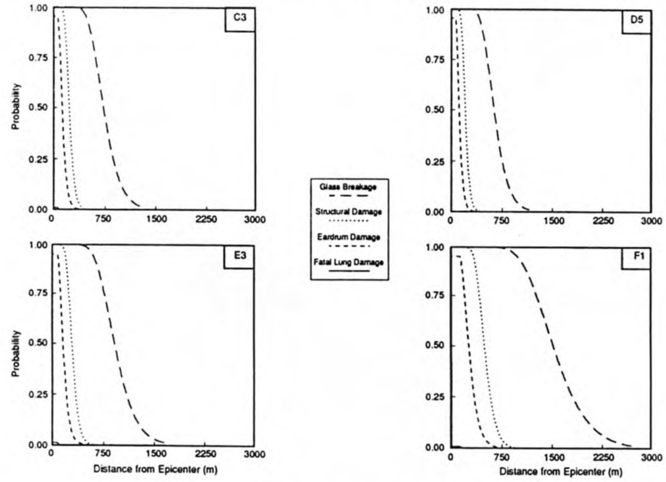

Figure 5. Overpressure effects resulting from the explosion of the predicted maximum flammable mass of NGL vapour dispersed from a full rupture.

4.7 Asphyxiation

The danger of asphyxiation must be considered at high concentrations of NGL. If the NGL concentration in air exceeds 24% (about twice the UFL), the oxygen concentration is less than 16% in the NGL-air mixture. To be conservative, the UFL will be used as the NGL concentration where people may be temporarily effected by asphyxiation. At 16% oxygen, breathing and pulse rate increases, and muscular coordination is slightly disturbed (Clayton and Clayton, 1982).

The black area shown in Figure 4 is where the NGL concentration exceeds the UFL and conservatively represents the asphyxiation effect zone. The effect zone occurs near the source. A person near the source would most likely flee the area to safety upon recognizing that a rupture has occurred. If the cloud is not ignited and there is no one near the source, the cloud safely disperses into the atmosphere.

5. FREQUENCY ANALYSIS

The frequency of occurrence of hazardous incidents is estimated from historical data and event tree analyses. The frequency of a hazardous incident is a combination of the release frequency, the probability that the meteorological condition occurs and the probability that ignition occurs.

5.1 Release Frequencies

Alberta's Energy Utilities Board maintains a computerized database of HVP pipeline failures in the province of Alberta (AEUB, 1991). The AEUB has the following definitions for leaks and ruptures:

- A leak is a small opening or crack in the pipeline causing some product loss but not immediately impairing the operation of the line;
- A rupture is the instantaneous tearing or fracturing of the pipe material causing immediate impairment of the operation of the pipeline.

The historical frequency of ruptures in Alberta is 1.9×10^{-4} ruptures/km·yr and the frequency of leaks is 3.2×10^{-4} leaks/km·yr. Leaks occur 1.7 times more than ruptures. One-ninth of pipeline ruptures are assumed to be full ruptures, based on an analysis of sour gas pipeline ruptures (AEUB, 1990). Similar data does not exist for HVP pipelines. The other eight-ninths of pipeline ruptures are represented by the partial rupture release case.

5.2 Meteorological Condition Probabilities

Table 3 gives the meteorological conditions selected to represent the range of annual weather conditions in the risk assessment (Atmospheric Environment Service, 1987). The wind speed measurements refer to those observed at the 10 m level. The dense gas dispersion model accounts for the decrease in windspeed near ground level. In this example a uniform wind rose will be assumed to produce results which are applicable to any pipeline orientation.

Table 3.
Representative Meteorological Conditions and Their Frequency of Occurrence

Code [a]	Stability	Wind Speed (m/s)	Frequency (%)
C3	Unstable	3	17.6
D5	Neutral	5	49.1
E3	Stable	3	16.4
F1	Stable	1	16.9
			100.0

a Code identifies representative meteorological condition for category, based on stability class and windspeed in m/s. For example, F1 identifies stability class F with windspeeds of 1 m/s (1 m/s = 3.6 km/h).

5.3 Ignition Probabilities

The sequence of possible incidents following a release was shown schematically in the event tree given in Figure 2. The Health and Safety Executive (HSE) of the United Kingdom was the major source of information to quantify the probabilities of ignition (Crossthwaite *et al*, 1988). Each step in the event tree is discussed. Table 4 gave the probabilities of flash fires, vapour cloud explosions, jet fires and no ignition, for each meteorological condition examined for rural and urban areas.

5.3.1 Immediate Ignition. The probability of immediate ignition following a rupture is assumed to be 5%. Immediate ignition leads to a fireball, followed by a jet fire. For a leak, the probability of immediate ignition is assumed to be zero.

For a rural area the estimated probability of a jet fire, given a rupture occurs, is 9%. For a rupture in an urban area, the probability of a jet fire is higher at 73% due to the higher number of potential ignition sources.

5.3.2 Delayed Ignition. The probability of delayed ignition depends on the density of ignition sources (e.g., residences) and the atmospheric stability. If a release were to occur in a rural area, the probability of ignition is much less than if it were to occur in an urban area. The probability of delayed ignition in stable weather is slightly less (0.9 times) than that of the probability of delayed ignition in neutral or unstable weather. This is to reconcile a larger flammable cloud area in stable weather with a wider but lower cloud and a likely lower density of ignition sources when stable weather occurs (generally at night). The assumed probabilities of delayed ignition for each condition are:

	Neutral Unstable	Stable
Urban	0.800	0.720
Rural	0.040	0.036

The overall chance of a flash fire occurring due to a rupture in a rural area is about 3%. In an urban area, the chance of a flash fire if a rupture occurs is 54%, due to the higher density of potential ignition sources.

5.3.3 Explosive Conditions. The delayed ignition of a flammable cloud may, under certain circumstances, generate damaging overpressure blast waves as well as thermal radiation. A vapour cloud explosion results if overpressures are produced. Flash fires are more likely to make the transition to vapour cloud explosions if partial confinement and turbulence are present. The probabilities of explosive conditions vary with atmospheric turbulence and are:

	Neutral Unstable	Stable
Explosion	0.33	0.10
Flash Fire	0.67	0.90

If a rupture were to occur in a rural area, there is less than a 1% chance of an explosion. However, if the release were to occur in an urban area, the probability of a vapour cloud explosion increases to 19%.

5.3.4 No Ignition. The probabilities of non-ignition for an NGL pipeline rupture were given in Table 4. There is a 91% chance that an NGL cloud is not ignited in rural areas along pipelines. If the pipeline were located in an urban area, the chance that the cloud is not ignited is 22%.

6. RISK ESTIMATION AND EVALUATION

Up to this point, risk has been treated as independent triplet combinations of hazardous incident, consequences and frequency. Risk estimation is the process of combining the estimated consequences and frequencies of the selected hazardous incidents to provide a quantitative measure of risk. Risk evaluation is the

Table 4.
Probabilities of Flash Fires, Vapour Cloud Explosions, Jet Fires, and No Ignition for Ruptures.

	Rural Area			Urban Area		
Meteorological Condition Code[a]	Vapour Cloud Explosion	Flash Fire	No Ignition	Vapour Cloud Explosion	Flash Fire	No Ignition
C3	0.0008	0.0016	0.0556	0.0153	0.0311	0.0116
D5	0.0047	0.0096	0.3447	0.0948	0.1925	0.0718
E3	0.0003	0.0023	0.0687	0.0051	0.0462	0.0200
F1	0.0003	0.0028	0.0843	0.0063	0.0566	0.0245
TOTAL	0.0095	0.0272	0.9133	0.1901	0.5446	0.2153
	Probability of a Jet Fire is 0.0867 (=0.0500[b] + 0.0095 + 0.0272)			Probability of a Jet Fire is 0.7347 (=0.0500[b] + 0.1901 + 0.5446)		

a See Table 3 for description of conditions

b The probability of a jet fire, following a fireball, under all meteorological conditions.

process by which these results are used to make decisions. To provide some perspective on the estimated levels of risk, and to assist parties interested in evaluating the acceptability of these risks, information on common risks and risk criteria is provided.

6.1 Risk Criteria

Decisions with respect to the acceptability of risk are personal and social value-judgments, involving the public exposed to the risks, government agencies and the industrial proponent of the risk-producing project. The Major Industrial Accidents Council of Canada has published risk-based land use planning guidelines (MIACC, 1995). Their individual risk guideline for land use planning are summarized in Table 5 and are based on consideration of criterion adopted in the United Kingdom and the Netherlands. These criteria assume an effective emergency response plan is in place. If not, the individual risk level shown in Table 5 should be decreased by a factor of 10 (i.e., 100 chances in a million becomes 10 chances in a million).

Table 5.
MIACC Risk-Based Land Use Planning Guidelines

Individual Risk (chances in a million of a fatality per year)	Adjacent Land Use[a]
Above 100	No other land uses than the source facility.
Between 100 to 10	Uses involving continuous access and the presence of limited numbers of people but easy evacuation, e.g., parks, warehouses, manufacturing plants.
Between 10 to 1	Uses involving continuous access but easy evacuation, e.g., commercial uses, low density residential areas, offices.
Below 1	All other land uses without restriction including institutional uses, high density residential areas, etc.

a These risk criteria assume that an effective emergency response plan is in place. Otherwise, decrease the risk levels by a factor of 10.

6.2 Risk Estimation

Pipeline risk estimation is especially difficult because a receptor can be effected by releases anywhere along the pipeline within the distance of the effect zone (Alp and Zelensky, 1995). A receptor does not have to be directly downwind of the release, on the plume centerline, to be effected. Both the downwind and crosswind extents of the plume must be considered. Winds from many directions can result in receptors being effected. A uniform wind rose was assumed.

An important parameter in determining the risk to a receptor is the "interaction length". This is the length of pipeline, that, if a release were to occur within, would expose a receptor to the hazard. The interaction length (m) for a hazard decreases with receptor distance from the pipeline and changes with the wind direction. It is multiplied by the release frequency (releases/m • yr), the incident probability (incidents/releases) and the probability of lethality (fatalities/ incident) to obtain the individual risk (probability of fatality/year).

Individual risk is defined as the annual chance of fatality a receptor is exposed to from **all** hazardous incidents. Flash fires and vapour cloud explosions are the major hazards which have the potential to cause fatalities. The probability of lethality from fireballs and jet fires is also significant near the pipeline. The incident probability of fireballs and jet fires are assumed to be independent of the weather and wind direction. However, for flash fires and vapour cloud explosions, the incident probability also accounts for the wind direction and meteorological condition.

The consequences and frequencies associated with the three release scenarios and the four meteorological conditions were combined. Risks in rural and urban areas were estimated, assuming the receptor is at the location for 100% of the time.

Estimates of individual risk were made for various distances from the pipeline, as shown in Figure 6. Individual risk is a maximum on the pipeline and decreases with distance from the pipeline. Within the pipeline right-of-way, the maximum risk is 5 and 30 chances in a million of fatality per year for rural and urban areas, respectively.

At about 300 m from the pipeline in a rural area, the risk of fatality is less than 0.1 chances in a million and is considered to be negligible. In an urban area, the risk is negligible about 800 m from the pipeline.

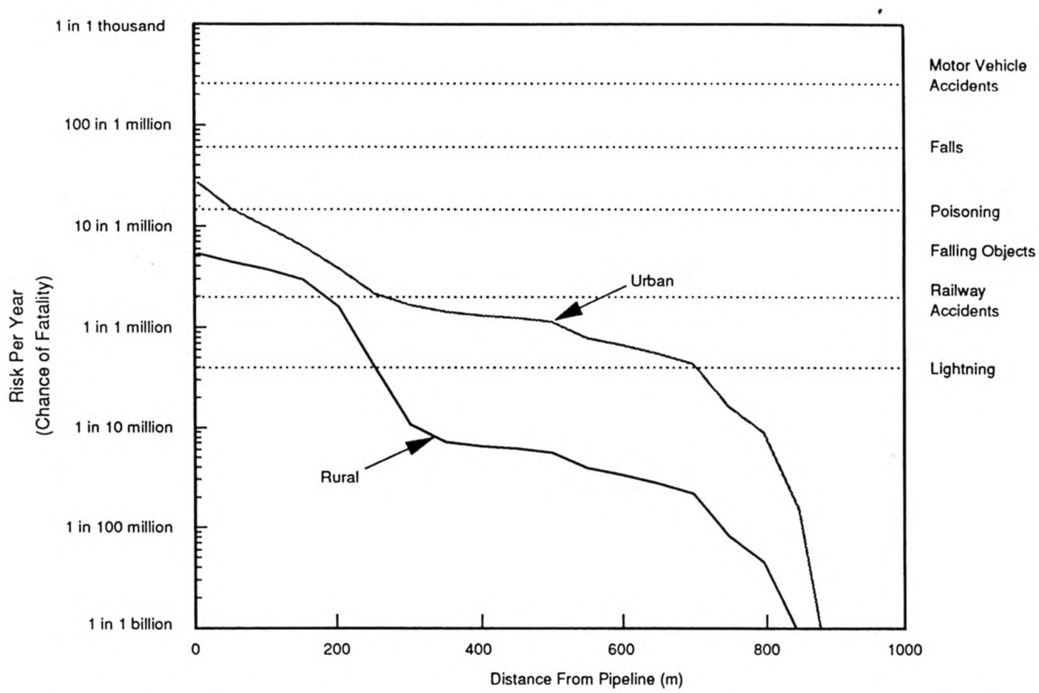

Figure 6. Individual Risk to permanent residents in rural and urban areas due to an NGL pipeline.

6.3 Risk Assessment

One way to understand the magnitude of a risk is to compare it with other risks. Therefore, also shown on Figure 6, for comparative purposes, are the individual risk levels for common risks in Alberta. These data are based on fatality statistics compiled by Statistics Canada for the 10 year period 1978 to 1987.

Referring to MIACC's risk-based land use planning guidelines (Table 5), individual risk levels between 100 and 10 chances in a million would be applicable to areas where there is continuous access and the presence of a limited number of people with easy evacuation. Risk levels less than 10 chances in a million would be applicable to areas with low to high population densities.

The estimated individual risk for rural areas is less than 10 chances in a million. For an urban area, the individual risk is less than 10 chances in a million at a distance of about 100 m from the pipeline. Increased setback distances reduce the risk to the public.

6.4 Concluding Remarks

In summary, the estimated levels of individual risk from a typical NGL pipeline are comparable or less than involuntary risks faced by people in everyday life. Risks in rural areas meet MIACC's guidelines. In urban areas MIACC's risk-based land use planning guidelines should be adopted in order to reduce the risk to the public.

7. REFERENCES

Alberta Energy Utilities Board (AEUB). 1990. Risk Approach. Prepared by Concord Environmental. ERCB Report 90-B. Volume 6, p.3-21.

Alberta Energy Utilities Board (AEUB). 1991. Pipeline-Gas and Liquid Releases. Environment Information's System.

Alp, E. and M.J. Zelensky. 1995. Risk Quantification for Meteorology-and Direction-Dependent Hazards due to Point and Linear Risk Sources. Accepted for publication in J.Loss Prevention in the Process Industries.

American Institute of Chemical Engineers (AIChE). 1989. Guidelines for Chemical Process Quantitative Risk Analysis. AIChE New York, New York.

Atmospheric Environment Service (AES). 1987. STAR Data Set for Edmonton Namao from 1973 to 1984. Downsview, Ontario.

Clay, G.A., R.D. Fitzpatrick, N.W. Hurst, D.A. Carter, P.J. Crossthwaite. 1988. Risk Assessment for Installations where Liquified Petroleum Gas (LPG) is stored in bulk vessels above ground. J. Hazardous Materials, 20, pp 357-374.

Clayton and Clayton. 1982. Patty's Industrial Hygiene and Toxicology. Wiley and Sons, New York, New York. p 4056.

Crocker, W.P. and D.H. Napier. 1988. Assessment of Mathematical Models for Fire and Explosion Hazards of Liquified Petroleum Gases. Hazardous Materials. Vol. 20, pp 109-135.

Crossthwaite, P.J., R.D. Fitzpatrick, N.W. Hurst. 1988. Risk Assessment for Siting of Developments near Liquified Petroleum Gas Installations. I. Chem. E. Symposium No. 110. pp 373-400.

Environment Canada. 1988. Principal Station Data, Edmonton Namao A. ISBN 0-660-52411-2.

Ermak, D.L. 1990. Users Manual for SLAB: An Atmospheric Dispersion Model for Denser than Air Releases. Physics Department, Atmospheric and Geophysical Sciences Division, University of California, Lawrence Livermore National Laboratory. Livermore, California.

Fauske, H.K. and M. Epstein. 1988. Source Term Considerations in Connection with Chemical Accidents and Vapour Cloud Modelling. J.Loss Prevention in the Process Industries. Vol. 1, pp 75-83.

Major Industrial Accidents Council of Canada (MIACC). 1995. Risk-Based Land Use Planning Guidelines. Ottawa, Ontario.

TNO. 1988. Guide to Hazardous Industrial Activities. Prepared for Fire Service Directorate of the Ministry of Home Affairs and the Transport and Public Works Department of the Province of South Holland. The Hague, Netherlands.