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ENVIRO

Technical

Information for

Problem

Spills

NATURAL GAS

October 1984

Canada

ENVIRONMENTAL AND TECHNICAL INFORMATION FOR PROBLEM SPILLS MANUALS

Environmental and Technical Information for Problem Spills (EnviroTIPS) manuals provide detailed information on chemical substances. This information is intended to assist the reader in planning for and designing countermeasures for spills of these substances. The manual has been reviewed by the Environmental Protection Service and approved for publication. Approval does not necessarily signify that the contents reflect the views and policies of the Environmental Protection Service. Readers are advised to consult other sources of information before making critical decisions. Mention of trade names or commercial products does not constitute endorsement for use.

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NATURAL GAS

ENVIRONMENTAL AND TECHNICAL INFORMATION FOR PROBLEM SPILLS

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FOREWORD

The Environmental and Technical Information for Problem Spills (EnviroTIPS) manuals were initiated in 1981 to provide comprehensive information on chemicals that are spilled frequently in Canada. The manuals are intended to be used by spill specialists for designing countermeasures for spills and to assess their effects on the environment. The major focus of EnviroTIPS manuals is environmental. The manuals are not intended to be used by first-response personnel because of the length and technical content; a number of manuals intended for first-response use are available. The information presented in this manual was largely obtained from literature review. Efforts were made, both in compilation and in review, to ensure that the information is as correct as possible. Publication of these data does not signify that they are recommended by the Government of Canada, nor by any other group.

ACKNOWLEDGEMENTS

The final version of this manual was prepared by the staff of the Environmental Protection Service who wrote extensive revisions to the text, drafted illustrations and incorporated all comments and additions.

The draft of this manual was prepared under contract to Environment Canada by M.M. Dillon Consulting Engineers and Planners, Concord Scientific Corporation, and Waterloo Engineering Limited. The level of detail present was made possible by the many individuals, organizations and associations who provided technical data and comments throughout the compilation and subsequent review.

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1 SUMMARY

NATURAL GAS (CH_4, Methane)

Colourless, odourless gas. Consumer gas will have an odourant added for warning purposes. Crude natural gas may be heavily contaminated with hydrogen sulphide, a serious health and environmental hazard.

SYNONYMS

Methyl Hydride, Marsh Gas, Fire Damp

IDENTIFICATION NUMBERS

UN. No. 1971 (compressed), 1972 (refrigerated); CAS No. 74-82-8; STCC No. 4905755

IMMEDIATE CONCERNS

Fire: Flammable

Human Health: Low toxicity by all routes. An asphyxiant

PHYSICAL PROPERTY DATA

Shipping state: gas or liquid (liquefied gas)
State: (15°C, 1 atm): gas
Boiling Point: -154°C
Melting Point: -183°C
Flammability: flammable

Vapour Pressure: 3560 kPa (-86°C)
Solubility (in water): 0.0023 g/100 mL
Behaviour (on water): floats and boils
Behaviour (in air): warm vapours disperse rapidly, cold vapours are denser than air

ENVIRONMENTAL CONCERNS

Not seriously harmful to aquatic life.

HUMAN HEALTH

No TLV or IDLH established.

Exposure Effects

Inhalation: In high concentrations, causes headache, laboured breathing, unconsciousness

Contact: Contact with liquefied material causes frostbite to skin and eyes

IMMEDIATE ACTION

Spill Control

Restrict access to spill site. Issue warning: "FLAMMABLE". Call fire department and notify distributor. Stop the flow and contain spill, if safe to do so.

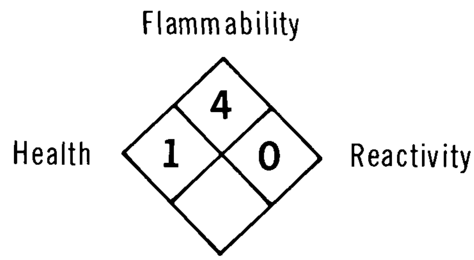
Fire Control

Do not extinguish fire unless release can be stopped. Use foam, dry chemical, carbon dioxide, halogenated extinguishing agent, water spray or fog. Cool fire-exposed containers with water spray.

NAS HAZARD RATING

Category (methane)	Rating
Fire	4
Health	
Vapour Irritant	0
Liquid or Solid Irritant	0
Poison	0
Water Pollution	
Human Toxicity	0
Aquatic Toxicity	0
Aesthetic Effect	0
Reactivity	
Other Chemicals	0
Water	0
Self-reaction	0

NFPA
HAZARD
CLASSIFICATION



2 PHYSICAL AND CHEMICAL DATA

Physical State Properties

	Methane (the major constituent of natural gas)	A Typical Natural Gas[1]
Appearance	Colourless gas (Merck 1976)	Colourless gas
Usual shipping state(s)	Gas Liquid: liquefied gas (CCD 1977)	Gas Liquid: liquefied gas
Physical state at 15°C, 1 atm	Gas	Gas
Melting point	-182.48°C (CRC 1980)	-182.7°C
Boiling point	-162°C (Kirk-Othmer 1980; Ullmann 1975)	-154°C
Vapour pressure	4040 kPa (-86°C) (CRC 1980)	3560 kPa (-86°C)

Densities

Density	Gas: 0.257 g/L (-162°C) (Kirk-Othmer 1980), 0.722 g/L (20°C) (Kirk-Othmer 1980; Matheson 1980)	Gas: 0.717 g/L (0°C)
	Liquid: 0.4507 g/mL (liquid at -162°C) (Kirk-Othmer 1980)	Liquid: 0.47 g/mL (-154°C)
Specific gravity	Gas (air = 1): 0.555 (0°C) (Matheson 1980)	1.00 (-73°C) (Konzek 1982) 0.609 (0°C)

Fire Properties

Flammability	Flammable gas (NFPA 1978)	Flammable gas
Flash point	-188°C (Kirk-Othmer 1980)	
Autoignition temperature	482-632°C (NFPA 1978) 600°C (Robinson 1984) 537°C (LPG 1982; Matheson 1980)	531°C
Burning rate	12.5 mm/min (CHRIS 1978)	11.6 mm/min (maximum for thin pool) (NMAB 1980)

---

1 Calculated average of a gas with 92 percent methane, 5 percent ethane and 3 percent propane; all date calculated from Matheson (1980) unless reference is given.

	Methane	A Typical Natural Gas
Upper flammability limit	13-17 percent (v/v) (NFPA 1978) 15 percent (v/v) (LPG 1982; Ullmann 1975)	-
Lower flammability limit	3.8-6.5 percent (v/v) (NFPA 1978) 5 percent (v/v) (Kirk-Othmer 1980; LPG 1982; Ullmann 1975)	-
Flame speed	55 cm/s (Lange's Handbook 1979), 33.8 cm/s (LPG 1982)	1200 cm/s (typical maximum in a series of tests) (Blackmore 1982)
Burning characteristics	Burns with a pale, faintly luminous flame (Merck 1976)	Burns with a pale, faintly luminous flame
Heat of combustion	890.3 kJ/mole (25°C) (CRC 1980)	940 kJ/mole
Combustion products	Carbon dioxide and water (CRC 1980)	Carbon dioxide and water (yield in burning is 1 m^3 CO_2, 2 m^3, H_2O and 7.5 m^3 N_2 per m^3 gas; 11.8 percent is average CO_2 content in flue gas (LPG 1982))
Flame temperature	1500°C (LPG 1982)	1918°C (LPG 1982)
Flashback potential	May travel considerable distance to a source of ignition and flash back	May travel considerable distance to a source of ignition and flash back
Electrical ignition hazard	May be ignited by static discharge	May be ignited by static discharge

Other Properties

Molecular weight of pure substance	16.04 (CRC 1980)	
Constituent components of typical commercial grade	Taken as pure methane	92 percent methane, 5 percent ethane, 3 percent propane (this example; see chapter 3 for other data)
Viscosity	Gas: 0.0109 mPa•s (20°C) (CRC 1980) Liquid: 0.202 mPa•s (-180°C) (Matheson 1980)	Gas: 0.0110 mPa•s (20°C) Liquid: 0.204 mPa•s (-165°C)

	Methane	A Typical Natural Gas
Latent heat of fusion	974 kJ/mole (at melting point) (CRC 1980)	-
Latent heat of vaporization	8.2 kJ/mole (at boiling point) (Kirk-Othmer 1980; Ullmann 1975)	-
Heat of formation	-74.87 kJ/mole (25°C) (JANAF 1971)	-
Entropy	186.31 J/(mole•K) (Ullmann 1975)	-
Ionization potential	12.62 eV (Rosenstock 1977)	-
Heat capacity		
constant pressure (C_p)	35.941 J/(mole•°C) (26.8°C) (Matheson 1980)	37.9 J/(mole•°C) (26.8°C)
constant volume (C_v)	27.531 J/(mole•°C) (15°C) (Matheson 1980)	29.5 J/(mole•°C) (26.8°C)
specific heat ratio (γ) (C_p/C_v)	1.305 (Matheson 1980)	1.285
Critical pressure	4633 kPa (CRC 1980)	4624 kPa
Critical temperature	-82.5°C (CRC 1980)	-71°C
Interfacial tension with air	15.8 mN/m (liquid at -170°C) (Ullmann 1975)	-
Coefficient of thermal expansion	3.68 x 10^{-3}/°C (Perry 1973)	-
Thermal conductivity	Gas: 0.0342 W/(m•K) (26.7°C) (Matheson 1980)	Gas: 0.033 W/(m•K) (25°C)
	Liquid: 0.226 W/(m•K) (-180°C) (Matheson 1980)	Liquid: 0.201 W/(m•K) (-165°C)
Log_{10} octanol/water partition coefficient	1.09 (Hansch and Leo 1979)	-
Dielectric constant	Gas: 1.0009 (0°C) (Matheson 1980)	-
	Liquid: 1.70 (-173°C) (Matheson 1980)	-
Solubility		
In water	0.0023 g/100 g (20°C) (0.034 cm^3/cm^3) (Matheson 1980)	-

	Methane	A Typical Natural Gas
In other common materials	Soluble in ethanol, methanol and benzene (CRC 1980)	-
	Solubility in ethanol is 0.023 g/100 mL and in ether, 0.079 g/100 mL (0°C) (Ullmann 1975)	-
Azeotropes	Methane forms an azeotrope or hydrate with water at high pressures. This hydrate ($CH_4 \cdot 6H_2O$) is known as gas hydrates	-

Vapour Weight to Volume Conversion Factor 1 ppm = 0.665 mg/m^3 (20°C) (Verschueren 1984)

Behaviour and Property Studies

Rapid Phase Transitions (RPTs) or Flameless Explosions. The phenomenon of a rapid phase transition or flameless explosion is sometimes observed when a cold hydrocarbon liquid such as LNG is spilled on water. The "explosive" interaction is caused by the rapid transformation to a vapour state. A thin layer of LNG becomes superheated at the water interface and violently expands to the vapour form. No burning or chemical reaction is involved. The energy involved in such transitions has been measured to be on the order of 2 kJ/cm^2 of interface area. The energy of a single explosion is limited by the surface area which can be generated before a further explosion takes place. Often explosions will take place as "pops" since the mixing caused by one explosion prevents further superheated liquid areas from forming in the same area. Measurements in a number of studies have shown that, for small spill amounts, RPTs will only occur with a methane content of 40 percent (by volume) or less. Later studies have shown that RPTs will occur at methane contents of greater than 40 percent if a large spill is involved or if the propane content if high. Enrichment by selective boiling of the methane has been postulated as the reason that RPTs have been observed on spills involving LNG with a starting methane content of over 90 percent. Research to date indicates that RPTs of LNG would not be a major problem (Enger 1972; NMAB 1980; Koopman 1981).

Deflagration to Detonation Transition (DDT). A number of investigators studied the combustion of natural gas mixtures to determine the conditions for a deflagration (burning) to detonation (explosion) transition. The results to date indicate that detonation can occur in confined situations; however, a natural gas containing

90 percent or higher methane will not detonate in open situations. A mixture containing 13.6 to 18.4 percent or higher will detonate (USCG 1980; Parnarouskis 1980).

Combustion. A number of studies on the burning of natural gas (usually from LNG spill experiments) have been conducted. In a series of tests, the U.S. Coast Guard conducted a series of pool fires on a small pond; release rates varied from 0.02 to 0.11 m^3/s of LNG. The burning rates of the liquid were 4×10^{-4} m/s and higher and correlated with the release rate. The flame temperatures were measured as 1500 K. The thermal emissive power was measured as 210 to 220 kW/m^2 - twice the predicted value. This higher value has been subsequently confirmed by other investigators. Flame velocities ranged up to 17 m/s. No fireball or flame acceleration phenomena were observed. All burning was classified as diffusive. Ignition of methane by a heated surface requires a combination of adequate surface area and high temperature (537 to 1200°C, depending on the surface) (USCG 1977, 1980; Parnarouskis 1980; NMAB 1980).

Another study examined the probability of ignition. On the basis of experience, it was concluded that a wide range of ignition probabilities exists. It was noted that most small releases do not ignite; at the other extreme, large releases such as caused by collision and penetration of a tanker almost always ignite (NMAB 1980).

A series of burning tests were conducted on sea near Britain; results similar to the above were obtained. Flame speeds of 5 to 28 m/s were measured; 12 m/s was most typical. The maximum overpressure measured during burning was 0.1 kPa. The thermal radiation measured was 173 kW/m^2 for cloud fires and 203 kW/m^2 for pool fires. The clouds generally burned in a steady, nonexplosive manner. Flames propagated the rich vapour cloud as "walls of fire"; no fireball behaviour was observed. RPTs occurred on one spill test (Blackmore 1982).

Rollover. Rollover (rapid vaporization resulting from lack of mixing) has been reported on several occasions. If LNG is added to a tank containing LNG of different composition, stratification can result if mixing does not occur on loading. If the bottom layer is lower in methane content and is warmer, vaporization is suppressed by the lower-density layer on top. Mixing between layers is slow and only the top layer is in thermal equilibrium with the vapour space. As the bottom layer warms, the density differences become smaller until they are about equal. At this point, the layers mix rapidly - hence the term rollover. When rollover occurs, vapour is released rapidly and often unexpectedly. The danger lies in overpressuring the tank or by the emission of a large vapour cloud from the safety valve (NMAB 1981; USCG 1977).

Vapour Cloud Visibility. The vapour cloud resulting from an LNG spill is visible due to condensation of humidity from the cold gas. One study showed that gas clouds from an LNG spill on water are visible beyond their lower flammability limit (5 percent). The calculated humidity for which the LFL and the visible edge coincided was about 50 percent relative humidity (Blackmore 1982).

Evaporation Rate. The evaporation rate of LNG spilled on the sea surface was measured in one study to be 85 $g/(m^2s)$ (Blackmore 1982). The following are evaporation rates for LNG from various surfaces (NMAB 1980). They are calculated using the formula

$$E = 2\,Bt^{1/2}$$

where: E evaporation rate, in kg/m^2

B = constant as listed below ($kg/m^2\ s^{1/2}$)

t = time

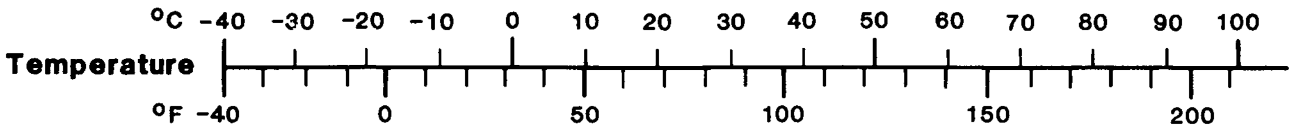
Material	B
Dry sand	0.53
Sand, 1-3 percent moisture	0.58
Soil, 0-8 percent moisture	0.50
Soil, unspecified	0.70
Wet soil (T = 50°C)	1.5
Dry soil (T = 15°C)	1.0
Wet sand	0.46
Insulated concrete	0.047-0.088

Behaviour on Water. When spilled on water, LNG continuously spreads until completely evaporated. Boiling is rapid. No coherent ice layer forms on the water, probably because of the vigorous nature of boiling. Water convection causes the evaporation rate to be relatively constant over time. One study noted that a white material having the appearance of ice remained after a burn and continued to burn somewhat. The material could not be sampled but probably was water ice with trapped LNG (Parnarouskis 1980). In one study, a constant LNG spreading velocity of 0.38 m/s was reported (NMAB 1980).

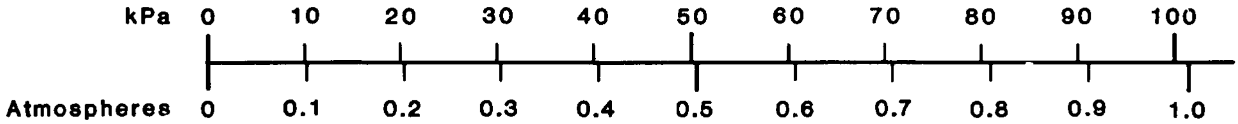
Plume Behaviour. At ambient temperatures, natural gas has a density less than air and thus rises while rapidly dispersing. LNG has a temperature of about -164°C;

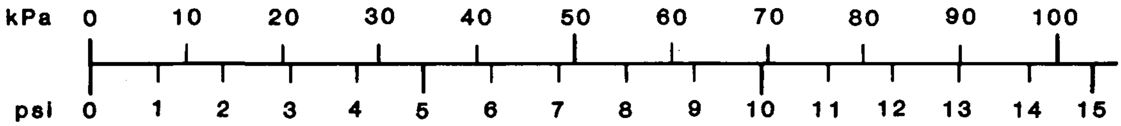
the temperature of the vapour released will be between this and ambient temperature. The density of air and natural gas vapour is equal when the latter is -73°C (Konzek 1982). Thus, vapour from an LNG spill will initially hug the ground and only slowly rise as the vapours approach ambient air temperatures. It has been noted that when wind speed is low and atmospheric conditions are stable, plume movement will be dominated by gravity flow and can displace surrounding air without mixing for a significant period of time (minutes) (Koopman 1981). It has generally been noted that smaller spills of LNG produce more buoyant plumes. In one study, LNG was released under water; this produced a more buoyant plume due to the warming effect of the water (Blackmore 1982).

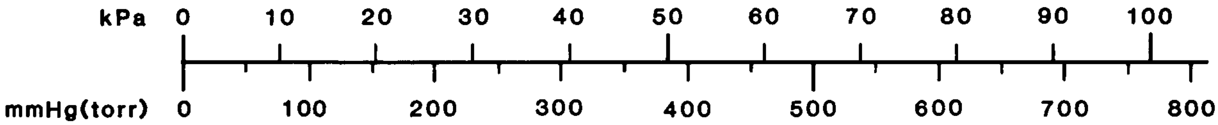
CONVERSION NOMOGRAMS



Pressure 1 kPa = 1,000 Pa







Viscosity

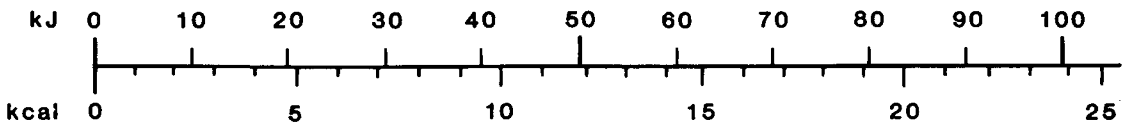
Dynamic 1 Pa·s = 1 000 centipoise (cP)

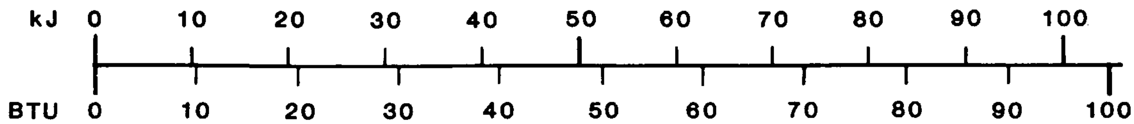
Kinematic 1 m^2/s = 1 000 000 centistokes (cSt)

Concentration (in water)

1 ppm ≅ 1 mg/L

Energy (heat) 1 kJ = 1 000 J





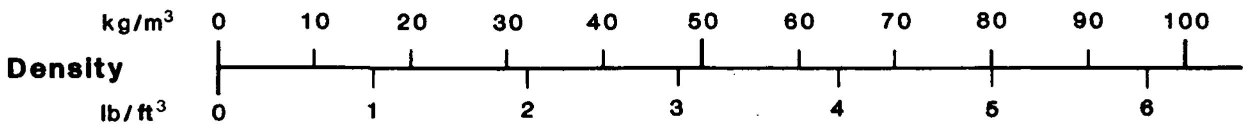


FIGURE 1

METHANE

VAPOUR PRESSURE VS TEMPERATURE

Reference: Chem. Eng. 1975

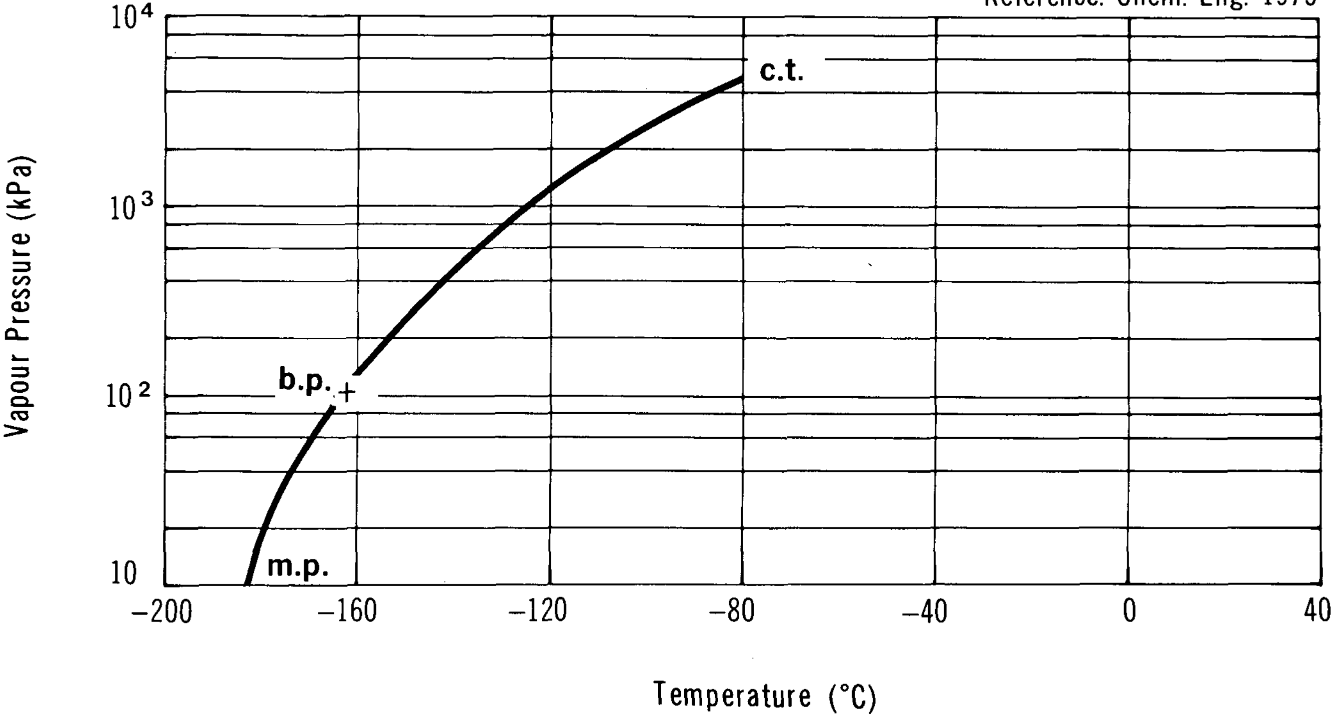


FIGURE 2

METHANE

LIQUID DENSITY vs TEMPERATURE

Reference: Chem. Eng..1975

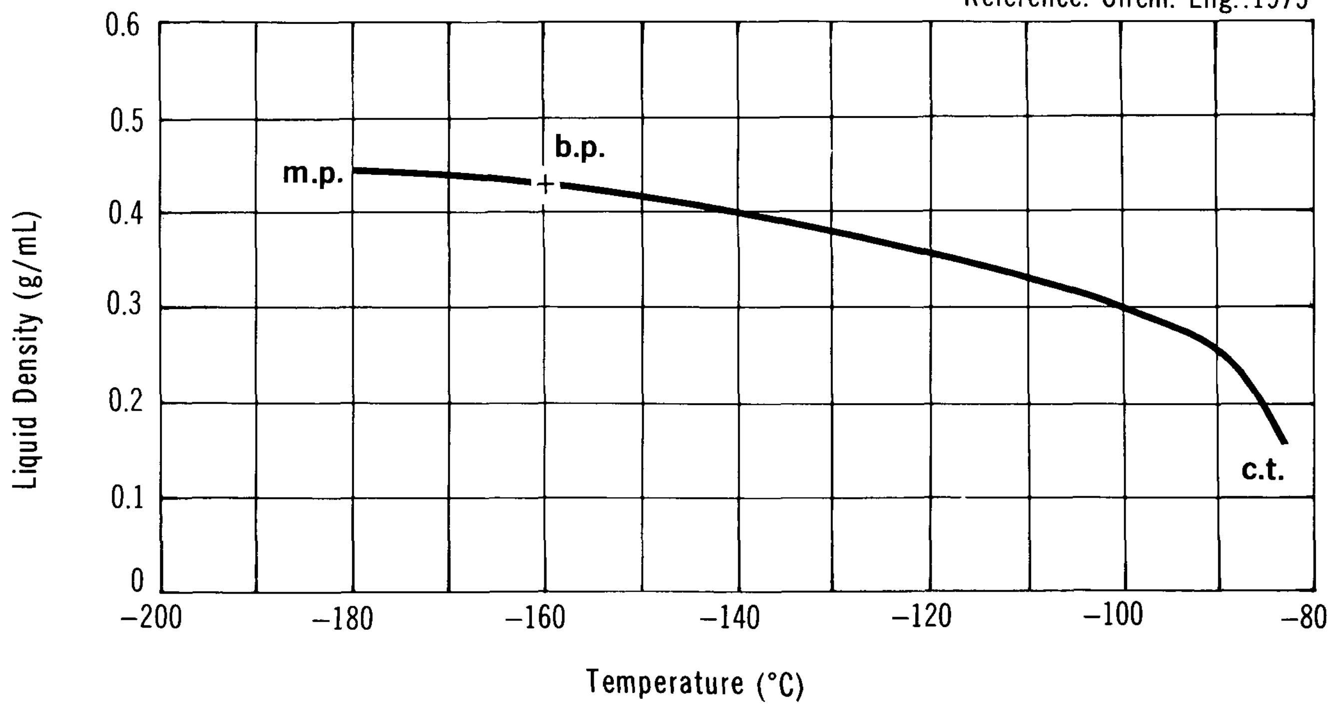


FIGURE 3

NATURAL GAS – TYPICAL COMPOSITION

LIQUID/GAS BALANCE

Reference: HNGE 1959

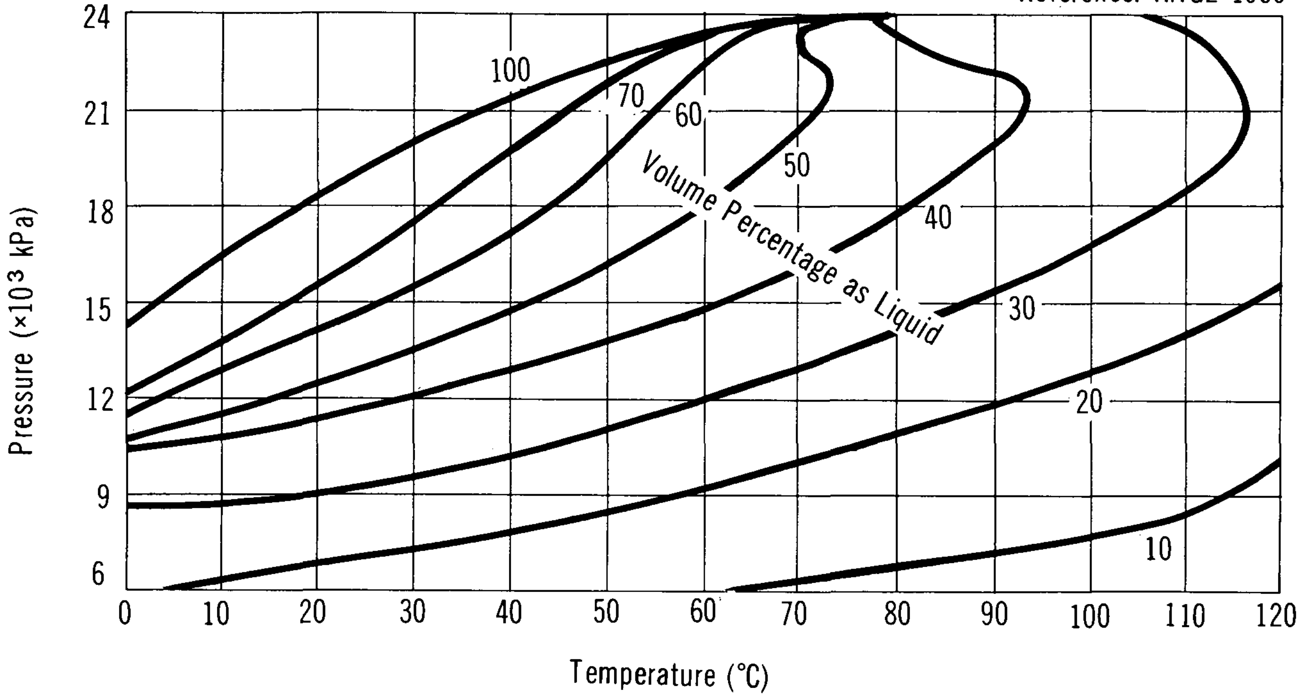


FIGURE 4

LIQUEFIED METHANE

LIQUID VISCOSITY vs TEMPERATURE

Reference: Chem. Eng. 1975

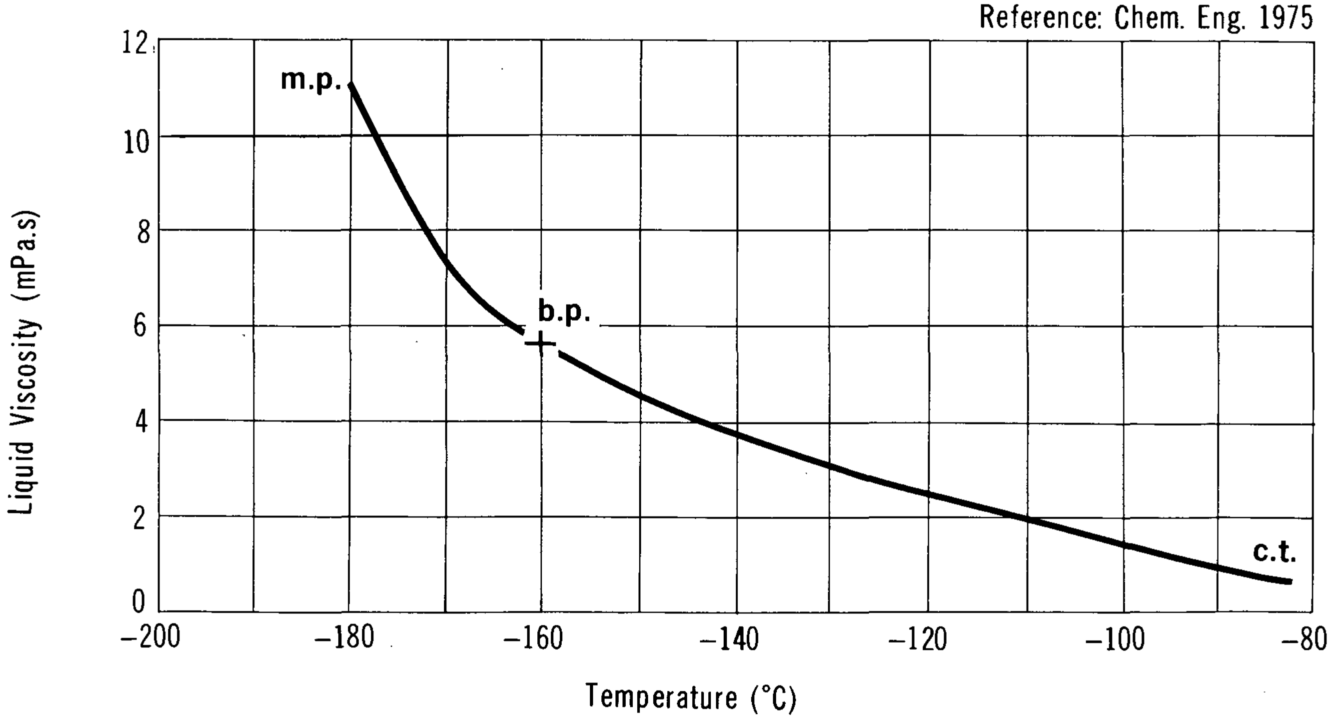


FIGURE 5

METHANE

VAPOUR VISCOSITY vs TEMPERATURE

Reference: Chem. Eng. 1975

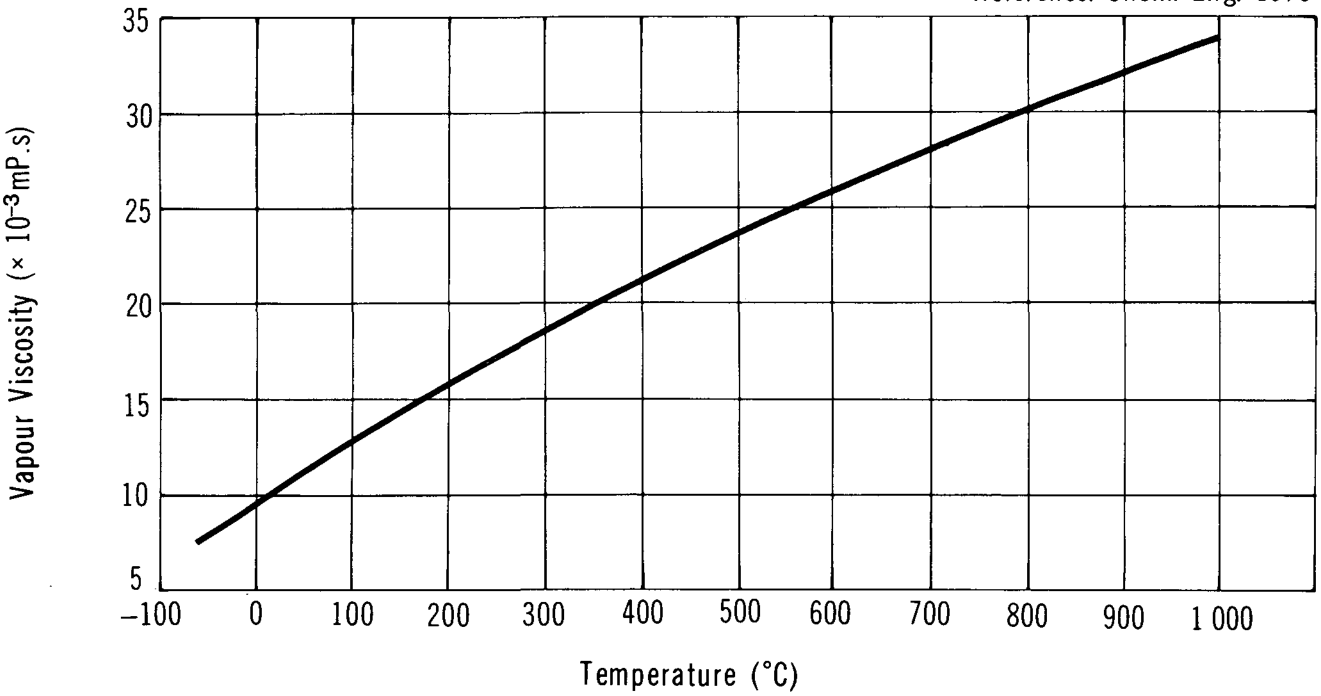
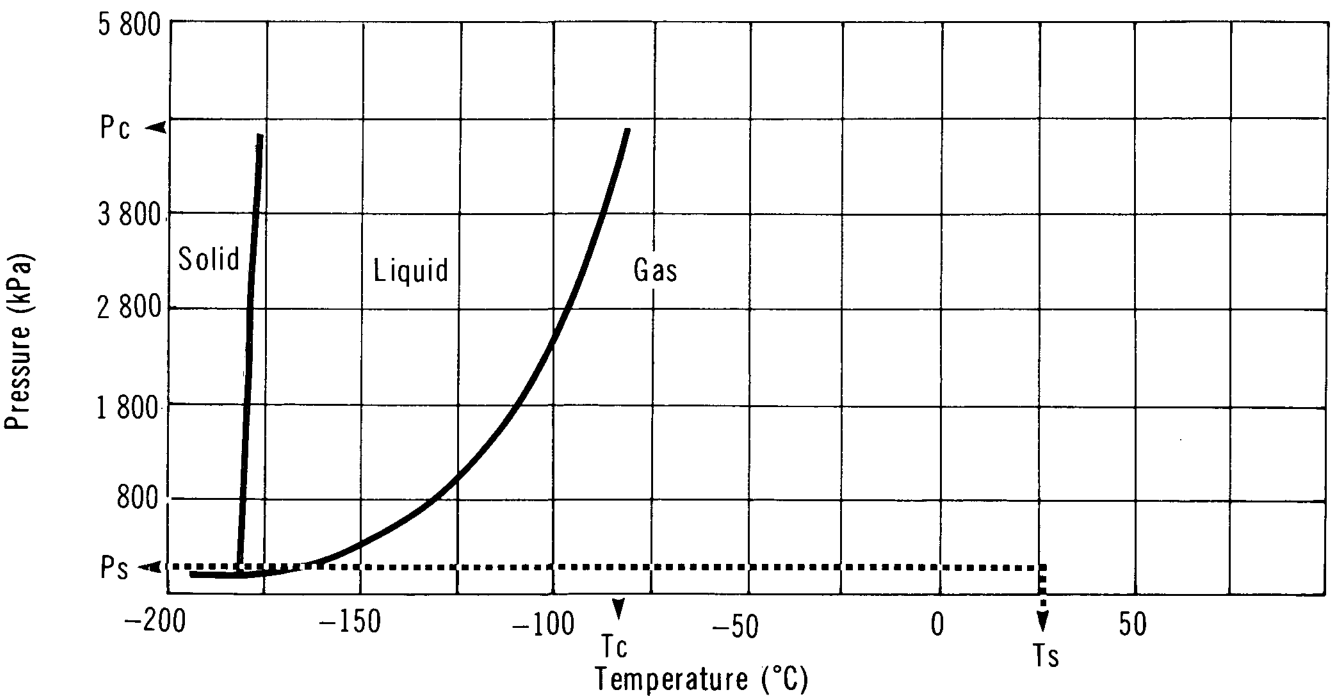


FIGURE 6

METHANE

PHASE DIAGRAM



3 COMMERCE AND PRODUCTION

3.1 Grades, Purities

The composition of natural gas varies widely. Factors used to describe it include:

1) Composition - methane, ethane, butane, propane, etc., content;
2) Refined versus Crude - crude comes directly from wells and often contains hydrogen sulphide, carbon dioxide and condensate. These are largely removed for consumers in refining processes;
3) Sweet versus Sour - sour gas is that which contains significant amounts of hydrogen sulphide (H_2S) and other sulphur compounds; sweet gas has insignificant amounts of these substances;
4) Wet versus Dry - wet gas contains significant amounts of condensate (higher hydrocarbon compounds) and is somewhat similar to gasoline. Dry gas contains little condensable material; and
5) Heat of Combustion - the heat of combustion for a specific blend may be given or specified.

An example of the difference between the content of some of these appears in the following table (Ullmann 1975).

	Sour Gas (Crude)	Sweet Gas (Crude)	Refined Gas
H_2S	7-12% (by volume)	0.017-0.022%	Max. 5 mg/m^3
CO_2	6-12%	5.8-5.9%	2%
N_2	4-6%	3-4%	8%
C_2 and higher	5-20%	5-20%	5-20%
Methane	Remainder	Remainder	Remainder
Organic Sulphur	Max. 500 ppm	Max. 12 ppm	Max. 50 ppm of S
Oxygen	-	-	Max. 0.5%
NO_x	-	-	Max. 0.2 ppm
H_2O	-	-	dewpoint -5°C
Heat of Combustion	-	-	36 000 $\pm$ 420 kJ/m^3

The following tables provide a sample of the compositional differences between natural gases (HNGE 1959; Kirk-Othmer 1980) (values in volume (mole) percent):

	Refined			Crude							
	A	B	C	D	E	F[1]	G[2]	H	I	J	K
Methane	73.5	73.1	95.6	94.1	76.5	72	88.8	96.7	98.5	70	65.8
Ethane	25.7	6.1	3.6	2.7	7.9	9.9	4.8	2.1	0.9	3.0	3.8
Propane	0.2	3.4	0.5	0.9	4.3	5.1	2.7	0.5	0.2	1.4	1.7
Isobutane	-	0.2	-	0.2	1.2	0.7	0.4	0.1	0.1	0.3	0.4
n-Butane	-	0.6	-	0.3	1.9	1.7	0.2	0.1	0.1	0.3	0.4
C_5 + higher	-	-	-	0.7	5.9	1.9	0.7	0.6	0.1	-	0.5
Nitrogen	0.6	15.8	0.3	-	1.4	-	0.2	-	-	-	25.6
Carbon dioxide	-	-	-	-	0.7	-	2.3	0.3	0.3	-	-
Hydrogen[3] sulphide	-	-	-	-	-	-	-	-	-	15	-

1. Attributed to a well near Leduc, Alberta.
2. Attributed to a well near Viking, Alberta.
3. Hydrogen sulphide content is highly variable, ranging in value from parts-per-million for a sweet or refined gas, to 5-10 percent for a sour gas; analysis on one well in Alberta showed a hydrogen sulphide content of 85 percent which is unusually high but demonstrates the possible range.

3.2 Domestic Manufacturers (CMR 1979)

3.2.1 General. Natural gas is produced at a large number of wells - over 3500 successful gas wells were being drilled in 1979 alone. Alberta produces most of this, some 86 percent, with British Columbia producing 12 percent and Saskatchewan, Ontario and the North West Territories the balance. Net production in 1979 was 64 000 Mm^3.

3.2.2 Natural Gas Processing Plants in Canada (Oil Week 1984).

Area	Location	Operator	Process Type[1]	Raw Gas Capacity (x 1000 m^3/d)
ALBERTA				
Abee	1-32-61-22W4	Camel	D-DEA-C-R	310

Area	Location	Operator	Process Type[1]	Raw Gas Capacity (x 1000 m^3/d)
Acadia	6-19-26-4W4	JSE Enterprises	A-D	28
Acadia Valley	13-12-26-2W4 (Graindale)	Acadia Valley Gas	D-C-Spn-R	178
Acheson	SW2-53-26W4	ICG Exploration	Ab-MEA	281
Alderson	W 10-28-15-15W4	PanCanadian	Ab-Stb-R	282
Alderson	6-2-16-15W4	PanCanadian	DEA	85
Alix	11-20-39-23W4	Landbank	R	187
Amisk	1-22-41-8W4	Dome Petroleum	C-R-IS	292
Ante Creek	NW18-65-23W5	Amoco	R-D-MEA	282
Ante Creek	4-13-65-24W5	Amoco	R-Stb	56
Ante Creek	10-4-66-23W4	Amoco	R	282
Atim	10-19-54-26W4	Quasar	C-R	84
Bantry	15-23-18-14W4	Delta Consultants	R-DEA	22
Bantry	4-33-17-12W4	Goliad Ltd.	C-R-MEA	130
Bantry	8-19-13W4	Merland	C-D-MEA	394
Baptiste	5-28-67-22W4	Gulf Canada	D-C-Spn-IS	296
Baptiste (Isl L)	8-68-23W4	Dome Petroleum	C-MEA	110
Baptiste	1-20-67-22W4	Marathon	R-IS	73
Bashaw	10-6-42-22W4	Gulf Canada	D-R	84
Bashaw	8-10-42-22W4	Home Oil	C-A	338
Bassano	10-5-22-18W4	PanCanadian	A	704
Beaverhill Lk	4-17-52-18W4	Merland	C-R	141
Belloy	7-18-78-2W6	BP Expln Ltd.	R-DEA	169
Bellshill Lk	1-35-41-13W4	Inelco Ind.	C-R	58
Bellshill Lk	3-28-41-12W4	Petro-Canada	R-MEA	60
Berry	4-30-27-11W4	Bow Valley	D-R-Spn	169
Berry	6-19-27-12W4	Bighart	R	34
Berry	2-4-27-13W4	Ladd Explor	R	64
Big Bend	13-36-66-27W4	Sulpetro	D-MEA	986
Big Bend	5-14-67-2W5	Home Oil	D-MEA	298
Big Bend	13-36-66-27W4	Pennzoil	D-IS	563
Big Bend	2-7-67-26W4	Dome Petroleum	D	212
Big Coulee	10-23-67-24W4	Cavalier	MEA	14
Bigoray	6-28-51-8W5	Amoco	R-MEA	375
Bigoray	9-8-51-9W5	J M Huber	R-DEA	30
Bigoray	10-7-51-9W5	Chevron	R-DEA	92
Bigoray	10-22-51-8W5	Norcen	R	84
Bigstone	10-61-22W5	Amoco	R-Sfl	1 577
Bittern Lk	11-27-46-21W4	BP Expln	D-R	169
Black Butte	1-18-1-8W4	Cdn-Montana	A-MEA	281
Black Diamond	10-12-19-2W5 (Hartell)	Suncor	R-MEA	347
Blood	7-8-6-22W4	Gulf	R	325
Blueberry Mtn	11-16-82-7W6	Dekalb	R-D	431

Area	Location	Operator	Process Type[1]	Raw Gas Capacity (x 1000 m^3/d)
Bonnie Glen	SW17-47-27W4	Texaco Canada	Ab-MEA-R	3 097
Bonnie Glen	SW17-47-27W4	Texaco Canada	R-C-MEA-T-A	4 226
Boundary Lk	10/15-13-86-13W6	Golden Eagle	R-C-D-MEA	206
Boundary Lk	SE14-85-13W6	Esso Resources	A-D-MEA	789
Boundary Lk	S10-10-84-12W6	Golden Eagle	IS	17
Bouvier	15-29-70-24W4	Dome	C-D-MEA	148
Braeburn	16-19-77-10W6	Dome	D-C-MEA	158
Brazeau R.	W10-44-12W5 (Nordegg R.)	Canterra	A-D-MEA	1 897
Brazeau	16-35-48-12W5	Chevron	R-D-DEA	282
Brazeau-Elk R.	4-6-47-12W5	Dome Petroleum	R-DEA	199
Brazeau R.	1/12-46-14W5	Dome	Ab-DEA-R	6 180
Brazeau	SW31-48-12W5	Petro-Canada	R	509
Bruce	SW6-47-15W4	Norcen	A-C	845
Buffalo Lk	11-24-41-21W4 (Regnier)	Gulf Canada	C-R-Spn	197
Buffalo Lk	N11-25-42-21W4	Kandex	R	99
Burnt Timber	10-13-30-7W5	Shell Canada	A-Sfl	3 610
Cache	1-32-59-13W4	Brenda Mines	C-D	424
Calling Lk	S1-20-70-22W4	Suncor	DEA-C-D-R	282
Calling Lk	33-71-17W4	Suncor	D	423
Campbell-Namao	13-12-54-25W4	Oakland	R-IS	127
Camrose	1-25-46-19W4	Ranger	R-D-C	141
Carbon	3/6-3-29-23W4	Bumper	A	201
Carbon	8-17-29-22W4	Can. Western NG	R	3 944
Caroline	12-36-34-6W5	Altana	R-MEA	366
Caroline	3/4-20-34-4W5	Dome	A-R-DEA	1 520
Caroline	1-11-35-6W5	Dome Petroleum	R-DEA-C	1 479
Caroline	3-26-33-6W5 (Wwd Ho)	Citadel	R-DEA	510
Carrot Ck.	2-18-52-11W5	Amoco	R	875
Carrot Ck.-Granada	10-16-53-13W5	Sabine	R-C	225
Carson Ck.	N4-23-61-12W5	Mobil Oil	R-Ab-DEA	2 450
Carstairs	7-13-30-2W5	Lochfayne	R	43
Carstairs-Crsfld	SE3-30-2W5	Home Oil	R-Ab-DEA-C	9 861
Castor	4-3-38-13W4	Sulpetro	D-R-Spn	42
Cecil	6-10-84-8W6	Shell Canada	R	149
Cessford	4-15-27-15W4	Amerada	A-D	620
Cessford	11-11-26-15W4	Flamingo	R-D-DEA	72
Cessford	7-17-26-14W4	Francana	R	197
Cessford	2-8-24-12W4	HBOG-Candel	C-R	3 521

Area	Location	Operator	Process Type[1]	Raw Gas Capacity (x 1000 m^3/d)
Cessford	7-5-26-12W4	Sabine	C-R	141
Cessford	2-31-22-11W4	Placer-CEGO	A-D	620
Cessford	3-6-24-10W4	Canterra	A-D	239
Chain	7-23-33-16W4	Citadel Res.	A-R	212
Chard	14-32-79-5W4	Paramount	C	230
Cherhill	4-24-56-5W5	Dome Petroleum	R-DEA	127
Chigwell	11-8-41-23W4	Bluesky Oil	R-D	142
Chigwell	9-7-41-24W4	Esso Resources		
Chigwell	5-22-41-25W4	Ladd Expl.	R	57
Chinchaga	N5-32-98-7W6	Chevron	CO_2 strip	241
Chin Lake	N7-9-9-17W4	Koch Expl (pilot)	CRemsweet	84
Chip Lake	10-29-53-10W5	Lario O & G	R-Stb	135
Clive	6-24-40-24W5	Blake Min	R-D	56
Cluny	4-1-22-21W4 (Gleichen)	KanEnergy	R	148
Coleman	SE11-8-5W5 (Savanna Ck)	Saratoga Proc.	Ab-MEA	1 465
Compeer	6-26-33-2W4	Western Decalta	R-Sw	183
Connorsville	9-32-25-15W4	Petro-Canada	R-D-Ab	563
Corbett Ck	13-26-61-8W5	North Canadian	D-C-R-Spn	254
Countess	12-33-22-18W4 (Makepeace)	PanCanadian	Ab-D-C	1 410
Countess	10-20-18-15W4	PanCanadian	R-DEA	172
Countess	8-36-20-16W4	Suncor	A-D	620
Coyote	NE33-28-15W4	Maynard	R	338
Cranberry	4-20-96-3W6	Shell	Selexol-R-D	443
Cranberry	4-20-96-3W6	Shell	R-C	540
Cranberry	1-24-96-5W6 (Chinchaga)	Dome Petroleum	R-C-DEA	2 500
Crossfield	8-20-30-3W5	Steen Resources	D-C-Spn-R	56
Crossfield	1-2-26-29W4 (Balzac)	Petrogas	R-Ab-DEA-Sfn	8 988
Crossfield E.	9-14-28-1W5	Amoco	R-Sfl-C-Sfn	5 128
Crossfield E.	9-14-28-1W5	Procor	S granules	
Crystal	16-36-45-4W5	Bumper Dev.	R	113
Cutbank-Route	7-16-62-8W6	Dome Petroleum	R	1 981
Cyn-Pem	7-7-51-11W5	Highland Res.	R	169
Cyn-Pem	9-16-51-11W5	Champlin	R	23
Davey	11-35-34-27W4	Can. Superior	D-R	268
Deanne	6-36-38-11W5 (Phoenix)	Can. Occid.	R	42
Dobson	8-21-29-9W4	Sundance	R-C-Stb	141
Drumheller	6-33-30-19W4	Bluesky	R	169
Drumheller	10-23-29-20W4	Dome Petroleum	A-R	1 375
Duhamel	3-32-45-21W4	Mobil Oil	R	106
Duhamel	5-31-45-20W4 (Bittern L.)	Panther Res.	Sepasolv	275

Area	Location	Operator	Process Type[1]	Raw Gas Capacity (x 1000 m^3/d)
Dunvegan	15-3-81-4W6	Anderson Exp.	R-Spn-A	6 762
Eaglesham	5-13-77-26W5	Can. Occidental	R	225
Eaglesham S.	2-14-77-25W5	Dome	R-DEA	113
Edson	3/4-11-53-18W5	Dome	R-A-DEA	10 537
Edson	10-30-52-17W5	Sabine	R	70
Edson	16-15-53-18W5	Sabine	A-R	206
Edson	1-13-54-19W5	Sabine	R	112
Elmworth	4-8-69-8W6	Sulpetro	R	3 381
Elmworth	7-5-69-9W6	Sulpetro	IS	425
Elmworth	SE8-70-11W6	Can. Hunter	A	12 678
Elnora	5-19-35-22W4	Kerr McGee	D-C-R	510
Enchant	10-35-15-16W4	Int. Mogul	R	85
Enchant	11-35-13-17W4	Suncor	A-Spn	563
Entice	SE24-28-24W4	Canterra	A	289
Entice	10-7-28-23W4	PanCanadian	C-R-D-Stb	197
Esther	6-9-31-1W4 (N. Sibbald)	Gulf	C-D-IS	141
Fairydell Bon. Acc.	NE-20-56-23W4	NUL	R	423
Fenn-Big Valley	8-27-35-19W4	Merland	R-C	226
Ferintosh	8-12-44-21W4	Hewitt Oil	R-D	141
Ferrier	2-6-41-7W5	Amerada	R	2 817
Ferrier	14-20-38-7W5	Esso Resources	R-D	280
Ferrier	SE34-40-9W5	Norcen	R-D	580
Ferrier	7-24-39-9W5	Oriole	R-Deeth	42
Ferrier	9-22-39-8W5	Petro-Canada	R	225
Ferrier	1-20-39-7W5	Texas Pac.	R	563
Ferrybank	14-11-45-27W4	Chevron	R-D-Deeth	148
Ferrybank	3-31-44-27W4	Kerr McGee	R	240
Ferrybank	2-1-44-28W4	PanCanadian	R	732
Ferrybank	5-21-45-27W4	Cimarron	R-DEA	225
Ferrybank	14-33-43-27W4	Ocelot	R-DEA	230
Forestburg	13-14-42-16W4 (Heisler)	Signalta	R-C	369
Fort Saskatchewan	N14/S23-55-22W4	Dome	IS-Fcn	7 840
Fort Saskatchewan	S14-55-22W4	Chevron	Fcn	4 452
Galloway	14-14-53-20W5	Ranger	R-DEA	434
Garden Plains	W15-33-13W5	Eden Gas	A-C	282
Garrington	2-20-34-3W5	Amerada	D-C	197
Garrington	13-5-34-3W5	Dekalb	R	304
Garrington	11-17-34-3W5	Dome Petroleum	R-A-C	563
George	9-7-82-5W6	Sundance	D-R-Stb	431

Area	Location	Operator	Process Type[1]	Raw Gas Capacity (x 1000 m^3/d)
Ghost Pine	8-11-31-21W4	Gulf Canada (Morrin)	D-R	3 099
Ghost Pine	10-4-32-23W4	Canterra	C-D-R	85
Gilby	6-21-40-2W5	PanCanadian	R-D-C	59
Gilby	10-10-41-3W5	ICG	A-IS	341
Gilby	1-24-41-3W5	Chevron	A-Ds	620
Gilby	6-36-40-3W5	Gen. American	R-D-C	71
Gilby	6-13-40-3W5	Gulf Canada	A-Ds	704
Gilby	8-26-40-3W5	Dome	A-Ds	254
Gilby	9-12-41-4W5	Dome	R	130
Gilby	10-8-41-1W5	Norcen	D-R-Dth	99
Gilby	2-27-40-3W5	Petro-Canada	Dth-R-DEA	704
Gilby	7-27-40-3W5	Petro-Canada	D-C-R	118
Gilby	15-22-40-3W5	Texaco Canada	A-R-Ds	1 634
Gilby	10-12-41-3W5	Total Petroleum	A-Ds-DEA	282
Gilby-Med. R.	5-5-40-3W5	Petro-Canada	R-A-MEA	793
Girous Lk-Steele	10-11-66-22W4	Merland	R	85
Gladys (Blackie)	6-15-20-27W4	Sabine	R	148
Gleichen	2-30-22-22W4 (Blackfoot)	Grand Pix	C	85
Gold Creek	NW27-67-5W6	Petro-Canada	R-DEA	648
Golden Spike	NW22-51-27-W4	Esso Resources	C-Cyc-DEA	197
Goodwin	10-36-59-13W5	Ranchmen's	R	9
Gordondale	NW24-79-11W6	Shell	D	432
Graham	11-19-80-4W4	ICG	C	1 568
Granor	7-25-83-18W4	Paramount	C	437
Greencourt	9-26-59-9W5	Petro-Canada	D-Ab	1 050
Gunn	14-8-55-3W5	Glenora Res	R	57
Hackett	11-20-3517W4	Bow Valley	R-C-D	197
Halkirk	2-34-38-16W4	Husky	R	141
Hanlan	11/12-49-20W5	Gulf Canada	R-DEA-Sfn	8 610
Hanna	2-36-31-14W4	Gulf Canada	R	85
Hanna	6-1-31-14W4	Samedan	C-D-Spn-R	113
Hanna	SE25-31-14W4	Westcoast Petroleum	A-R	508
Hardisty	NW20-42-9W4	Gibson	Fcn	340
Harmattan Area	9-27-31-4W5	Can. Superior	R-DEA	13 890
Harmattan	10-27-31-4W5	Can. Superior	Sfl	704
Harmattan Elkton	2-3-31-4W5	Home Oil	R-MEA	141
Haro (Bassett)	10-29-106-5W6	Can. Hunter	C-D-R-Spn	113
Haro (Haig R.)	11-33-104-5W6	Can. Hunter	D-R-C-Spn	225
Heisler	4-26-41-16W4	Voyager	R-C	56

Area	Location	Operator	Process Type[1]	Raw Gas Capacity (x 1000 m^3/d)
Hercules	6-34-51-23W4	Redco Expl.	D-R	85
Highvale	10-4-51-4W5	Andex	R-MEA-Dth	211
Hill	10-33-85-11W6 (Clear R.)	Conwest	R	28
Holmberg	11-16-44-18W4	Ranchmen's	R-D	197
Homeglen-Rimbey	S5-44-1W5	Gulf Canada	Ab-R-MEA	11 918
Hotchkiss	2-35-94-2W6	Dome Petroleum	C-D	585
Hotchkiss	6-6-94-1W6	Dome Petroleum	IS	80
Hotchkiss	7-13-94-3W6	Paloma	C	168
Hotchkiss	SW35-94-2W6	West. Decalta	C-D-Sfl	563
Hotchkiss	7-31-93-1W6	West. Decalta	IS-D	58
House Algar	16-1-82-17W4	Chevron	IS-C	211
Hudson	4-31-30-2W4	Petrodyne	R-Stb	169
Hussar	13-36-24-21W4	Canterra	R	2 367
Hussar	6-33-24-18W4	Czar Resources	C-D-R-Ab	316
Hussar	2-1-27-21W4	Pennzoil	C-D-R	437
Hussar	14/15-1-24-22W4	PanCanadian	R-C	790
Huxley	6-17-34-24W4	Francana	A	352
Inland (Lavoy W)	4-25-51-15W4	Dome Petroleum	D-R-C-Sp-St	211
Innisfail	1-3-35-1W5	Shell Canada	R-MEA	564
Irish	5-27-50-10W4	Sulpetro	R-C	566
Jarvie	15-5-62-1W5	Canterra	R	324
Joarcam	13-11-48-20W4	Bow Valley	R	113
Joarcam	7-14-50-22W4	Norcen	R	85
Joffre	13-12-38-27W4	Suncor	R	170
Joffre N.	11-31-39-26W4	Bluesky	R-C	28
Joffre	14-36-38-27W4	Chevron	R-C-Dth	254
Joffre	15-17-39-26W4	Esso Resources	R-A-MEA	127
Joffre	16-12-38-25W4	Petromark Min.	R-C	23
Josephine	NE1-83-10W6	Amoco	R-D	1 409
Judy Creek	15-25-64-11W5	Esso Resources	A-R-MEA	7 466
Judy Creek	19-64-11W5	Norcen	A-D	141
Judy Creek	1-21-63-11W5	Sceptre Oils	R-D	141
Judy Creek	8-24-63-10W5	Canterra	C-R	113
Jumping Pound	13-13-25-5W5	Shell Canada	R-Ab-MEA	7 262
Karr	NW10-65-2W6	Can. Hunter	R	1 195
Kaybob	8-9-64-19W5	Petro-Canada	C-R-DEA	3 149
Kaybob	11-36-63-19W5	Conwest	D-R-C	56
Kaybob S. (Fir.)	15-59-18W5	Chevron III	Ab-R-DEA	13 805
Kaybob S.	1/12-62-20W5	Dome 1	Ab-R-DEA	6 395
Kaybob S.	3/4-12-62-20W5	Dome 2	Ab-R-DEA	4 790
Kaybob S.	13-22-60-19W5	Dome	C-D-R-Spn	445

Area	Location	Operator	Process Type[1]	Raw Gas Capacity (x 1000 m^3/d)
Kaybob	1-4-62-21W5	Dome Petroleum	R-Spn-Stb	423
Kaybob S.	9-34-60-18W5	Numac	R	184
Kaybob S.	10-22-61-20W5	Samedan	C-D-R-Stb	28
Killam	10-27-42-13W4	Husky	C-D-MEA	141
Killam	4-5-44-9W4	Ranger	D-R	282
Killam	10-11-46-14W4	Ranger	C	85
Killam	12-23-43-11W4	Suncor	A	564
Killam (Hattie L.)	14-16-46-12W4	Voyager	R-D	283
Killam	1-17-42-13W4	Zoller & Danneberg	D-C-DEA	169
Killam N.	8-14-44-13W4	Can. Superior	R-C	67
Killam N.	SW5-45-12W4	Voyager	IS	704
Killam	SW27-41-13W4 (Sedgwick)	Voyager	Ab-DGA	56
Killam (Hardisty)	15-11-43-9W4	Voyager	R-C	225
Kirby	NW25-73-5W4	Amoco	D-C	1 500
Kirkwall	1-29-27-5W4	Bonanza	R	140
Knobhill	3-23-46-2W5	Texaco Canada	D-R-DEA	57
Knopcik	9-10-74-11W6	Turbo	R-C	398
Lacombe	7-28-40-26W4	Sulpetro	R-C	145
Leahurst	15-18-40-18W4	Husky	A	282
Leahurst-Gadsby	6-16-39-19W4	Czar Resources	R-C-Ds	169
Leaman/Niton	11-10-56-11W5	Dome Petroleum	D-R	502
Leduc/Wbd	2-34-50-26W4	Esso Resources	C-R-MEA	1 071
Leduc-Wbd	5-20-49-25W4	West. Decalta	D-R-DGA	141
Leedale	7-11-43-4W5	TransCanada GP	D-Spn	113
Leo	NW24-36-17W4	Wainoco	R	563
Liege	6-29-92-20W4	Paramount		1 000
Little Bow-Travers	16-31-14-18W4	Dome Petroleum	R-DEA-C	524
Lone Pine Ck	6-27-29-28W4	Can. Superior	R-DEA	986
Lone Pine Ck	6-23-30-28W4	Dome	R-C-DEA	2 096
Long Coulee	6-30-15-21W4	PanCanadian	R-DEA	230
Lookout Butte	4-13-2-29W4	Gulf Canada	R-d	840
MacLeod R.	7-34-54-14W5	Norcen	R	147
Magee	11-20-42-25W4	Can. Reserve	R	169
Majeau Lake	9-16-57-3W5	Bonanza	R	395
Manyberries	6-18-6-6-W4	Cimarron	R	60
Maple Glen	15-36-36-16W4 (Leo)	Wainoco	C-R	310
Marten Hills	18-76-25W4	Amoco	A-D-C	4 029
Marten Hills	11-20-74-23W4	Atco	MEA	99

Area	Location	Operator	Process Type[1]	Raw Gas Capacity (x 1000 m^3/d)
Marten Hills	14-22-74-24W4	Home Oil	D-IS	704
Marten Hills	NW29-74-25W4	Home Oil	D-Sw-MEA	237
Matziwin	6-10-23-14W4	Oakwood Petroleum	D-R	70
Meanook	6-10-63-22W4	Dome Petroleum	DEA-Sw	148
Medicine R.	6-16-38-4W5	Dome Petroleum	R-Spn	225
Medicine R.	10-14-39-3W5	Sabine	R-DEA	173
Michichi	SW8-31-18W4	Maynard	C	169
Mikwan	10-8-37-23W4	Ceja Corp	A-D-R	394
Mikwan	9-21-38-23W4	Cimarron	R	29
Mikwan	9-16-37-22W4	Pancana	R	200
Minnehik-Buck Lk	10-5-46-6W5	Sulpetro	A-C-MEA	3 043
Mirage	10-2-79-8W6	Anderson Exp	C	44
Mitsue	30-72-4W5	Chevron	R	850
Mitsue	7-28-71-2W5	Landbank	D-Spn	235
Monitor	10-3-35-4W4	Altana	C-D-R-Sw	141
Morinville	SE26-54-25W4	Norcen	Ab	564
Morley	NE2-26-7W5	PanCanadian	R-C-Selexol	282
Mundare	9-28-53-18W4	Voyager	R	423
Nevis	15-22-39-22W4	Chevron	R-DEA	2 254
Nevis	NW7-41-22W4	Dekalb	R	884
Nevis	9-33-38-22W4	Gulf Canada	Ab-R-MEA	3 522
Nipisi	30-72-4W5	Amoco	R	704
Niton	16-55-13W5	Altana	D-R	141
Niton	14-18-54-12W5	Esso Resources	R-Dth	1 784
Niton (McLeod)	7-34-54-14W5	Norcen	D-R	147
Normandville	13-9-79-22W5	Norcen	R-C	217
Okotoks	SW27-20-29W4	Kidd Creek Mines	A-MEA	981
Olds	6-18-32-1W5	Amerada	R-Ab-MEA	2 381
Olds	16-21-33-1W5	Norcen	C-D-R	54
Open Creek	9/10-34-42-5W5	Texaco	R-DEA	225
Oyen	16-26-29-4W4	Amer. Trading	A-D	70
Oyen	SW3-28-3W4	Dorchester	R-D	70
Oyen	14-36-28-5W4	Dome	A	113
Oyen	11-17-29-4W4	Canterra	C-D-Spn-A	113
Paddle R.	13-6-57-8W5	Can. Oxy	R-D-MEA-T	2 440
Parflesh	12-1-25-22W4	PanCanadian	A-D	56
Parkland	NE7-11-15-27W4	Czar Res.	R	846
Peco	12-1-49-16W5	Ocelot	R-C	986
Peco N.	11-27-48-16W5	Novalta	D-R	99
Pembina-Alder Fl.	10-25-45-9W5	Dome Petroleum	R	28
Pembina	SW2-50-6W5	Amoco	R	366
Pembina	9-17-50-7W5 (Lobstick)	Amoco	R	1 250

Area	Location	Operator	Process Type[1]	Raw Gas Capacity (x 1000 m^3/d)
Pembina	NW24-48-7W5	Amoco	Fcn-NGL	1 145
Pembina	NW25-48-7W5	Amoco Stn 1	R	232
Pembina	E15-47-7W5	Amoco Stn 2	R	453
Pembina	NE5-49-7W5	Amoco Stn 3	R	310
Pembina	NE16-49-8W5	Mobil Stn 4	R	310
Pembina	SW2-48-8W5	Amoco Stn 5	R	197
Pembina	SW34-47-9W5	Amoco Stn 7	R	387
Pembina	SW5-49-9W5	Amoco Stn 8	R	310
Pembina-Bigoray	17-50-7W5	Amoco	R	564
Pembina	6-15-48-3W5	Dome Petroleum	R	211
Pembina	NE36-47-4W5	West Decalta	D-R-Dth	94
Pembina	11-31-49-5W5	Lorne H Reed	R	56
Pembina	5-35-48-4W5	Can. Oxy	R	580
Pembina	15-22-48-2W5	Star Oil & Gas	D-R	141
Pembina	13-22-49-10W5	Texaco Canada	R-MEA	296
Pembina W.	11-22-49-12W5	Chevron/Norcen	R-C-DEA	838
Penhold	10-30-36-27W4	Ceja Corp	R	186
Phoenix	7-21-39-10W5	PanCanadian	Ab-D	70
Pincher Ck.	S23-4-29W4	Gulf Canada	A-DEA	2 536
Pouce Coupe	7-8-80-12W4	Shell Canada	D-Spn-R	85
Princess	12-12-20-12W4	Chevron	A-MEA	366
Provost-Amisk	7-20-40-10W4	Sulpetro	R-DEA	85
Provost	9-2-35-9W4	Nova	A-C	564
Provost	2-2-37-13W4	Aries Res	R	259
Provost	11-14-39-7W4	Carlyle Eagle	MEA	14
Provost (Choice)	5-27-40-10W4	Blake Min	R	197
Provost (Choice)	10-21-40-9W4	Dome Petroleum	D-Ab-DEA	28
Provost	7-34-34-6W4	Chieftain	A	338
Provost	5-16-33-7W4	Placer CEGO	C-R	158
Provost	10-12-36-8W4	TransC. Res.	A	338
Provost (Castor)	4/5-3-38-13W4	Dome Petroleum	C-A	564
Provost	3-30-37-2W4	Dome Petroleum	C-D-A	268
Provost	2-2-39-11W4	Dome Petroleum	A-Ds	564
Provost (Choice)	NW17-40-9W4	Dome Petroleum	A-Stb	281
Provost-Kirk L.	13-9-33-8W4	Dome Petroleum	R	47
Provost	2-3-35-5W4 (Monitor)	Dome Petroleum	D-C-Spn-R	183
Provost	12-5-39-8W4 (Kessler)	Norcen	A	169

Area	Location	Operator	Process Type[1]	Raw Gas Capacity (x 1000 m^3/d)
Provost	8-19-36-5W4	Provo Gas	A-R	2 000
Provost	NW5-39-8W4 (Kessler)	Ranchmen's	R	169
Provost	NE31-37-2W4	Norcen	C-D-R	189
Provost	15-20-34-8W4	Canterra	R-Spn	282
Provost	6-7-33-8W4	Canterra	R	99
Quirk Ck	4-21-4W5	Esso Resources	D-R-DEA-Sfl	2 635
Rainbow	10-10-109-8W6	Canterra	R-MEA	2 800
Rainbow	12-23-110-7W6	Esso Resources	D-MEA-R	373
Rainbow	10-110-6W6	Mobil Oil	R	592
Rainbow S.	25-7-108-6W6	Petro-Canada	C-D-R-Spn	404
Ram River	6-2-37-10W5	Canterra	R-DEA-Sfn	17 749
Redwater	8-25-57-23W4	Star Oil	R-C-Stb	183
Redwater (Lamont)	5-14-55-19W4	Voyager	R	282
Redwater	SE29-57-21W4	Esso Resources	R-MEA	648
Redwater	15-16-56-20W4	NSM Resources	R	85
Red Willow	6-20-40-16W4	Husky	D-MEA	99
Red Willow	14-11-39-16W4	Merland	D-C-R	99
Red Willow	16-28-38-15W4	Pangaea	R	113
Retlaw (Turin)	12-19-12-18W4	Turin Gas	D-R-DEA	423
Retlaw	11-2-13-19W4	Home Oil	A-D-C-IS	248
Rich	16-22-35-21W4	Kerr McGee	R	88
Rich	1-19-35-21W4	Ranger Oil	C-D-Spn-Dth	158
Richdale	7-9-30-12W4	Dome Petroleum	A-R-D-Stb	282
Ricinus	6-31-33-7W5 (Bearberry)	Amerada	D-R	240
Ricinus	11-30-35-8W5	Amoco	R-Cyc	3 255
Rockyford	10-24-26-23W4	West. Decalta	A	176
Rosalind	11-16-44-18W4	Ranchman's Res.	R-D-C	196
Rosevear	11-24-55-15W5	Alta. Helium	Dif. memb	85
Rosevear	NE11-54-15W5	Shell Canada	Sfl-R	1 700
Rosevear	NE33-54-15W5	Suncor	A-DEA	1 042
Roxana	10-27-78-19W5	Coop Energy	R-DEA	43
Saleski	8-36-86-19W4	Paramount	C-IS	148
Samson	11-9-44-24W4	Lindstrom Res	R-D-C	85
Scandia	16-35-16-16W4	PanCanadian	C-D-R	56
Sedalia	SW26-30-4W4	Amoco	C-D-R	240
Sedalia	1-13-30-5W4	Atco	R-D-C	268
Sedalia	9-29-31-5W4	Placer CEGO	A-Ds	200
Sedgwick	7-21-42-12W4	Merland	R-C	85
Sedgwick	2-16-42-12W4	Petro-Canada	D-C-Sw-MEA	169
Sibbald	5-6-28-2W4	Suncor	A-Ds	197
Simonette	NE6-63-25W5	Shell Canada	Ab-R-Sfl	1 042

Area	Location	Operator	Process Type[1]	Raw Gas Capacity (x 1000 m^3/d)
Sinclair	SW19-72-11W6 (Goodfare)	Dome	R	1 970
Sinclair (Hythe)	NW18-74-12W6	Chieftain	R-Sfl-MCRC	3 662
Sounding	11-29-30-9W4	Union Oil	D-R	282
S. Wapiti	NE36-67-9W6	Can Hunter	R	8 452
Spiers	6-28-34-15W4	Poco Petroleum	R-C	196
Stanmore	5-1-29-12W4	Provident	R	845
Stanmore	11-16-30-10W4	Ryerson	R-C	105
Stanmore	7-9-30-10W4	Westcoast Prod.	A	507
Steele	14-34-65-24W4 (Bap. L.)	Champlin Petroleum	A-C-Spn-DEA	576
Steele	10-19-66-24W4	Dome Petroleum	D-Sw-A	254
Stettler N.	16-19-39-19W4	Bow Valley	D-R-C	113
Strachan	11-35-37-9W5	Gulf Canada	R-DEA-T	7 748
Strathmore	16-21-22-25W4	PanCanadian	R	340
Strome	6-24-44-16W4	Cabre	R-C	86
Strome/ Holmberg	NW14-44-17W4	Francana	D-R-MEA	380
Sturgeon Lk	SE2-69-22W5	Dome	R-C-Sfl	642
Sturgeon Lk. S.	15-8-70-23W5	Pennzoil	D-R-Stb	113
Suffield	4-3-19-9W4	Alta Energy	R-C-IS	991
Sullivan Lake	1-25-35-14W4	Czar	R	56
Sundance	7-9-54-21W5	Dome Petroleum	IS	70
Sundance	6-25-54-21W5	Dome	R-C-Sfl	440
Sunnynook	10-26-26-11W4	Bow Valley	R-D-Stb	141
Swalwell	14-35-29-24W4	Bumper	C-R-D	676
Swalwell	15-33-29-24W4	Gulf Canada	A	113
Swan Hills	10-32-67-9W5	Petro-Canada	D-C-A	197
Swan Hills	1-8-70-10W5	Shell Canada	C-R-Dth-Sfl	254
Swan Hills	3-18-67-10W5	Esso	MEA	1 560
Swan Hills	10-28-69-10W5	Wainoco	IS-R	6
Sylvan Lk	1-21-38-2W5	Chevron	R-Spn	811
Sylvan Lk	13-25-37-3W5	Gen. American	A	845
Sylvan Lk	14-32-37-3W5 (Med R)	Dome	A-R-MEA	1 831
Sylvan Lk	10-3-38-2W5	Quasar	C-D-R	56
Sylvan Lk	10-12-38-3W5	Dome	D-Spn	113
Sylvan Lk	16-19-38-1W5	Star Oil & Gas	D-R	197
Tangent	16-20-80-24W5	Dome	R-DEA	211
Teepee Ck	SE2-74-4W6	Mobil	DEA-R-Sw	551
Thorsby	5-4-49-1W5	Zephyr Res	R	123
Three Hills Ck	13-13-35-26W4	Amoco	A-C-R-D	338

Area	Location	Operator	Process Type[1]	Raw Gas Capacity (x 1000 m^3/d)
Tony Creek	7-16-64-21W5	Amoco	R	338
Turner Valley	14-6-20-2W5	West. Decalta	Ab-MEA	1 127
Twinning	12-10-31-24W4	Bumper	C-R	465
Twinning	11-16-31-23W4	Lariat	C-R	141
Twinning	3-33-30-24W4	Bumper Dev.	IS	50
Twinning/ Equity	4-33-31-24W4	Mobil Oil	R	845
Twinning N.	4-2-33-25W4	Czar Res.	C-D-R	87
Twinning N.	SW31-32-24W4	Dome	C-R-Spn	234
Valhalla	8-20-76-9W6	Westcoast Petroleum	R	169
Valhalla	1-29-75-9W6	Dome Petroleum	R-D	890
Valhalla	10-17-75-10W6	Wainco	R	142
Verger	6-6-23-16W4	Canterra	C-D-R	56
Verger	7-6-22-16W4	Canterra	R	118
Virginia Hills	10-17-64-13W5 (Hope Ck)	Shell Canada	R-Sfi	153
Viking	11-10-47-12W4	Signalta	C-D-R	115
Vulcan	SE24-15-22W4	Dome Petroleum	R-Sfl-C	1 564
Waskahigan	NE7-64-23W5	Amoco	A	462
Watelet	7-14-47-26W4	J M Huber	R-DEA-IS	18
Waterton	1/2-20-4-30W4	Shell Canada	Ab-R-Sfl-T	13 326
Wayne-Rosedale	12-4-28-20W4	Canterra	A-Ds	572
Wayne-Rosedale	5-17-27-19W4	PanCanadian	A-Ds	535
Wayne-Rosedale	1-20-28-21W4	PanCanadian	R	620
Wayne-Rose-dale-Seiu	14-12-26-19W4	Sundance	R-Fcn	1 714
W. Drum-heller	12-1-30-21W4	Gulf Canada	MEA	95
Westlock	NE11-59-25W4	Amoco	DEA	294
Westlock	13-24-60-26W4	Merland	C-D-R-Spn-MEA	282
Westlock	8-15-60-2W5	Sundance	R	170
Whitecourt	SE1-60-11W5	Greensboro	DEA-A-R	170
Whitecourt	12-26-59-11W5	Petro-Canada	D-A-MEA	1 831
Wildcat Hills	6-16-26-5W5	Petro-Canada	A-MEA	3 522
Wildmere	5-24-47-5W5	Koch	R	70
Willesden Green	13-16-40-5W5	ICG	D-R-Dth	148
Willesden Green	1-17-42-6W5	Texaco Canada	C-R	344
Willesden Green	13-27-42-8W5	Dome Petroleum	R-DEA-Nitr	1 126

Area	Location	Operator	Process Type[1]	Raw Gas Capacity (x 1000 m^3/d)
Willow Ck	SE5-28-17W4	Maynard Ex.	C-D-R	564
Wilson Ck	1-29-43-4W5	Amerada	A-MEA	507
Wimborne	16-5-35-26W4	Canterra	C-D-R	104
Wimborne	4-12-34-26W4	Mobil Oil	R-DEA	986
Windfall (W. Wcrt)	8-17-60-15W5	Canterra	R-DEA-Sfn	11 941
Wintering Hills	6-25-23-16W4	Dome Petroleum	D-R	56
Wintering Hills	16-7-24-16W4	Mobil Oil	R	170
Wintering Hills	1-18-25-17W4	PanCanadian	A	563
Wisdom	7-10-9-6W4	Roan Res (Med. Hat)	Sw (Chem)	141
Woking	11-30-75-4W6	Anderson	Ex. R	160
Wodd River	16-9-43-23W4	Placer-CEGO	Ab	141
Worsley	7-22-87-7W6	Amoco Canada	A	1 606
Zama	NW12-116-6W6	Dome	D-R-DEA	713
Straddle plants				
Cochrane	NE16-26-5W5	Alberta Nat Gas	Ab-R-T	31 150
Empress	SW12-20-1W4	Dome TC Res/Pan-Alta	A-R-T	96 900
Empress	SE10-20-1W4	Empress Gas Liquids	T	9 860
Empress	NE11-20-1W4	Petro-Canada	R-T	56 348
S. Edmonton	SW4-52-24W4	Dome/CU	R-A	8 875
TOTAL ALBERTA at Dec. 31, 1983				**399 444**
SASKATCHEWAN				
Alsask	16-30-29W3	Dome-SPC	A-Ds-MEA	196
Beacon Hill	NE12-62-25W3	Canterra	C	877
Coleville	17-31-23W3	Sask Power	A	1 698
Dollard	22-7-10W3	Mobil Oil	C-R	57
Gull Lake	9-4-19W3	Sask Power	C-R	46
Hatton	16-13-29W3	Marathon	D-Ds	5 094
N. Dodsland	NE11-32-21W3	Murphy Oil	R	117
Nottingham/ Alida		Esso Resources	C-R	255
Smiley		Esso Resources	C-R	113
Steelman	21-4-5W2	Dome Petroleum	C-R	1 075
Success	17-17-16W3	Sask Power	A-Ds	708

Area	Location	Operator	Process Type[1]	Raw Gas Capacity (x 1000 m^3/d)
TOTAL SASKATCHEWAN at Dec. 31, 1983				**10 236**
MANITOBA				
Waskada	11-30-1-25WPM	Omega	R-C	85
BRITISH COLUMBIA AND NORTHWEST TERRITORIES				
Boundary Lake		Gas Trunk of BC	A-Ds	283
Boundary Lake		Esso Resources	A-R	538
Bullmoose	D77 E93 P3	BP Canada	R	2 406
Fort Nelson		Westcoast Trans	A-HP-Sfn	23 291
Grizzly N.	A-74-G-93-1-15	Quasar	Ab-Sw	14 150
Pine River	E1/4-1131 and 357A	Westcoast	Sfl-D	7 752
Sierra		Mobil Oil	D	1 840
Sukunka	B65 B93 P5	BP Canada	R	2 575
Taylor		Westcoast Trans	Ab-MEA	11 179
Pointed Mountain, NWT		Amoco	D	5 320
TOTAL BRITISH COLUMBIA AND NWT at Dec. 31, 1983				**69 334**
ONTARIO				
Sarnia		Dome Petroleum	Fcn	
Brigden		Consumers	D-C	28
Leepfrog (Port Colborne)		Consumers	D-C-Sw	56
Morpeth		Consumers	D-A-Sw	283
Port Stanley		Consumers	D-C-Sw	420
Port Alma		Union Gas	Ab-MEA	452
TOTAL ONTARIO at Dec. 31, 1983			**1 239**	
TOTAL CANADA at Dec. 31, 1983			**480 338**	

[1]Abbreviations for type of process: A-Adsorption, Ab-Absorption, C-Compression, D-Dehydration, Ds-Desiccant, DEA-Diethanolamine, Dth-Deethanizing, Fcn-Fractionation, IS-Iron sponge, MEA-Monoethanolamine, Nitr-Nitrogen rejection, R-Refrigeration, Sfl-Sulfinol, Sfn-Sulfreen, Spn-Separation, Stb-Stabilization, Sw-Sweetening, T-Turbo expander, Cyc-Cycling.

3.3 Transportation Routes

Natural gas is transported by pipeline across and throughout Canada. The total length of pipelines for oil and gas products in 1979 was 34 868 km, including 4900 km built in that year (CMR 1979).

3.4 Manufacturing Process

Crude natural gas is produced from wells, primarily in Western Canada. Prior to distribution for use, it is purified by absorption of acid gases (carbon dioxide, hydrogen sulphide) in amine solutions. These solutions are subsequently treated to recover sulphur, then recycled to the absorption process. "Gas liquids" (higher alkanes) are removed from the natural gas stream by cooling and washing with cold liquid hydrocarbon. Prior to distribution, odourants are added, generally in amounts such that odour is detectable at about 1/5 the lower flammability limit - about 4 to 24 g/km^3 (GEH 1965). Odourants include mercaptans, thioethers and thioaromatics (Kirk-Othmer 1980).

3.5 Major Uses

Natural gas is used for heating, in the manufacture of ammonia, and as feedstock for organic chemicals.

4 MATERIAL HANDLING AND COMPATIBILITY

4.1 Containers and Transportation Vessels

4.1.1 General. The most common means of transporting natural gas is by pipeline. Very small amounts are transported by cylinder, railway tank cars, or tank motor vehicles.

4.1.2 Pipelines. Most gas is transported in Canada by pipelines. Sizes of pipelines vary from the 2.5 cm (1 in.) service lines to the 107 cm (42 in.) main lines. Figures 7 and 8 show the major pipelines in Canada.

4.1.3 Railway Tank Cars. Railway tank cars used to transport liquid natural gas require special permits by the Canadian Transport Commission. Cars will be of type 113C120W, described in Table 2 (RTDCR 1974; TCM 1979). Basically, the rail car tanker is a double-walled tank with annulus insulated and evacuated to 13 kPa (100 mm Hg) or less. Natural gas may be shipped by rail as a nonliquefied compressed gas but only in cylinders (HCG 1981).

TABLE 2 RAILWAY TANK CAR SPECIFICATIONS

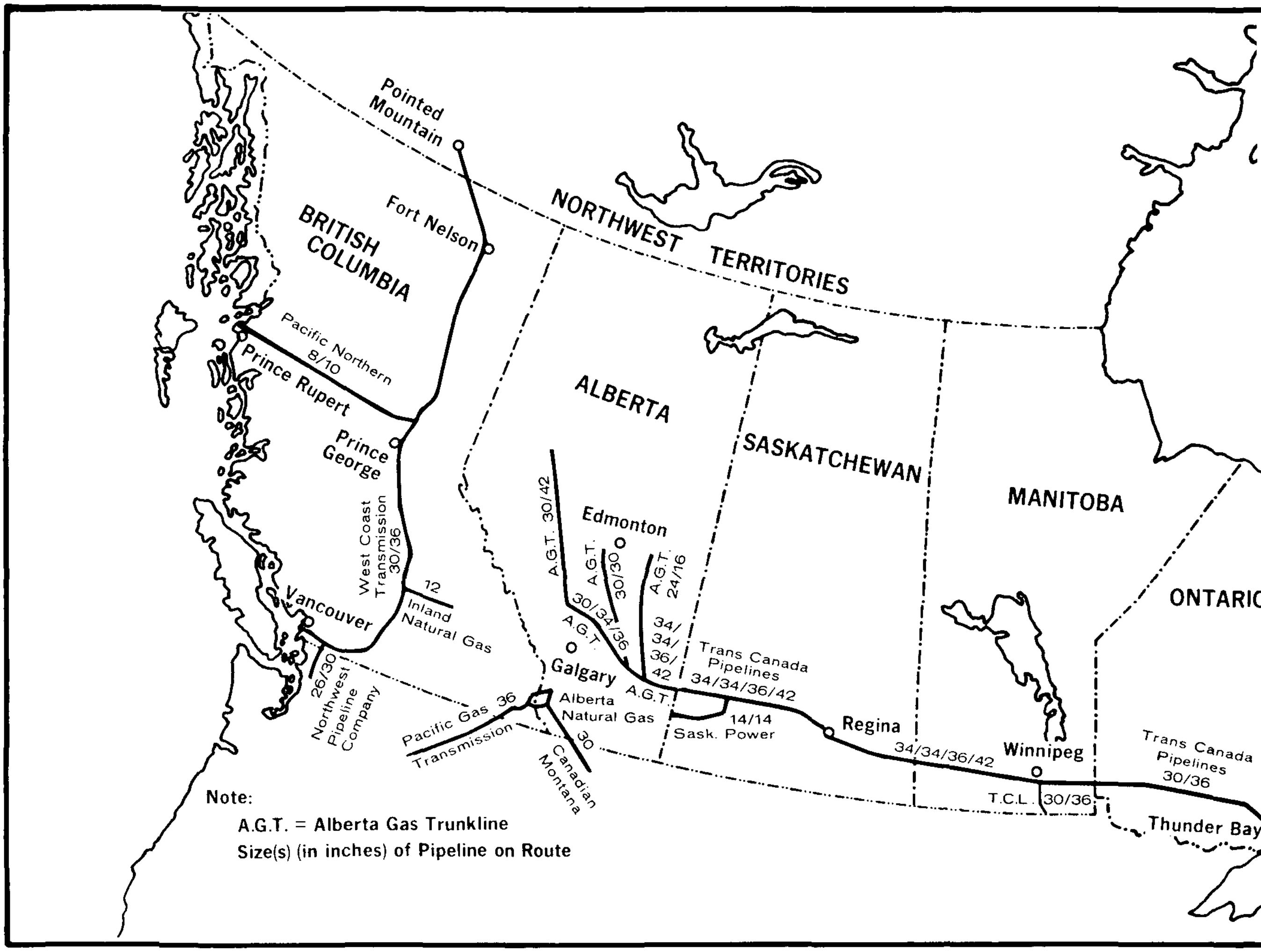
CTC/DOT* Specification Number	Description
113C120W	Alloy (nickel) steel fusion-welded tank without manway nozzle with steel fusion-welded outer shell. Rated for -196°C service. Vacuum annular space. Insulated. Gauging device. Vacuum gauges. Valves and fittings need not be mounted on top. Safety valve (518 kPa) (75 psi) on tank. Safety vent (828 kPa) (120 psi) on tank. Safety vent (110 kPa) (16 psi) on outer shell.

* Canadian Transport Commission and Department of Transportation (U.S.)

4.1.4 Tank Motor Vehicles. Tank motor vehicles carrying liquid natural gas also require special permit by Transport Canada and the U.S. Department of Transportation. Tanks are designed for cold compressed gases liquefied at low temperatures. Trucks may be used to carry nonliquefied compressed gas in cylinders (HCG 1981).

MAJOR GAS PIPELINES - WESTERN CANADA

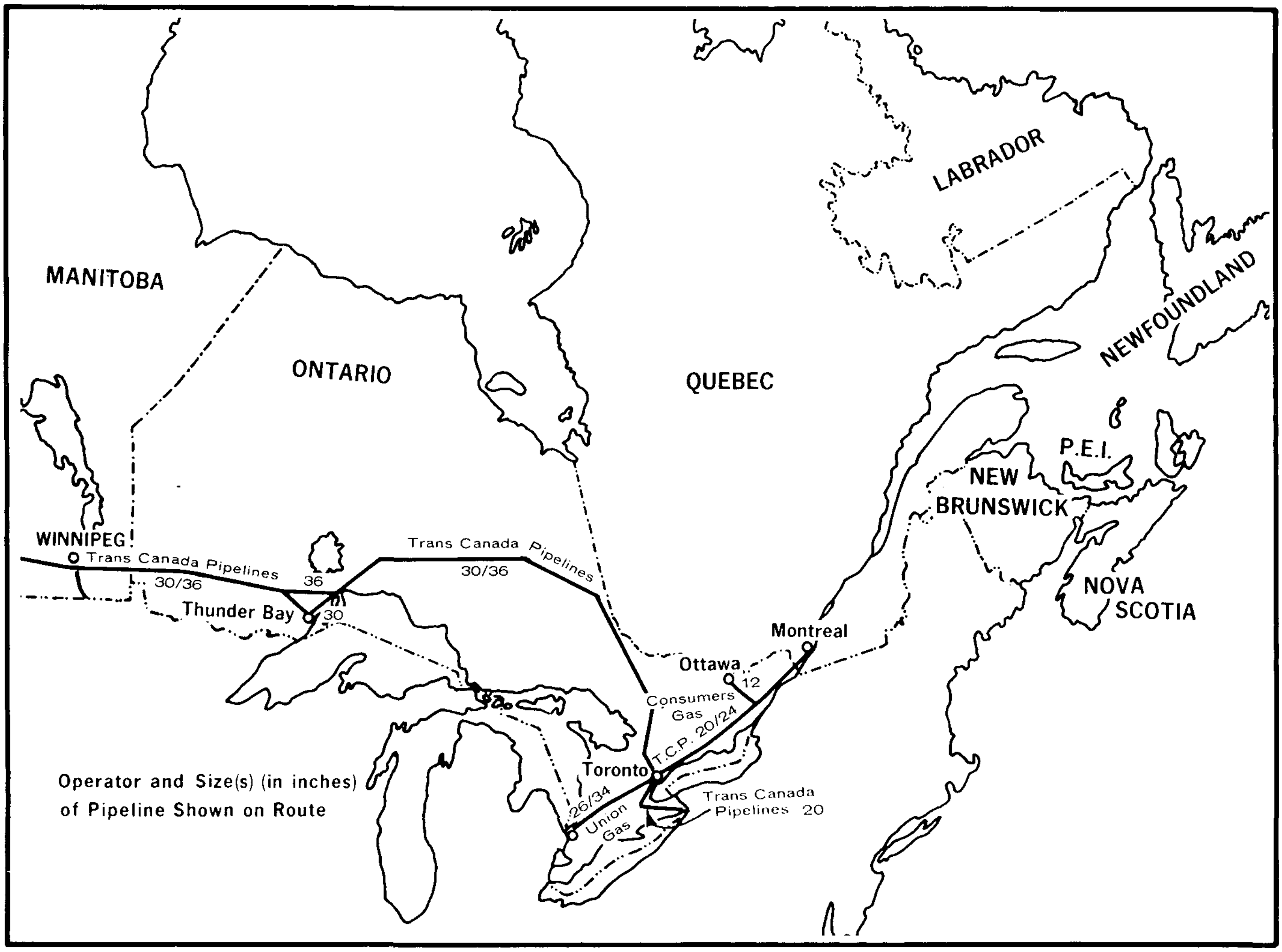
Reference: OILWEEK 1976, OGJ 1983, ROYAL 1980



NATURAL GAS

MAJOR GAS PIPELINES - EASTERN CANADA

Reference: OILWEEK 1976, OGJ 1983, ROYAL 1980



4.1.5 Cylinders. Any cylinders authorized for shipment of nonliquefied compressed gases may be used under CTC/DOT regulations; cylinders of the 3A and 3AA types described in Table 3 are probably those most commonly used (RTDCR 1974; HCG 1981). Laboratory cylinders are equipped with CGA valve outlet No. 350 with a thread size of 0.825 in. diameter - 14 threads per inch left hand external thread accepting a round nipple. Lecture bottles containing about a kilogram or less of product have a special 5/16 in., 32 threads per inch, female outlet and a 9/16 in., 18 threads per inch, male outlet (Matheson 1980).

TABLE 3 CYLINDER SPECIFICATIONS

CTC/DOT* Specification Number	Description
3A1800	Seamless steel cylinder. Maximum service pressure 12 400 kPa (1800 psi).
3AA1800	Seamless steel cylinder. Maximum service pressure 12 400 kPa (1800 psi). Steels definitely prescribed. Maximum carbon content 0.28%.
3AAX1800	Seamless steel cylinder. Maximum service pressure 12 400 kPa (1800 psi). Minimum water capacity 455 kg (1000 lb.).
3E1800	Seamless steel cylinder. Maximum service pressure 12 400 kPa (1800 psi). Maximum diameter: 51 mm (2 in.). Maximum length: 610 mm (24 in.).

* Canadian Transport Commission and Department of Transportation (U.S.)

4.1.6 Storage. A large portion of North America's natural gas demand is stored in underground caverns. Storage may be as a liquid, gas, or both (HNGE 1959). Special tanks have been designed for LNG storage, as shown in Figure 9. This tank would have a typical capacity of 65 000 m^3 (550 000 barrels or 14 000 000 gal.) of LNG (Pelto 1982).

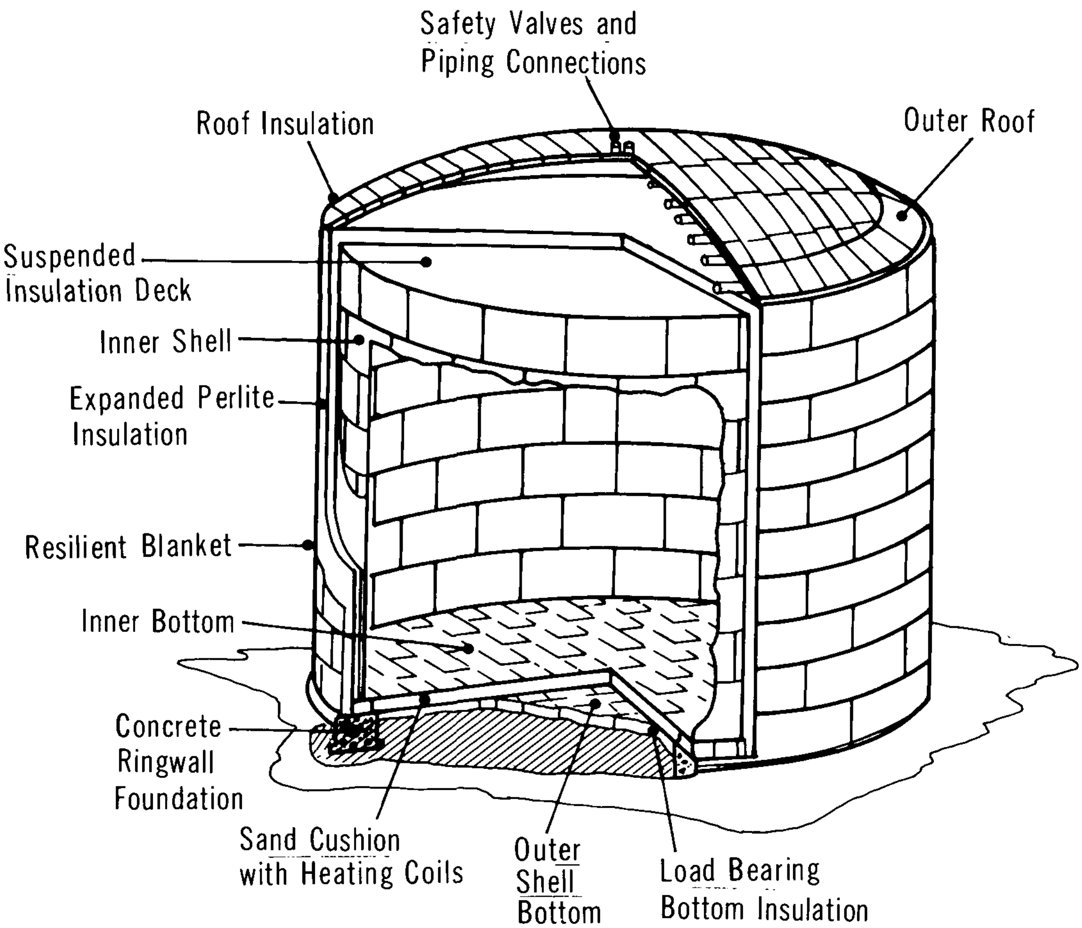
4.1.7 LNG Tankers. The transport of LNG by tanker is becoming increasingly common in the world. Currently, tanker transport of LNG from the west coast to Japan and from the high Arctic to the east coast has been proposed. The most typical tank size of an LNG tanker is 25 000 m^3 (10 000 tonnes); a tanker typically has five of these tanks,

FIGURE 9

NATURAL GAS (LIQUEFIED)

LNG STORAGE TANK

Reference: PELTO 1982



for a total capacity of 125 000 m^3. A tanker is illustrated in Figure 10. The tanks may be of several types; the spherical one shown in Figure 10 is known as the Moss-Rosenberg cargo tank and is the most common. This tank is designed to yield a low boil-off rate of about 0.18 percent of its cargo per 24 hours. Other tanks which have been proposed or are in use include the membrane, in which liquefied natural gas is contained by membranes directly on supporting insulation, and the independent vertical cylinder which is similar to the spherical except than two upright cylinders occupy one position (DOT 1980; Corkhill 1980; Cuneo 1980; Allsop 1980).

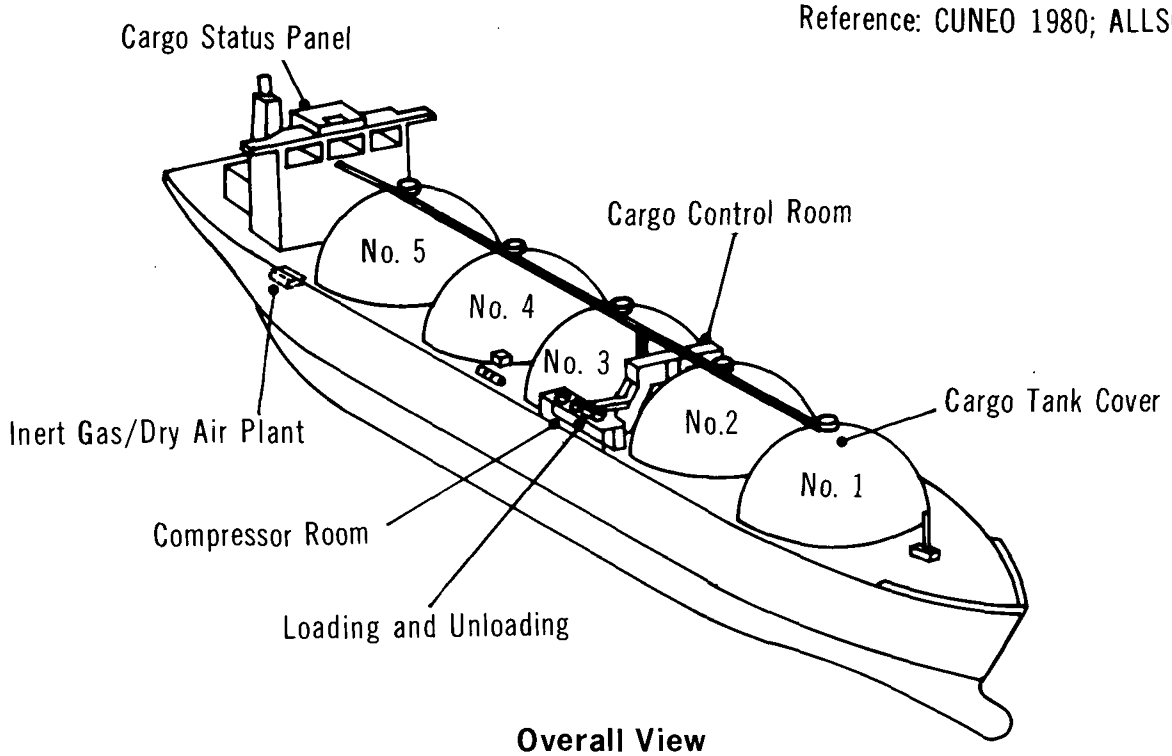
4.2 Compatibility with Materials of Construction

The compatibility of natural gas with materials of construction is indicated in Table 4. The unbracketed abbreviations are described in Table 5. The rating system for this report is briefly described below.

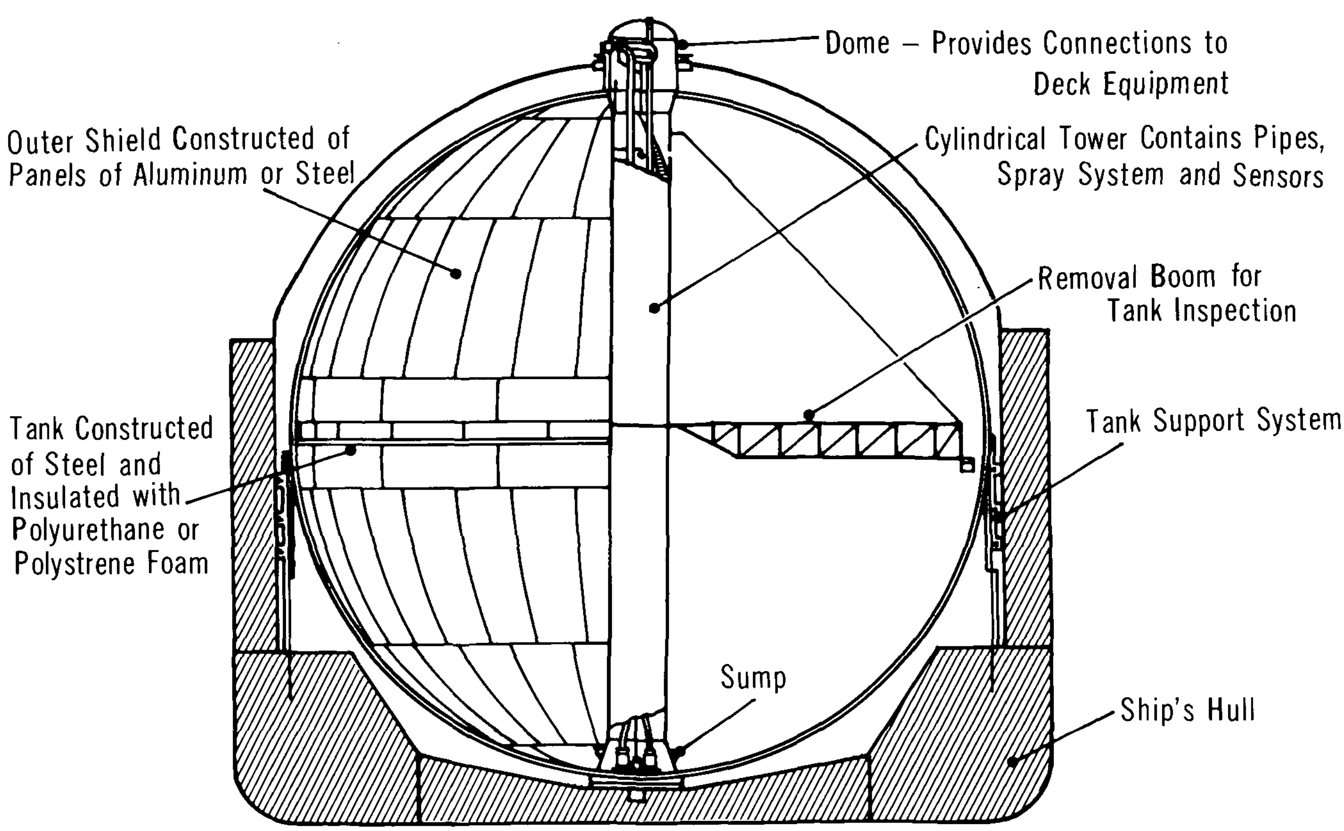
NATURAL GAS (LIQUEFIED)

LNG TANKER

Reference: CUNEO 1980; ALLSOP 1980



Overall View



Details of Spherical Tank

Recommended: This material will perform satisfactorily in the given application.

Conditional: Material will show deterioration in the given application; however, it may be suitable for intermittent or short-term service.

Not Recommended: Material will be severely affected in this application and should not be used.

TABLE 4 COMPATIBILITY WITH MATERIALS OF CONSTRUCTION

Chemical		Material of Construction		
State	Temp. (°C)	Recommended	Conditional	Not Recommended
gas	22	PVC CPVC (TPS 1978)		
gas	23	PP (TPS 1978) CR NBR CSM (GPP) CS SS (HCG 1981)	 NR SBR (GPP)	 IIR EPDM (GPP)
liquid	-115	LCNS (3.5% Ni) for land-based storage		
liquid	-115	LCNS (9% Ni) for cryogenic application		
liquid	-115	Al-Mg alloy (5000 series) for cryogenic application (LNG 1977)		

TABLE 5 MATERIALS OF CONSTRUCTION

Abbreviation	Material of Construction
Al-Mg	Aluminum-Magnesium Alloy
CPVC	Chlorinated Polyvinyl Chloride
CR	Polychloroprene (Neoprene) Rubber
CS	Carbon Steel
CSM	Chlorosulphonated Polyethylene (Hypalon)
EPDM	Ethylene Propylene Rubber
IIR	Isobutylene/Isoprene (Butyl) Rubber

TABLE 5 MATERIALS OF CONSTRUCTION (Cont'd)

Abbreviation	Material of Construction
LCNS	Low-Carbon Nickel Steel
NBR	Acrylonitrile/Butadiene (Nitrile, Buna N) Rubber
NR	Natural Rubber
PP	Polypropylene
PVC (followed by grade)	Polyvinyl Chloride
SBR	Styrene-Butadiene (GR-S, Buna S) Rubber
SS	Stainless Steel

5 CONTAMINANT TRANSPORT

5.1 General Summary

Natural gas is mostly transported as a gas by pipeline. Releases of natural gas will disperse rapidly as the gas is more buoyant than air. When released on water or land, liquid natural gas forms a flammable vapour cloud, since it is only slightly soluble in water. The vapour cloud tends to hug the water and spread until it warms, rather than lift off the water and disperse. A review of behaviour in some circumstances was present in section 2.

The following factors are considered for the transport of contaminants in the air, water and soil media.

- Contaminant Transport
  - Air
    - Vapour emission rate
    - Hazard zone
  - Water — Spread on water
  - Soil — Depth and time of penetration

For leaks of crude natural gas where hydrogen sulphide is a problem, the EnviroTIPS Hydrogen Sulphide manual should be consulted for modelling parameters as well as other information related to this toxic substance.

5.2 Leak Nomograms

Natural gas is transported predominantly by pipeline, with insignificant amounts transported by other means. It is used in large quantities in some process industries, however, and considerable quantities may be contained in process equipment on site. As it is not possible to representatively model leaks from such equipment, no leak nomograms have been prepared. Estimates of the quantity leaked will need to be based on site conditions, pipeline size, volume and flow rates, or process equipment capacity.

5.3 Dispersion in Air

5.3.1 Introduction. Since liquefied natural gas is extremely volatile, vapour released from a liquid pool spilled on a ground or water surface evaporates rapidly enough to consider the spill as producing instantaneous vapour in the form of a puff. Spills on ground or ice may be of the puff type if small or rapid. Larger spills on a ground surface may evaporate slowly due to the low heat transfer and thus produce a more continuous discharge. An initial amount would, however, be released as a puff.

To estimate the vapour concentrations downwind of the accident site for the determination of the flammability or toxicity hazard zone, the atmospheric transport and dispersion of the contaminant vapour must be modelled. The model used for the development of the EnviroTIPS series is Gaussian. For natural gas releases, especially cold vapours resulting from LNG releases, the Gaussian model has a tendancy to predict a longer and narrower danger zone than reality. Consequently, a number of models have been developed especially for LNG releases or for heavy gas. These include the Germeles-Drake, Eidsvik, Hegadas, Fem-3, and SLAB models (Energy 1982; Ermac 1981). In addition, a number of investigators have conducted experiments and measured the plume parameters. Lawrence Livermore Laboratories conducted several series of tests for the U.S. Department of Energy: in 1980, the Burro series was conducted and in 1981, the Coyote series (Koopman 1981; Ermac 1981; LGFS 1982). The following presents some of the results from the Burro series and comparative results when using the SLAB model:

Burro Test Number	Amount Spilled (m^3)	Wind Speed (km/h)	Field Test Results		SLAB Model Results	
			Distance to LFL* (m)	Width (m)	Distance to LFL* (m)	Width (m)
3	34.0	5.4	255	36	215	25
7	39.4	8.4	200	30	264	28
8**	28.4	1.8	420	120	418	110
9	24.2	5.7	325	48	315	48

* LFL is taken as 5 percent; ome modellers use 3.3 percent to allow for uneven mixing in the plume.

** In Burro 8, under low winds and stable atmospheric conditions, cold gravity flow occurred and the plume bifurcated.

It is interesting to note that the simplified nomogram presented in EnviroTIPS predicts a LFL hazard zone 800 m long and 700 m wide for conditions similar to Burro test number 8. This comparison indicates that the method presented here will yield a conservative result and is not as inaccurate as a direct Gaussian approach.

Tests were also conducted on the sea near Britain in 1980. These tests, conducted near Maplin Sands, employed continuous discharges of LNG. The results of some of these tests and Hegadas Model predictions are given below (Blackmore 1982):

Test Number	Discharge Rate (m^3/min)	Average Wind Speed (km/h)	Actual Distance to LFL (5 percent) (m)	Hegadas Predicted Distance to LFL (m)
15	29	39	150	245-335
39	47	45	130	335-420
56	25	48	110	235

Figure 11 depicts schematically the contaminant plume configuration from a "puff" surface release. The dispersion model represents the spill as an instantaneous point source (with a total vapour release quantity, Q_T) equal to the amount of contaminant spilled.

5.3.2 Vapour Dispersion Nomograms and Tables. The aim of the air dispersion nomograms is to define the hazard zone due to toxicity or flammability of a vapour cloud. The following nomograms and data tables are contained in this section (to be used in the order given):

Table 6: weather conditions

Figure 13: vapour concentration as a function of downwind distance and weather conditions

Table 7: maximum puff hazard half-widths

Figure 14: vapour puff travel distance as a function of time elapsed since the spill and wind speed

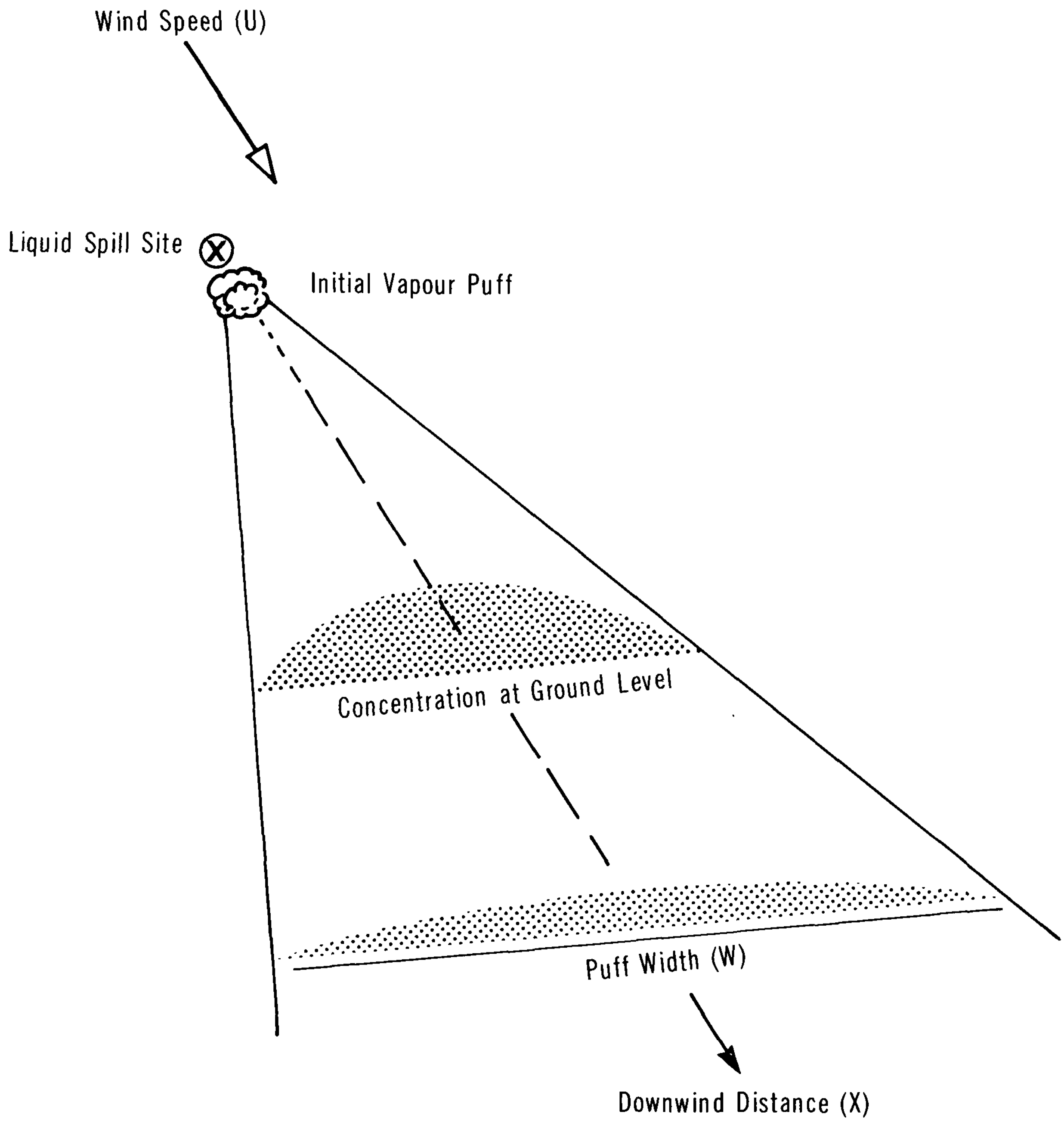
The flowchart given in Figure 12 outlines the steps necessary to make vapour dispersion calculations and identifies the nomograms or tables to be used. This section deals only with the portion contained within the dashed box. A description of each vapour dispersion nomogram and its use follows.

5.3.2.1 Figure 13: Vapour concentration versus downwind distance. Figure 13 shows the relationship between the vapour concentration and the downwind distance for weather conditions D and F. The nomograms were developed using the dispersion models described in the Introduction Manual. The vapour concentration is represented by the normalized, ground-level concentration (C/Q_T) at the centreline of the contaminant puff. Weather condition F is the poorest for dispersing a vapour cloud and condition D is the most common in most parts of Canada. Before using Figure 13, the weather condition must be determined from Table 6.

FIGURE 11

NATURAL GAS

SCHEMATIC OF CONTAMINANT PUFF



FLOW CHART TO DETERMINE VAPOUR HAZARD ZONE

ACCIDENT: LIQUID SPILLED

↓

DETERMINE TOTAL AMOUNT DISCHARGED

Step 1:

Determine quantity discharged to atmosphere based on site conditions

Q_T= .... L × density (kg/L) ÷ 1000 = ... tonnes

= .... tonnes × 10^6 grams/tonne = ... grams

↓

DETERMINE WIND SPEED (U) AND DIRECTION (D)

Step 2: Observed or estimated

U = ... km/h; D = ... degrees

↓

DETERMINE WEATHER CONDITION

Step 3: Use Table 6

Condition = ...

↓

DETERMINE HAZARD CONCENTRATION (C) - LOWER OF LFL or TLV® × 10

Step 4: C = 45 g/m³ for natural gas (LFL)

↓

COMPUTE C ÷ Q_T

Step 5: Computation required

C/Q_T = ... m^{-3}

↓

CALCULATE HAZARD DISTANCE FROM INSTANTANEOUS POINT SOURCE

Step 6: Use Figure 13

X = ... km

↓

CALCULATE HAZARD HALF-WIDTH $(W/2)_{max.}$

Step 7: Use Table 7

$(W/2)_{max.}$ = ... m

↓

DETERMINE TIME (t) SINCE SPILL

Step 8:

t = ... s

↓

CALCULATE DISTANCE (X_t) TRAVELLED BY PUFF SINCE TIME (t) OF ACCIDENT

Step 9: Use Figure 14 with U from Step 2

X_t = ... km

↓

HAZARD ZONE AND PUFF LOCATION DEFINED

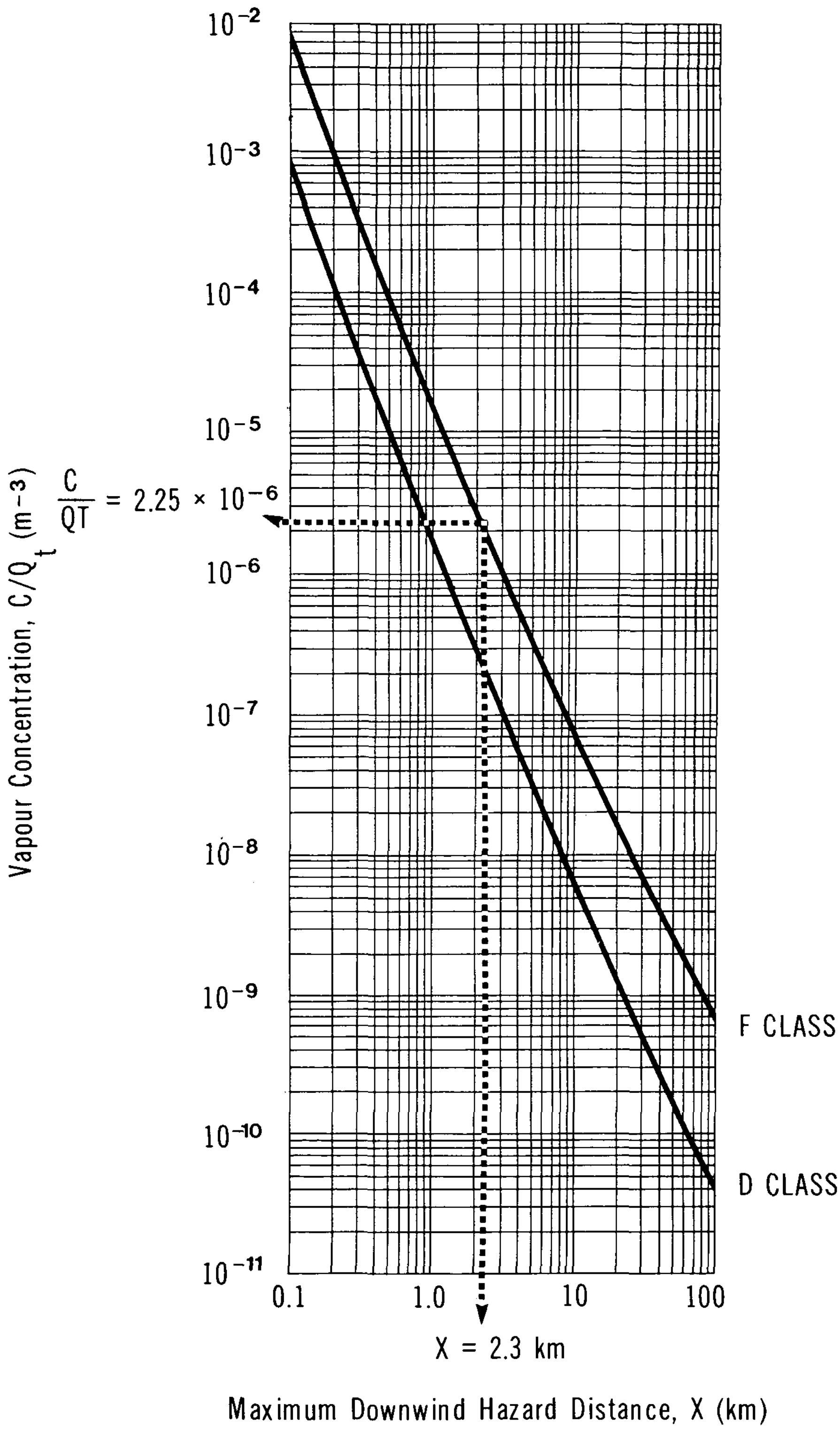

10^{-2}
10^{-3}
10^{-4}
10^{-5}
$\frac{C}{QT} = 2.25 \times 10^{-6}$
10^{-6}
10^{-7}
10^{-8}
10^{-9}
10^{-10}
10^{-11}
Vapour Concentration, C/Q_t (m^{-3})
0.1
1.0
10
100
X = 2.3 km
F CLASS
D CLASS
Maximum Downwind Hazard Distance, X (km)

TABLE 6 WEATHER CONDITIONS

Weather Condition F	Weather Condition D
Wind speed < 11 km/h (≃3 m/s) and one of the following: - overcast day - night time - severe temperature inversion	Most other weather conditions

Use: The maximum hazard distance, X, downwind of the spill can be calculated from Figure 13 knowing:

- Q_T, the mass of vapour emitted (equivalent to liquid spilled)
- U, the wind speed (m/s)
- the weather condition
- the hazard concentration limit, C, which is the lower value of 10 times the Threshold Limit Value® (TLV, in g/m^3), or the Lower Flammability Limit (LFL, in g/m^3). For a simple asphyxiant, no TLV® value is pertinent. The concentration of contaminant that will lower the oxygen level to less than 18 percent v/v (asphyxiation level) is 14 percent v/v. Therefore, the lower of 14 percent v/v or the LFL is used. Noted, to convert the LFL, in percent by volume, or the asphyxiation level, in percent by volume, to concentrations in g/m^3, use Figure 15. It should be noted that some models use a LFL of 3.3 percent or 28 g/m^3 to allow a safety margin for uneven mixing. Here, the standard value for the LFL, 5 percent, was used.

5.3.2.2 Table 7: Maximum puff hazard half-widths. This table presents data on the maximum puff hazard half-width, $(W/2)_{max}$, for a range of Q_T values under weather conditions D and F. These data were computed using the dispersion modelling techniques given in the Introduction Manual for a value of the natural gas Lower Flammability Limit (LFL) of 45 g/m^3. The maximum puff hazard half-width represents the maximum half-width of the natural gas vapour cloud, downwind of the spill site, corresponding to a hazard concentration limit of the LFL. Table 7 is therefore only applicable for a natural gas hazard concentration limit of the LFL or 45 g/m^3. Also, data are provided up to a maximum hazard distance downwind of 100 km.

Under weather condition D, the wind speed (U) range applicable is 1 to 30 m/s. The range of instantaneous vapour emission rates (Q_T) used was 1 to 1 400 000 tonnes,

TABLE 7 MAXIMUM PUFF HAZARD HALF-WIDTHS (FOR NATURAL GAS)

Weather Condition D			Weather Condition F		
Q_T (tonnes)	$(W/2)_{max}$ (m)		Q_T (tonnes)	$(W/2)_{max}$ (m)	
1 400 000	3 975	(98.0 km)*	65 000	1 830	(97.7 km)*
1 250 000	3 810		60 000	1 770	
1 000 000	3 500		50 000	1 640	
750 000	3 130		25 000	1 220	
500 000	2 680		10 000	825	
250 000	2 060		5 000	610	
200 000	1 890		2 500	455	
150 000	1 695		1 000	320	
100 000	1 450		500	245	
75 000	1 300		250	185	
50 000	1 110		100	130	
25 000	855		50	100	
10 000	610		25	75	
5 000	475	Q_T = 20 tonnes→	20	70	→ $(W/2)_{max}$ = 70 m
2 500	365		10	55	
1 000	260		5	40	
500	200		1	25	
250	155				
100	110				
50	85				
25	70				
20	60				
10	50				
5	40				
1	20				

* Data are provided up to a maximum downwind hazard distance of 100 km.

Example: Under weather condition F and Q_T = 20 tonnes, then puff hazard half-width $(W/2)_{max}$ = 70 m

Note: Above table is valid only for a natural gas concentration of the LFL value, or 45 g/m^3.

respectively. A tank on a typical LNG carrier contains 25 000 m^3, or 10 000 tonnes. A large tank may contain 65 000 m^3, or 29 000 tonnes. It is conceivable that a storage area could contain as many as 10 such tanks. A large gas well blowout could release about 5 000 000 m^3, or 2 000 000 tonnes, per day. For example, in the Vinland Incident near Sable Island, the well "blew" at an estimated rate of 1 000 000 to 2 000 000 m^3/day (of gas), or about 700 to 1400 tonnes per day. Thus, data are provided to cover most possible occurrences.

Under weather condition F, the wind speed (U) range applicable is 1 to 3 m/s. The range of instantaneous vapour emission rates (Q_T) used was 1 to 65 000 tonnes, respectively.

Use: Knowing the weather condition and Q_T, pick the closest value in the table and the corresponding $(W/2)_{max}$, the maximum puff hazard half-width, in metres. (For an intermediate value, interpolate Q_T and $(W/2)_{max}$ values.) Also refer to the example at the bottom of Table 7.

5.3.2.3 Figure 14: Puff travel time versus travel distance. Figure 14 presents plots of puff travel time (t) versus puff travel distance (X_t) as a function of different wind speeds (U). This is simply the graphical presentation of the relationship $X_t = Ut$ for a range of typical wind speeds.

Use: Knowing the time (t) since the spill occurred and the wind speed (U), the distance (X_t) can be determined, which indicates how far downwind the puff has travelled.

5.3.3 Sample Calculation. The sample calculation given below is intended to outline the steps required to estimate the downwind hazard zone which could result from a spill of liquid natural gas. The user is cautioned to take note of the limitations in the calculation procedures described herein and in the Introduction Manual. The estimates provided here apply only for conditions given. It is recommended that the user employ known or observational estimates (i.e., of the spill quantity) in a particular spill situation if possible.

Problem:

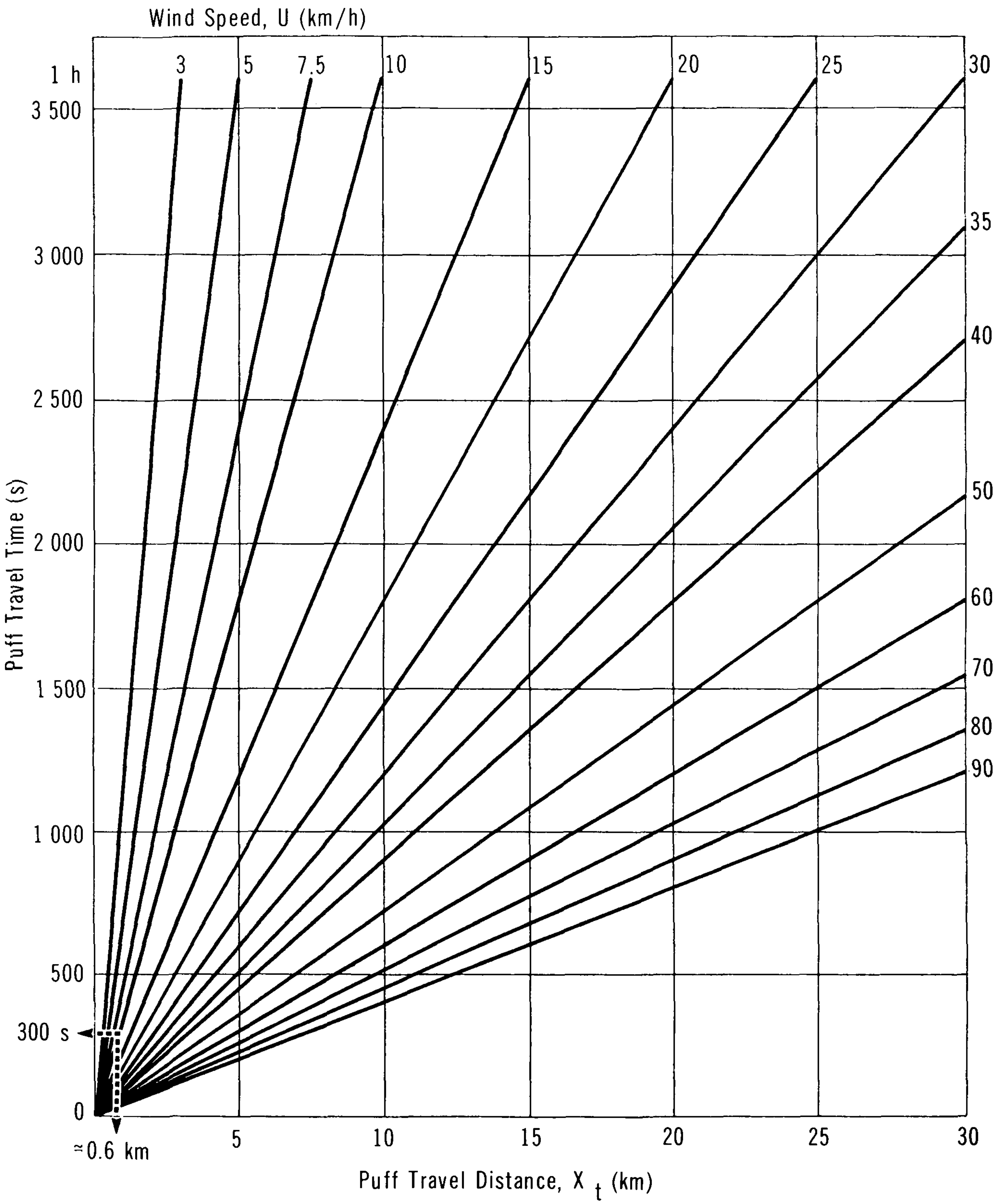
During the night, at about 2:00 a.m., 20 tonnes of liquid natural gas were spilled on a flat ground surface. It is now 2:05 a.m. The temperature is 20°C and the wind is from the NW at 7.5 km/h. Determine the extent of the vapour hazard zone.

Solution:

Step 1: Quantity spilled is given, Q_T = 20 tonnes

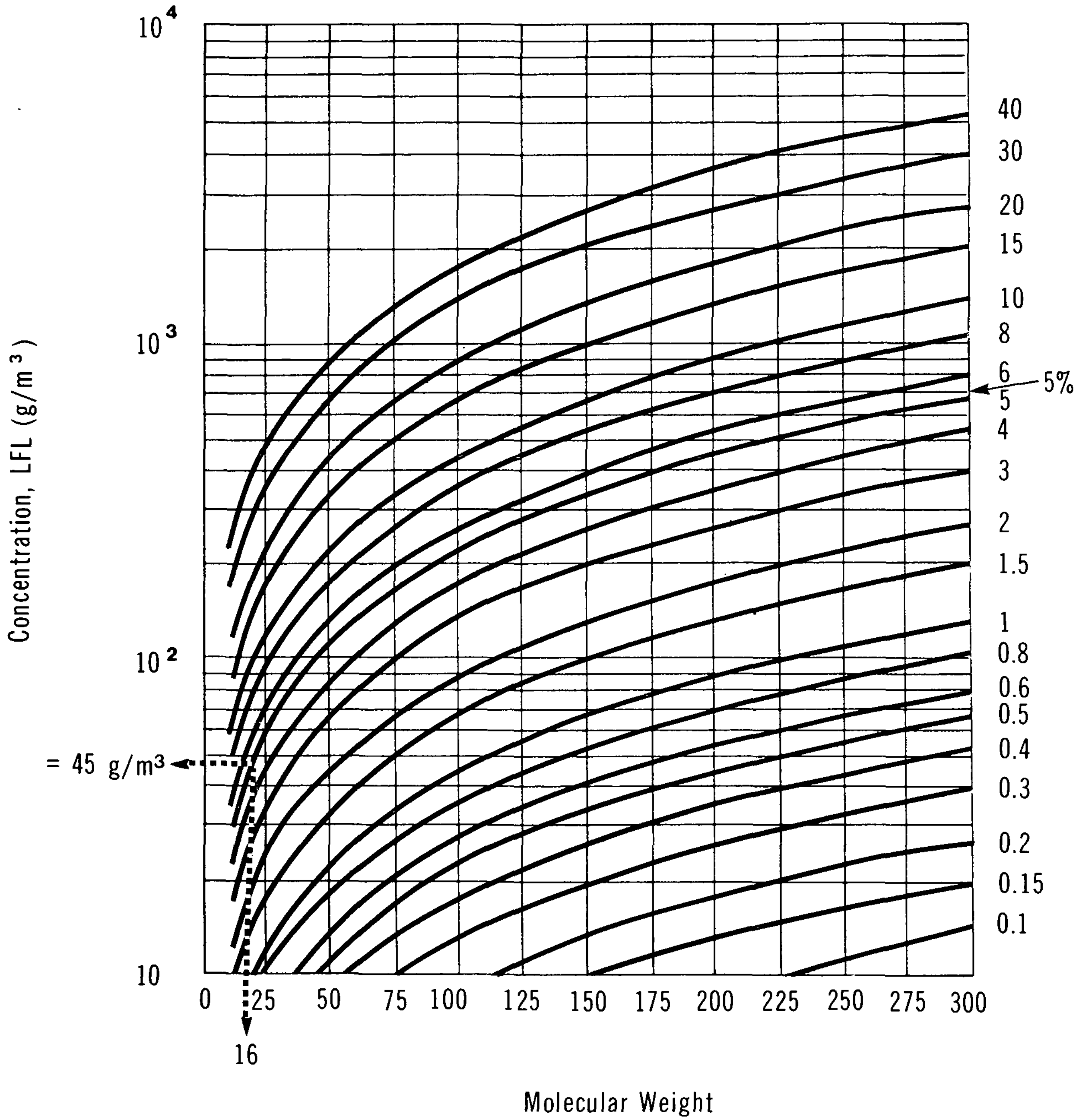
- Q_T = 20 tonnes or 20 x 10^6 g
- Q_T = 2 x 10^7 g

PUFF TRAVEL TIME VS TRAVEL DISTANCE



NATURAL GAS

CONVERSION OF LOWER FLAMMABILITY LIMIT (LFL) UNITS (volume % to g/m³)



Example: Natural Gas, MW = 16, LFL = 5%, then LFL in g/m³ = 45

Note: data applicable at 25°C and 760 mm Hg pressure

Step 2: Determine the wind speed (U) and direction (D)

- Use available weather information, preferably on-site observations
- Given: U = 7.5 km/h, then U = 7.5 ÷ 3.6 = 2.1 m/s
  D = NW or 315° (D = Direction from which wind is blowing)

Step 3: Determine the weather condition

- From Table 6, weather condition = F since U is less than 11 km/h and it is night

Step 4: Determine the hazard concentration limit (C)

- This is the lower of the asphyxiation level, or the LFL, so for natural gas C = 45 g/m^3 (LFL = 45 g/m^3; asphyxiation level ≃ 120 g/m^3)

Step 5: Compute C/Q_T

- $C/Q_T = \frac{45}{2 \times 10^7} = 2.25 \times 10^{-6}\ m^{-3}$

Step 6: Calculate the hazard distance (X) from the instantaneous point source

- From Figure 13 with $C/Q_T = 2.25 \times 10^{-6}\ m^{-3}$ and weather condition F, X ≃ 2.3 km

Step 7: Calculate the puff hazard half-width $(W/2)_{max}$

- Use Table 7
- With Q_T = 20 tonnes
- Then for weather condition F, $(W/2)_{max}$ = 70 m

Step 8: Determine the time since spill

- t = 5 min x 60 = 300 s

Step 9: Calculate the distance travelled (X_t) by the vapour puff since the time of the accident

- Using Figure 14, with t = 300 s and U = 7.5 km/h, then X_t = 0.6 km (more accurately from X_t = Ut = 2.1 m/s x 300 s = 630 m = 0.63 km)

Step 10: Map the hazard zone

- This is done by drawing a rectangular area with dimensions of twice the maximum puff hazard half-width (70 m) by the maximum hazard distance downwind of the instantaneous point source (2.3 km) along the direction of the wind, as shown in Figure 16
- If the wind is reported to be fluctuating by 20°C about 315°C (or from 315° ± 10°), the hazard zone is defined as shown in Figure 17
- Note that the puff has only travelled 0.63 km in the 5 minutes since the spill. At a wind speed of 7.5 km/h, there remain 13 minutes before the puff reaches the maximum downwind hazard distance of 2.3 km

FIGURE 16

NATURAL GAS

HAZARD AREA FOR STEADY WINDS, EXAMPLE PROBLEM

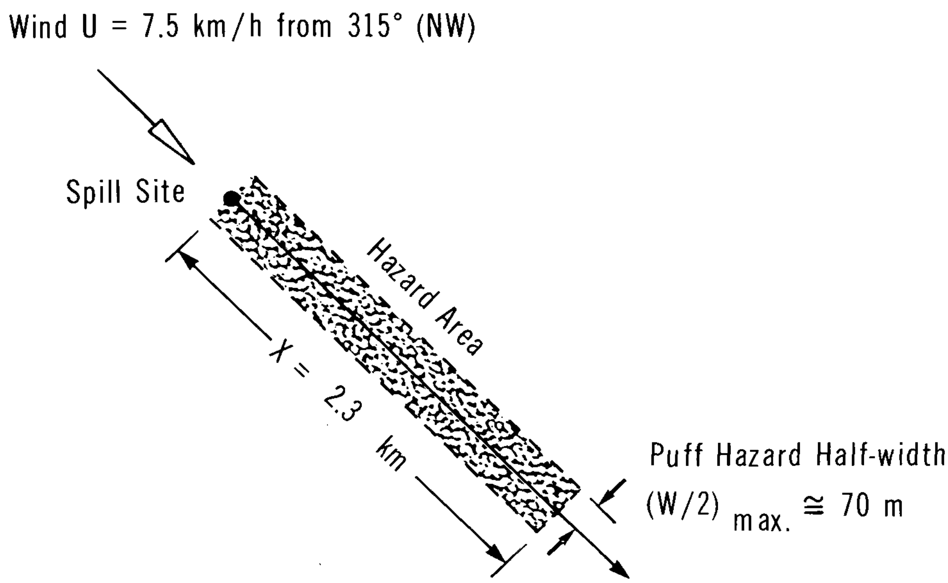
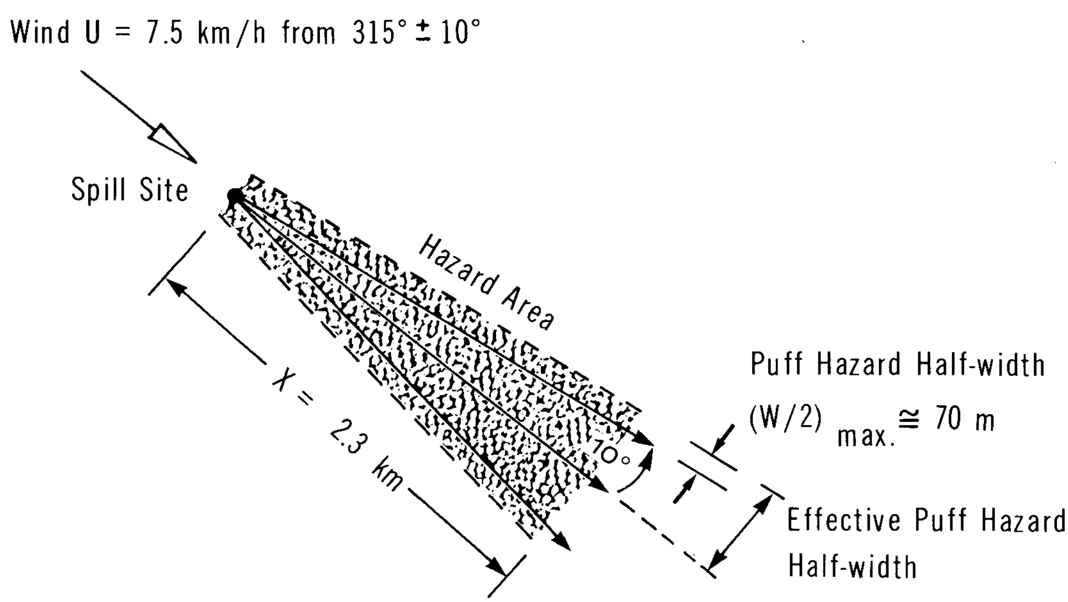


FIGURE 17

NATURAL GAS

HAZARD AREA FOR UNSTEADY WINDS , EXAMPLE PROBLEM



$= X \times 1000 \times \tan 10° + (W/2)_{max.}$

$= \underline{2.3 \times}\ 1000 \times \tan 10° + \underline{70\ m}$

$= \underline{475}\ m$

5.4 Behaviour in Water

When released into water, natural gas will not dissolve significantly but will dissipate to the atmosphere. Because of the slight solubility of natural gas components, no nomograms have been prepared for its behaviour in water.

5.5 Subsurface Behaviour: Penetration into Soil

Infiltration of natural gas into soil, either in gaseous form or as a water contaminant, is not considered to present a problem in foreseeable spill circumstances. Because of this, no nomograms have been prepared for its behaviour in soil.

6 ENVIRONMENTAL DATA

6.1 Suggested or Regulated Limits

6.1.1 Water. The concentration of methane in groundwaters should not be in excess of 3.1 $m^3/10^6$ L (50 cu. ft./100 000 gal.) (Water Management Goals 1978).

6.1.2 Air.

No specific limits have been promulgated or recommended in Canada or the United States.

6.2 Aquatic Toxicity

6.2.1 Canada. To protect aquatic organisms, the total dissolved gas concentrations in water should not exceed 110 percent of the saturation value for gases at existing atmospheric and hydrostatic pressure (Water Management Goals 1978).

6.2.2 U.S. Toxicity Rating. Not established.

6.2.3 Measured Toxicities.

Conc. (mg/L)	Time (hours)	Species	Result	Water Conditions	Reference
Fish Toxicity Tests					
not stated	not stated	Sunfish	not toxic or harmful	as methane	WQC 1963
65		Minnows	no effect	saturated solution of methane	WQC 1963

6.2.4 Aquatic Studies. Methane values were measured from the water column and sediments around an active offshore gas and oil field. Higher methane values at all depths during summer indicated in situ biological production associated with increases in zooplankton and bacterial biomass in the water column (Wiesenburg 1982).

6.3 Toxicity to Other Biota

6.3.1 Livestock. Methane is considered a simple asphyxiant without other physiologic effects. The limiting factor in methane exposure is available oxygen (TLV 1983).

6.4 Other Land and Air Toxicity. Methane is a product of the anaerobic decomposition of organic matter in marshes, mines and sludge-digestion tanks (WQC 1963). It has been reported that plants exposed to natural gas leaks have experienced diminished content of some minerals, including nitrogen, in their leaves; soil, on the other hand, showed an increase in nitrogen (Paul 1979, 1980).

6.5 Effect Studies

Natural gas will impart to water an odour similar to benzene, the odour being dependent on the volume of gas, the volume of water, and the period of contact (WQC 1963).

6.6 Degradation

B.O.D. (w/w)	% Theo	Days	Seed	Method	Reference
3.04	3.99	35	not stated	25°C	Verschueren 1984

7 HUMAN HEALTH

There is a limit amount of information in the published literature concerning the toxicological effects of test animal and human exposures to natural gas. A high concentration of gas may cause asphyxiation due to displacement of oxygen. Contact with liquid natural gas may result in frostbite. Sour gas, that containing hydrogen sulphide, can be quite toxic. Readers are referred to the manual on hydrogen sulphide for information on this product.

No data were found in the literature concerning the reproductive or carcinogenic effects of natural gas. No information pertaining to mutagenic properties was encountered.

The toxicological data summarized here have been extracted from reliable standard reference sources and are representative of information in the literature.

7.1 Recommended Exposure Limits

Exposure standards for natural gas were not encountered in the literature; methane, ethane, and propane are classified as simple asphyxiants by the USA-ACGIH. The guidelines given below pertain to simple asphyxiants. Canadian provincial guidelines generally are similar to those of USA-ACGIH, unless indicated otherwise.

Guideline (Time)	Origin	Recommended Level	Reference
Simple Asphyxiant	USA-ACGIH	Minimum oxygen content should be 18 percent by volume under normal conditions	TLV 1983
Short-term Exposure Limits (STEL)			
		No data	
Other Human Toxicities			
		No data	

7.2 Irritation Data

7.2.1 Skin Contact.

Exposure Level (and Dura*i^n)	Effects	Reference
Liquid	May cause frostbite	CHRIS 1978

7.2.2 Eye Contact.

Exposure Level (and Duration)	Effects	Reference
Vapour	Not irritating to eyes	CHRIS 1978

7.3 Threshold Perception Properties

7.3.1 Odour. Odour Characteristics: generally odourless. Consumer product has added odourant which can generally be detected at less than 1 percent by volume (Kirk-Othmer 1980).

7.4 Toxicity Studies

7.4.1 Inhalation.

Exposure Level (and Duration)	Effects	Reference
Acute Exposures		
SPECIES: Human		
Unspecified	Natural gas is a simple asphyxiant. Displacement of air by the gas may lead to shortness of breath, unconsciousness, and death from hypoxemia	USDHEW 1977
5 percent concentration in air	No detectable systemic effects	CHRIS 1978

7.5 Symptoms of Exposure

General symptoms of exposure found in most information sources have not been specifically referenced. Only those of a more specific or unusual nature have their sources indicated.

7.5.1 Inhalation (these symptoms are only relevant for high concentrations of natural gas).

1. Need for fresh air.
2. Rapid, occasionally irregular, breathing.

3. Headache.
4. Fatigue.
5. Exhaustion.
6. Loss of consciousness.
7. Convulsions.
8. Death.

7.5.2 **Ingestion.** Ingestion is unlikely as the liquefied product, and natural gas is in gaseous form under normal atomspheric conditions would be difficult to ingest.

7.5.3 **Skin Contact.** Liquid natural gas presents no appreciable hazard, but may cause frostbite (CHRIS 1978).

7.5.4 **Eye Contact.** Vapours are not irritating to eyes (CHRIS 1978).

8 CHEMICAL COMPATIBILITY

8.1 Compatibility of Natural Gas (Methane) with Other Chemicals or Chemical Groups

SPECIFIC CHEMICAL OR CHEMICAL GROUP	HEAT GENERATION	FIRE	EXPLOSION	FORMATION OF FLAMMABLE GASES	VIOLENT POLYMERIZATION	DECOMPOSITION	FORMATION OF TOXIC FUMES	FORMATION OF SUBSTANCES OF GREATER TOXICITY	PRESSURIZATION IN CLOSED VESSELS	SOLUBILIZATION	VIOLENT REACTION	NON-HAZARDOUS REACTION	SPECIFICS	REFERENCE
<u>GENERAL</u>														
Heat		•	•											Sax 1979
Fire		•	•											Sax 1979
<u>SPECIFIC CHEMICAL</u>														
Bromine Pentafluoride		•	•											NFPA 1978
Chlorine	•												Chlorine oxidizes most hydrocarbons	NFPA 1978
Chlorine Dioxide			•										Can explode with organics	NFPA 1978
Nitrogen Trifluoride			•										Explosive reactions occur on ignition	NFPA 1978
Oxygen (liquid)			•											NFPA 1978
Oxygen Difluoride			•										Explodes upon ignition	
<u>CHEMICAL GROUPS</u>														
Halogens			•											Bretherick 1979
Oxidizing Agents	•	•												EPA 600/2-80-076; Bretherick 1979

9 COUNTERMEASURES

9.1 Recommended Handling Procedures

The following procedures have been derived from a literature review. To avoid any deviation from the intended meaning, the wording of the original source has been presented essentially unchanged - in so doing, it is recognized that there may be some discrepancies between different sources of information. It is recognized that countermeasures are dependent on the situation, and thus what may appear to be conflicting information may in fact be correct for different situations. The following procedures should not be considered as Environment Canada's recommendations.

9.1.1 Fire Concerns. Natural gas forms flammable mixtures with air. Cold natural gas is heavier than air and will spread at ground level to distant ignition sources and flash back (NFPA 1978). A hazard of reignition or explosion may exist if a fire is extinguished without stopping the flow of gas or cooling the surroundings. Containers may explode in heat of fire (ERG 1980; GE 1980). Large fires, especially from an LNG tanker or a large storage facility, are beyond current firefighting capability (Konzek 1982).

9.1.2 Fire Extinguishing Agents. Use water spray to cool containers involved in a fire to prevent rupture and to direct flammable gas-air mixtures away from ignition sources. High-expansion foam may be used to reduce the rate of burning of relatively small spills (NFPA 1978). Water should not be used on pool fires. Water sprays can be used to aid in vapour dispersion and for protecting and cooling equipment (Konzek 1982).

Small fires: Dry chemical (sodium or potassium bicarbonate), CO_2, halogenated extinguishing agent (e.g., Halon 1301) (NFPA 1978; Konzek 1982).

Large fires: Water spray, fog or foam.

Move containers from fire area if this can be done without risk. Stay away from tank ends. For massive fires, use unmanned hose holder or monitor nozzles (ERG 1980).

9.1.3 Evacuation. The following information consists of evacuation distances which appear in the literature. Important parameters such as spill quantity, concentration level to which evacuation is suggested, and environmental conditions, may not be defined. Readers are advised to evaluate the use of these values with those derived from the methods to calculate hazard zones in Section 5.3 of this manual, which uses the above data.

In the event of an explosion, the minimum safe distance from flying fragments is 600 m in all directions. Keep internal combustion engines and other sources of ignition at least 55 m from probable ignition area (EAG 1978).

9.1.4 Spill Actions, Cleanup and Treatment.

9.1.4.1 General. Stop or reduce discharge of material if this can be done without risk. Eliminate all sources of ignition. Avoid skin contact and inhalation (GE 1980).

9.1.4.2 LNG tanker countermeasures. A number of studies have been conducted to examine countermeasures for a spill from a tanker. One study concluded that "curtains" hung in tanks could substantially reduce spillage in the event the tank was punctured (Little 1982). A catamaran-mounted flare burner has been proposed for burning off LNG in the event of an accident. It is proposed that most remaining LNG could be safely burned by this device (DOE 1982).

9.1.5 Disposal. Natural gas, if contained, may be disposed of by incineration at an approved facility.

9.1.6 Protective Measures. For entry into a situation where the spilled material and its characteristics are unknown, self-contained breathing apparatus and a totally encapsulated chemical suit should be worn. Note that crude natural gas may contain substantial quantities of (toxic) hydrogen sulphide.

If the spilled material is known to be natural gas:

- Special clothing designed to prevent liquefied natural gas or the cold vapours from coming in contact with the body should be worn (NFPA 1978).
- Air-supplied or self-contained breathing apparatus should be worn (GE 1980).
- Safety shields, gloves, glasses and safety shoes are recommended when handling cylinders (GE 1980).

9.1.7 Cylinder Storage Precautions. Store cylinders in a well-ventilated, low fire-risk area. Outdoor or detached storage is preferred. Keep cylinders away from oxidizing agents and sources of heat or ignition. Protect cylinders against physical damage. No part of a cylinder should be exposed to temperatures above 52°C. Ground all lines and equipment used with methane or LNG to prevent static sparks. Use nonsparking tools (GE 1980).

10 PREVIOUS SPILL EXPERIENCE

This section contains information on previous spill experiences which will be useful to readers in understanding spill response and countermeasures. Only those which meet the criteria are included, and thus, the number of experiences is not an indication of the problems or frequency of spillage. As technology in spill control advances, this section will be updated in future manual revisions to include the most useful information.

10.1 Explosion and Fire - Philadelphia (NTSB 1979).

On May 11, 1979, a gas pressure recorder connected to an 8-inch gas line in an older portion of Philadelphia relayed a signal that a dramatic pressure drop had occurred. Some time later, passers-by also reported the smell of gas in the area. Service men from PGW (Philadelphia Gas Works) were dispatched to check on the situation. Upon arrival, one serviceman found a 100-percent lower explosive reading on his combustible gas meter. He warned other PGW men in the area and was told to check buildings in the area. He entered a tavern to do this and seconds later the building exploded. The explosion destroyed the building containing the tavern and an apartment, an adjacent row house and a garage behind. A section of the street beside the buildings caved in. All of the buildings caught fire. The Philadelphia Fire Department arrived and began fighting the fire. To control the gas-fed fire, the fire crew injected grease into the gas main and service lines. The fire was stopped 1 hour and 10 minutes after it began. Seven persons were killed and 19 were injured.

The procedure used to cut off gas lines bears note. Injecting grease into a gas service line or main will shut off the flow in a low-pressure system. "Greasing off" service lines and mains is a faster method of sealing-off flows than another method occasionally used - the inflatable bag method. After the emergency - depending on the amount of grease used - the affected lines are abandoned, replaced, or blown clean. The inflated bag method takes longer to deploy, but does not leave any residues in the lines.

After the event, investigators found that the cause of the gas leak was a completely ruptured 8-inch gas main. The cause of rupture was erosion around and under the pipe. The cavity beneath the street had not been detected and collapsed during the explosion. The rupture of the gas line was simply caused by breaking under its own weight (it was cast iron) in the cavity. Analysis of the pipe also showed that it had cracked some time before the rupture. Gas from the under-street cavity had migrated to the adjacent buildings via the looser soil along utility corridors.

11 ANALYTICAL METHODS

The general approach adopted for each of the Priority Chemicals was as follows.

Methods have been documented here for the analysis of samples from air or water in a normally equipped chemical laboratory remote from the spill site. Customary sources of standard or recommended analytical methods were consulted, and outlines are presented for each chemical. These sources included publications of the U.S. National Institute for Occupational Safety and Health (NIOSH), the U.S. Environmental Protection Agency (EPA), the American Water Works Association (AWWA), the American Society for Testing and Materials (ASTM), and the American National Standards Institute (ANSI).

If the standard or recommended methods were judged to be reliable and specific enough for the analysis of environmental and materials samples from spill sites and if they do not require highly specialized laboratory equipment, no additional methods were sought.

If especially simple, reliable tests (e.g., commonly used industrial methods) were found, they have been presented as well.

11.1 Quantitative Method for the Detection of Natural Gas in Air

11.1.1 Gas Chromatography (APHA 1977). A range of up to 655 $\mu g/m^3$ (1 ppm) of methane in air may be determined using a gas chromatograph equipped with a flame ionization detector. The range may be extended by attenuation changes on the gas chromatograph.

Sampled air is pulled at 100 mL/min through a sample loop hooked up to a stripper column which is 30 cm x 0.6 cm O.D. stainless steel packed with 10 percent Carbowax 400 on 60/80 mesh Chromosorb-W.H.P., 60/80 mesh silica gel, and Malcosorb. The sampled air is then passed through a catalytic reduction tube which is 15 cm x 0.6 cm O.D. stainless steel packed with 10 percent nickel on 42/60 mesh C-22 firebrick, and then through the flame ionization detector. The natural gas is determined by peak height and retention time as well as a standard curve. Typical gas chromatograph operating conditions are: helium carrier gas flow at 200 mL/min, hydrogen to catalytic tube at 30 mL/min, hydrogen to flame at 60 mL/min, air to flame at 400 mL/min, detector temperature 150°C, stripper column 25°C, catalytic tube at 360°C.

11.2 Qualitative Method for the Detection of Natural Gas in Air. Due to the relatively unreactive nature of methane, the simplest method of qualitative detection would be a Drager detection tube for natural gas. Air is drawn through a Drager detection tube using a Drager multi-gas detector pump. A colour change on the indicating layer from white to brownish-green to greyish-violet indicates natural gas (Drager 1979).

11.3 Quantitative Method for the Detection of Natural Gas in Water

11.3.1 Gas Chromatography (AWWA 1980). Methane in water may be determined by gas chromatography using thermal conductivity detection. Up to 1 ppm methane in water may be determined, but this may be extended by sample dilution.

A minimal volume of 1 L of representative sample is collected in an appropriate glass container. A 1 to 2 mL volume of sample is injected into a suitable gas chromatograph equipped with a thermal conductivity detector. The methane is determined using peak heights and retention times as well as a calibration curve. Typical gas chromatograph operating conditions are: helium carrier gas at 80 mL/min and ambient column temperature, in an analytical column of 30 percent hexamethylphosphoramide on Chromosorb P.

11.4 Qualitative Method for the Detection of Natural Gas in Water. A qualitative partition infrared (IR) method may be used for the detection of natural gas in water. Freon 113® (1,1,2-trichloro-1,2,2-trifluoroethane) is used to extract the natural gas from the water. Using 1 cm quartz cells with Freon 113® in the reference beam of a double-beam IR spectrophotometer, the sample is scanned from 3200 to 2700 cm^{-1}. The presence of characteristic bands between 3200 and 2700 cm^{-1} indicates the presence of natural gas (AWWA 1980).

12 REFERENCES AND BIBLIOGRAPHY

12.1 References

Allsop 1980: Allsop, D.G.W., "Transporting LNG from Indonesia to Japan", Sixth International Conference on Liquefied Natural Gas, Institute of Gas Technology, Chicago, IL. (1980).

APHA 1977: Katz, M. (ed.), Methods of Air Sampling and Analysis, Second Edition, American Public Health Association, Washington, DC, Method 201. (1977).

AWWA 1980: American Water Works Association, Standard Methods for the Examination of Water and Wastewater, 15th Edition, American Public Health Association, Washington, DC, pp. 527-529, 461-463. (1976).

Blackmore 1982: Blackmore, D.R., Eyre, J.A., Summers, G.G., "Dispersion and Combustion Behaviour of Gas Clouds Resulting from Large Spillages of LNG and LPG on to the Sea", Trans. 1 Mar. E, Vol. 94, paper 29. (1982).

Bretherick 1979: Bretherick, L., Handbook of Reactive Chemical Hazards, Second Edition, Butterworths, London, England. (1979).

CCD 1977: Hawley, G.G., The Condensed Chemical Dictionary, Ninth Edition, Van Nostrand Reinhold Company, New York, NY. (1977).

Chem. Eng. 1975: Yaws, C.L., "Physical and Thermodynamic Properties", Chemical Engineering, Vol. 82, No. 10, pp. 89-97. (12 May 1975).

CHRIS 1978: U.S. Department of Transportation, Coast Guard, Chemical Hazards Response Information System (CHRIS), Washington, DC. (1978).

CMR 1979: Barry, G.S., "Salt", Canadian Mineral Reviews, Canadian Government Publishing Centre, Hull, Quebec. (1979).

Corkhill 1980: Corkhill, M., "LNG Shipping: Past, Present and Future Directions", Sixth International Conference on Liquefied Natural Gas, Institute of Gas Technology, Chicago, IL. (1980).

CRC 1980: Weast, R.C. (ed.), CRC Handbook of Chemistry and Physics, 60th Edition, Chemical Rubber Publishing Company, Cleveland, OH. (1980).

Cuneo 1980: Cuneo, J.J., Anderson, O.D., Iverson, H.H., "Operating Experience with LNG Carriers - Applying the Skirt Supported, Spherical Cargo Tand Design", Sixth International Conference on Liquefied Natural Gas, Institute of Gas Technology, Chicago, IL. (1980).

Doc. TLV 1981: American Conference of Governmental Industrial Hygienists (ACGIH), Documentation of Threshold Limit Values, Fourth Edition, Cincinnati, OH. (1981).

DOE 1982: A.D. Little Inc., Flare System for Safe Disposal of LNG from a Disabled Tanker, for U.S. Department of Energy, Washington, DC, Report No. DOE/EV/10502-3. (1982).

DOT 1980: United States Coast Guard, Liquefied Natural Gas and Liquefied Petroleum Gas: Views and Practices, Policy and Safety, G-MHM-3/TP14. (1980).

Drager 1979: Leichnitz, K. (ed.), "Air Investigations and Technical Gas Analysis with Drager Tubes", Detector Tube Handbook, Fourth Edition, Lubeck, Germany, p. 112. (1979).

EAG 1978: U.S. Department of Transportation, Emergency Action Guide for Selected Hazardous Materials, Research and Special Programs Administration, Materials Transportation Bureau, Washington, DC. (1978).

Energy 1982: Energy Analysts Inc., Supplementary Risk Analysis for the Melford Point LNG Receiving Terminal, prepared for Arctic Pilot Project and Trans Canada Pipelines Limited by Energy Analysts Inc., Norman, OK. (1982).

Enger 1972: Enger, T., Hartman, D.E., LNG Spillage on Wager: Final Report on Rapid Phase Transformations, Industry Consortium on LNG, Dallas, TX. (1972).

EPA 600/2-80-076: Hatayama, H.K., Chen, J.J., deVera, E.R., Stephens, R.D., Storm, D.L., A Method for Determining the Compatibility of Hazardous Wastes, Municipal Environmental Research Laboratory, Office of Research and Development, U.S. Environmental Protection Agency, Cincinnati, OH. (April, 1980).

ERG 1980: U.S. Department of Transportation, Hazardous Materials, 1980 Emergency Response Guidebook, Research and Special Programs Administration, Materials Transportation Bureau, Washington, DC. (1980).

Ermak 1981: Ermak, D.L., Chan, S.T., Morgan, D.L., Morris, L.K., A Comparison of Dense Gas Dispersion Model Simulations with Burro Series LNG Spill Test Results, Lawrence Livermore Laboratories, Livermore, CA, Report No. UCRL-86713. (1981).

FP 1980: The Financial Port Survey of Mines and Energy Resources 1980, MacLean-Hunter Limited, Toronto, Ontario. (1980).

GE 1980: General Electric Company, Material Safety Data Sheets, Material Safety Information Services, Schenectady, NY. (July, 1980).

GEH 1965: Gas Engineers Handbook, The Industrial Press, New York, NY. (1965).

GPP: Uniroy 1, Guide to Polymer Properties, Uniroyal Inc., Mishawaka, IN. Not dated.

Hansch and Leo 1979: Hansch, C., Leo, A., Substitute Constants for Correlation Analysis in Chemistry and Biology, John Wiley & Sons Inc., New York, NY. (1979).

HCG 1981: Compressed Gas Association, Inc., Handbook of Compressed Gases, Second Edition, Van Nostrand Reinhold Company, New York, NY. (1981).

HNGE 1959: Katz, D.L., Cornell, D., Vary, J.A., et al., Handbook of Natural Gas Engineering, McGraw-Hill Book Company, New York, NY. (1959).

JANAF 1971: Stull, D.R., Prophet, H., JANAF Thermochemical Tables, Second Edition, Office of Standard Reference Data, U.S. National Bureau of Standards, Washington, DC. (June, 1971).

Kirk-Othmer 1980: Grayson, M., Eckroth, D. (ed.), Kirk-Othmer Encyclopedia of Chemical Technology, Third Edition, Vol. 1, John Wiley & Sons Inc., New York, NY. (1980).

Konzek 1982: Konzek, G.J., Yasutake, K.M., Franklin, A.L., LNG Fire and Vapour Control System Technologies, Pacific Northwest Laboratory, for U.S. Department of Energy, Washington, D.C., Report No. PNL-4398. (1982).

Koopman 1981: Koopman, R.P., Cederwall, R.T., Ermak, D.L., et al., Description and Analysis of Burro Series 40-m^3 LNG Spill Experiments, Lawrence Livermore Laboratory, for U.S. Department of Energy, Washington, DC. (1981).

Lange's Handbook 1979: Dean, J.A. (ed.), Lange's Handbook of Chemistry, 12th Edition, McGraw-Hill Book Company, New York, NY. (1979).

LGFS 1982: Liquefied Gaseous Fuels Safety and Environmental Control Assessment Program: Third Status Report, Pacific Northwest Laboratory, for U.S. Department of Energy, Washington, DC, PNL-4172. (1982).

Lefèvre 1980: Lefèvre, M.J., Becker, E.O., First Aid Manual for Chemical Accidents - For Use with Nonpharmaceutical Chemicals, Dowden, Hutchinson, and Ross, Inc., Stroudsburg, PA. (1980).

Little 1982: A.D. Little Inc., Prevention and Control of LNG Tanker Spills with Membrane Barrier Systems Inside Cargo Tanks, for U.S. Department of Energy, Washington, DC, Report No. DOE/EV/10502-2. (1982).

LNG 1977: Canuck Engineering Ltd., LNG Pipelines a Technology Assessment, Calgary, Alberta. (1977).

LPG 1982: Williams, A.F., Lom, W.L., Liquefied Petroleum Gases, John Wiley & Sons, New York, NY. (1982).

Matheson 1972: Matheson Gas Products, Material Safety Data Sheet, Lyndhurst, NJ. (1972).

Matheson 1974: Matheson Gas Products, The Matheson Unabridged Gas Data Book, Lyndhurst, NJ. (1974).

Matheson 1980: Matheson Gas Products, Matheson Gas Data Book, Sixth Edition, Lyndhurst, NJ. (1980).

Merck 1976: Windholz, M., Budavari, S., Stroumtsos, L.Y., Fertig, M.N. (ed.), The Merck Index, Ninth Edition, Merck & Co. Inc., Rahway, NJ. (1976).

NFPA 1978: National Fire Protection Association, Fire Protection Guide on Hazardous Materials, Seventh Edition, Boston, MA. (1978).

NIOSH/OSHA 1981: U.S. Department of Health and Human Services, National Institute for Occupational Safety and Health (NIOSH), U.S. Department of Labor, Occupational Safety and Health Administration (OSHA), Occupational Health Guidelines for Chemical Hazards, NIOSH Publication No. 81-123. (1981).

NMAB 1980: National Materials Advisory Board, Safety Aspects of Liquefied Natural Gas in the Marine Environment, for the United States Coast Guard, Washington, DC, PB80-207210. (1980).

NTSB 1979: National Transportation Safety Board, Pipeline Accident Report - Philadelphia Gas Works - Natural Gas Pipeline Rupture, and Explosion - Philadelphia Pennsylvania, May 11, 1979, Washington, DC, Report No. NTSB-PAR-79-31. (1979).

OGJ 1983: The Petroleum Company, "Major Natural Gas Pipelines in the United States and Canada", Oil and Gas Journal, Tulsa, OK. (1983).

Oilweek 1976: "Oilweek Pipeline Wall Map, 1976-1977", Oilweek. (November 1, 1976).

Oilweek 1984: "Gas Processing Plant Capacities", Oilweek. (January 16, 1984).

Parnarouskis 1980: Parnarouskis, M.C., Taylor, M.W., Lind, C.D., Raj, P.P.K., Cece, J.M., "Vapour Cloud Explosion Study", Sixth International Conference on Liquefied Natural Gas, Institute of Gas Technology, IL. (1980).

Patty 1981: Clayton, G.D., Clayton, F.E. (ed.), Patty's Industrial Hygiene and Toxicology, Vols. 2A, 2B, Third Revised Edition, John Wiley and Sons Canada Limited, Toronto, Ontario. (1981).

Paul 1979: Paul, R., Clarembeaux, A., "Nitrogen and Its Availability for Plants in Soils Submitted to Natural Gas Leaks", Bull. Soc. R. Bot. Belg., Vol. 112, No. 2, pp. 179-185. (1979).

Paul 1980: Paul, R., Delcarte, E., Tilman, J., Godefroid, C., "Effect of Natural Gas Leaks on Mineral Nutrition of Street Trees", Trib. CEBEDEAU, Vol. 33, No. 445, pp. 543-537. (1980).

Pelto 1982: Pelto, P.J., Baker, E.G., Holter, G.M., Powers, T.B., An Overview Study of LNG Release Prevention and Control Systems, Pacific Northwest Laboratory, for U.S. Department of Energy, Washington, DC, Report No. PNL-4014. (1982).

Perry 1973: Perry, R.H., Chilton, C.H. (ed.), Chemical Engineer's Handbook, Fifth Edition, McGraw-Hill Book Company, New York, NY. (1973).

Robinson 1984: Robinson, C., Smith, D.B., "The Auto-Ignition Temperature of Methane", Journal of Hazardous Materials, Vol. 8, pp. 199-203. (1984).

Rosenstock 1977: Rosenstock, H.M., Draxl, K., Steiner, B., Herron, J.T., Energetics of Gaseous Ions, National Bureau of Standards, Washington, DC. (1977).

RTDCR 1974: Canadian Transport Commission, Regulations for the Transportation of Dangerous Commodities by Rail, published by Supply and Services Canada, Ottawa, Ontario. (1974).

Royal 1980: Royal Bank of Canada, Canadian Oil and Gas Map, Energy and Mineral Resources Department, Calgary, Alberta. (1980).

Sax 1979: Sax, N.I., Dangerous Properties of Industrial Materials, Fifth Edition, Van Nostrand Reinhold Company, New York, NY. (1979).

TCM 1979: General American Transportation Corporation, Tank Car Manual, Chicago, IL. (May, 1979).

TLV 1983: American Conference of Governmental Industrial Hygienists, TLV*s Threshold Limit Values for Chemical Substances and Physical Agents in the Workroom Environment with Intended Changes for 1983-84, Cincinnati, OH. (1983).

TPS 1978: GSR Fluid Handling, Thermoplastic Piping Systems, Sun Valley, CA. (1978).

Ullmann 1975: Ullmanns Encyklopaedie der technischen Chemie, Verlag Chemie, Weinheim. (1975).

USCG 1977: United States Coast Guard, Predictability of LNG Vapor Dispersion from Catastrophic Spills onto Water, Washington, DC, ADA040525. (1977).

USCG 1980: Schneider, A.L., Lind, C.B., Parnarouskis, M.C., U.S. Coast Guard Liquefied Natural Gas Research at China Lake, United States Coast Guard, Washington, DC, ADA081644. (1980).

USDHEW 1977: U.S. Department of Health, Education and Welfare, Occupational Diseases. A Guide to Their Recognition, National Institute for Occupational Safety and Health, DHEW (NIOSH) No. 77-181. (1977).

Verschueren 1984: Verschueren, K., Handbook of Environmental Data on Organic Chemicals, Van Nostrand Reinhold Company, New York, NY. (1984).

Water Management Goals 1978: Ontario Ministry of the Environment, Water Management Goals, Policies, Objectives and Implementation Procedures for the Ministry of the Environment, Toronto, Ontario. (November, 1978).

Wiesenburg 1982: Wiesenburg, D.A., Brooks, J.M., Burke, R.A. Jr., "Gaseous Hydrocarbons Around An Active Offshore Gas and Oil Field", Environ. Sci. Technol., Vol. 16, No. 5, pp. 278-282. (1982).

WQC 1963: McKee, J.E., Wolf, H.W., Water Quality Criteria, Second Edition, Resources Agency of California, State Water Quality Control Board, pp. 198, 219. (1963).

WQC 1972: National Academy of Sciences, Water Quality Criteria 1972: A Report of the Committee on Water Quality Criteria, Environmental Studies Board, National Academy of Sciences, Washington, DC, p. 148. (1972).

12.2 Bibliography

Allsop, D.G.W., "Transporting LNG from Indonesia to Japan", Sixth International Conference on Liquefied Natural Gas, Institute of Gas Technology, Chicago, IL. (1980).

American Conference of Governmental Industrial Hygienists (ACGIH), Documentation of Threshold Limit Values, Fourth Edition, Cincinnati, OH. (1981).

American Conference of Governmental Industrial Hygienists, TLV*s Threshold Limit Values for Chemical Substances and Physical Agents in the Workroom Environment with Intended Changes for 1983-84, Cincinnati, OH. (1983).

American Water Works Association, Standard Methods for the Examination of Water and Wastewater, 15th Edition, American Public Health Association, Washington, DC, pp. 527-529, 461-463. (1976).

Barry, G.S., "Salt", Canadian Mineral Reviews, Canadian Government Publishing Centre, Hull, Quebec. (1979).

Blackmore, D.R., Eyre, J.A., Summers, G.G., "Dispersion and Combustion Behaviour of Gas Clouds Resulting from Large Spillages of LNG and LPG on to the Sea", Trans 1 Mar E, Vol. 94, paper 29. (1982).

Bretherick, L., Handbook of Reactive Chemical Hazards, Second Edition, Butterworths, London, England. (1979).

Canadian Transport Commission, Regulations for the Transportation of Dangerous Commodities by Rail, published by Supply and Services Canada, Ottawa, Ontario. (1974).

Canuck Engineering Ltd., LNG Pipelines a Technology Assessment, Calgary, Alberta. (1977).

Clayton, G.D., Clayton, F.E. (ed.), Patty's Industrial Hygiene and Toxicology, Vols. 2A, 2B, Third Revised Edition, John Wiley and Sons Canada Limited, Toronto, Ontario. (1981).

Compressed Gas Association, Inc., Handbook of Compressed Gases, Second Edition, Van Nostrand Reinhold Company, New York, NY. (1981).

Corkhill, M., "LNG Shipping: Past, Present and Future Directions", Sixth International Conference on Liquefied Natural Gas, Institute of Gas Technology, Chicago, IL. (1980).

Cuneo, J.J., Anderson, O.D., Iverson, H.H., "Operating Experience with LNG Carriers - Applying the Skirt Supported, Spherical Cargo Tank Design", Sixth International Conference on Liquefied Natural Gas, Institute of Gas Technology, Chicago, IL. (1980).

Dean, J.A. (ed.), Lange's Handbook of Chemistry, 12th Edition, McGraw-Hill Book Company, New York, NY. (1979).

Energy Analysts Inc., Supplementary Risk Analysis for the Melford Point LNG Receiving Terminal, prepared for Arctic Pilot Project and Trans Canada Pipelines Limited by Energy Analysts Inc., Norman, OK. (1982).

Enger, T., Hartman, D.E., LNG Spillage on Water: Fianl Report on Rapid Phase Transformations, Industry Consortium on LNG, Dallas, TX. (1972).

Ermak, P.L., Chan, S.T., Morgan, D.L., Morris, L.K., A Comparison of Dense Gas Dispersion Model Simulations with Burro Series LNG Spill Test Results, Lawrence Livermore Laboratories, Livermore, CA, Report No. UCRL-86713. (1981).

The Financial Port Survey of Mines and Energy Resources 1980, MacLean-Hunter Limited, Toronto, Ontario. (1980).

Gas Engineers Handbook, The Industrial Press, New York, NY. (1965).

General American Transportation Corporation, Tank Car Manual, Chicago, IL. (May, 1979).

General Electric Company, Material Safety Data Sheets, Material Safety Information Services, Schenectady, NY. (July, 1980)

Grayson, M., Eckroth, D. (ed.), Kirk-Othmer Encyclopedia of Chemical Technology, Third Edition, Vol. 1, John Wiley & Sons Inc., New York, NY. (1980).

GSR Fluid Handling, Thermoplastic Piping Systems, Sun Valley, CA. (1978).

Hansch, C., Leo, A., Substitute Constants for Correlation Analysis in Chemistry and Biology, John Wiley & Sons Inc., New York, NY. (1979).

Hatayama, H.K., Chen, J.J., deVera, E.R., Stephens, R.D., Storm, D.L., A Method for Determining the Compatibility of Hazardous Wastes, Municipal Environmental Research Laboratory, Office of Research and Development, U.S. Environmental Protection Agency, Cincinnati, OH. (April, 1980).

Hawley, G.G., The Condensed Chemical Dictionary, Ninth Edition, Van Nostrand Reinhold Company, New York, NY. (1977).

Katz, D.L., Cornell, D., Vary, J.A., et al., Handbook of Natural Gas Engineering, McGraw-Hill Book Company, New York, NY. (1959).

Katz, M. (ed.), Methods of Air Sampling and Analysis, Second Edition, American Public Health Association, Washington, DC, Method 201. (1977).

Konzek, G.J., Yasutake, K.M., Franklin, A.L., LNG Fire and Vapour Control System Technologies, Pacific Northwest Laboratory, for U.S. Department of Energy, Washington, DC, Report No. PNL-4398. (1982).

Koopman, R.P., Cederwall, R.T., Ermak, D.L., et al., Description and Analysis of Burro Series 40-m^3 LNG Spill Experiments, Lawrence Livermore Laboratory, for U.S. Department of Energy, Washington, DC. (1981).

Lefèvre, M.J., Becker, E.O., First Aid Manual for Chemical Accidents - For Use with Nonpharmaceutical Chemicals, Dowden, Hutchinson, and Ross, Inc., Stroudsburg, PA. (1980).

Leichnitz, K. (ed.), "Air Investigations and Technical Gas Analysis with Drager Tubes", Detector Tube Handbook, Fourth Edition, Lubeck, Germany, p. 112. (1979).

Liquefied Gaseous Fuels Safety and Environmental Control Assessment Program: Third Status Report, Pacific Northwest Laboratory, for U.S. Department of Energy, Washington, DC, PNL-4172. (1982).

A.D. Little Inc., Flare System for Safe Disposal of LNG from a Disabled Tanker, for U.S. Department of Energy, Washington, DC, Report No. DOE/EV/10502-3. (1982).

A.D. Little Inc., Prevention and Control of LNG Tanker Spills with Membrane Barrier Systems Inside Cargo Tanks, for U.S. Department of Energy, Washington, DC, Report No. DOE/EV/10502-2. (1982).

Matheson Gas Products, The Matheson Unabridged Gas Data Book, Lyndhurst, NJ. (1974).

Matheson Gas Products, Material Safety Data Sheet, Lyndhurst, NJ. (1972).

Matheson Gas Products, Matheson Gas Data Book, Sixth Edition, Lyndhurst, NJ. (1980).

McKee, J.E., Wolf, H.W., Water Quality Criteria, Second Edition, Resources Agency of California, State Water Quality Control Board, pp. 198, 219. (1963).

National Academy of Sciences, Water Quality Criteria 1972: A Report of the Committee on Water Quality Criteria, Environmental Studies Board; National Academy of Sciences, Washington, DC, p. 148. (1972).

National Fire Protection Association, Fire Protection Guide on Hazardous Materials, Seventh Edition, Boston, MA. (1978).

National Materials Advisory Board, Safety Aspects of Liquefied Natural Gas in the Marine Environment, for the United States Coast Guard, Washington, DC, PB80-207210. (1980).

National Transportation Safety Board, Pipeline Accident Report - Philadelphia Gas Works - Natural Gas Pipeline Rupture and Explosion - Philadelphia, Pennsylvania, Washington, DC, Report No. NTSB-PAR-79-31. (1979).

Oilweek, "Gas Processing Plant Capacities". (January 16, 1984).

Oilweek, "Oilweek Pipeline Wall Map, 1976-1977". (November 1, 1976).

Ontario Ministry of the Environment, Water Management Goals, Policies, Objectives and Implementation Procedures for the Ministry of the Environment, Toronto, Ontario. (November, 1978).

Parnarouskis, M.C., Taylor, M.W., Lind, C.D., Raj, P.P.K., Cece, J.M., "Vapour Cloud Explosion Study", Sixth International Conference on Liquefied Natural Gas, Institute of Gas Technology, Chicago, IL. (1980).

Paul, R., Clarembeaux, A., "Nitrogen and Its Availability for Plants in Soils Submitted to Natural Gas Leaks", Bull. Soc. R. Bot. Belg., Vol. 112, No. 2, pp. 179-185. (1979).

Paul, R., Delcarte, E., Tilmân, J., Godefroid, C., "Effect of Natural Gas Leaks on Mineral Nutrition of Street Trees", Trib. CEBEDEAU, Vol. 33, No. 445, pp. 543-537. (1980).

Pelto, P.J., Baker, E.G., Holter, G.M., Powers, T.B., An Overview Study of LNG Release Prevention and Control Systems, Pacific Northwest Laboratory, for U.S. Department of Energy, Washington, DC, Report No. PNL-4014. (1982).

Perry, R.H., Chilton, C.H. (ed.), Chemical Engineer's Handbook, Fifth Edition, McGraw-Hill Book Company, New York, NY. (1973).

Petroleum Publishing Company, "Major Natural Gas Pipelines in the United States and Canada", Oil and Gas Journal, Tulsa, OK. (1983).

Robinson, C., Smith, D.B. "The Auto-Ignition Temperature of Methane", Journal of Hazardous Materials, Vol. 8, pp. 199-203. (1984).

Rosenstock, H.M., Draxl, K., Steiner, B., Herron, J.T., Energetics of Gaseous Ions, National Bureau of Standards, Washington, DC. (1977).

Royal Bank of Canada, Canadian Oil and Gas Map, Energy and Mineral Resources Department, Calgary, Alberta. (1980).

Sax, N.I., Dangerous Properties of Industrial Materials, Fifth Edition, Van Nostrand Reinhold Company, New York, NY. (1979).

Schneider, A.L., Lind, C.B., Parnarouskis, M.C., U.S. Coast Guard Liquefied Natural Gas Research at China Lake, United States Coast Guard, Washington, DC, ADA081644. (1980).

Stull, D.R., Prophet, H., JANAF Thermochemical Tables, Second Edition, Office of Standard Reference Data, U.S. National Bureau of Standards, Washington, DC. (June, 1971).

Ullmanns Encyklopaedie der technischen Chemie, Verlag Chemie, Weinheim. (1975).

Uniroyal, Guide to Polymer Properties, Uniroyal Inc., Mishawaka, IN. Not dated.

United States Coast Guard, Predictability of LNG Vapor Dispersion from Catastrophic Spills onto Water, Washington, DC, ADA040525. (1977).

United States Coast Guard, Liquefied Natural Gas and Liquefied Petroleum Gas: Views and Practices, Policy and Safety, 6-MHM-3/TP14. (1980).

U.S. Department of Health, Education and Welfare, Occupational Diseases. A Guide to Their Recognition, National Institute for Occupational Safety and Health, DHEW (NIOSH) No. 77-181. (1977).

U.S. Department of Health and Human Services, National Institute for Occupational Safety and Health (NIOSH), U.S. Department of Labor, Occupational Safety and Health Administration (OSHA), Occupational Health Guidelines for Chemical Hazards, NIOSH Publication No. 81-123. (1981).

U.S. Department of Transportation, Emergency Action Guide for Selected Hazardous Materials, Research and Special Programs Administration, Materials Transportation Bureau, Washington, DC. (1978).

U.S. Department of Transportation, Hazardous Materials, 1980 Emergency Response Guidebook, Research and Special Programs Administration, Materials Transportation Bureau, Washington, DC. (1980).

U.S. Department of Transportation, Coast Guard, Chemical Hazards Response Information System (CHRIS), Washington, DC. (1978).

Verschueren, K., Handbook of Environmental Data on Organic Chemicals, Van Nostrand Reinhold Company, New York, NY. (1984).

Weast, R.C. (ed.), CRC Handbook of Chemistry and Physics, 60th Edition, Chemical Rubber Publishing Company, Cleveland, OH. (1980).

Wiesenburg, D.A., Brooks, J.M., Burke, R.A. Jr., "Gaseous Hydrocarbons Around An Active Offshore Gas and Oil Field", Environ. Sci. Technol., Vol. 16, No. 5, pp. 278-282. (1982).

Williams, A.F., Lom, W.L., Liquefied Petroleum Gases, John Wiley & Sons, New York, NY. (1982).

Windholz, M., Budavari, S., Stroumtsos, L.Y., Fertig, M.N. (ed.), The Merck Index, Ninth Edition, Merck & Co. Inc., Rahway, NJ. (1976).

Yaws, C.L., "Physical and Thermodynamic Properties", Chemical Engineering, Vol. 82, No. 10, pp. 89-97. (12 May, 1975).

EnviroTIPS

Common Abbreviations

BOD	biological oxygen demand
b.p.	boiling point
CC	closed cup
cm	centimetre
CMD	count median diameter
COD	chemical oxygen demand
conc	concentration
c.t.	critical temperature
eV	electron volt
g	gram
ha	hectare
Hg	mercury
IDLH	immediately dangerous to life and health
Imp. gal.	imperial gallon
in.	inch
J	joule
kg	kilogram
kJ	kilojoule
km	kilometre
kPa	kilopascal
kt	kilotonne
L	litre
lb.	pound
LC_{50}	lethal concentration fifty
LC_{LO}	lethal concentration low
LD_{50}	lethal dose fifty
LD_{LO}	lethal dose low
LEL	lower explosive limit
LFL	lower flammability limit
m	metre
m	meta
M	molar
MAC	maximum acceptable concentration
max	maximum
mg	milligram
MIC	maximum immission concentration
min	minute or minimum
mm	millimetre
µg	microgram
µm	micrometre
°Be	degrees Baumé (density)
MMAD	mass median aerodynamic diameter
MMD	mass median diameter
m.p.	melting point
MW	molecular weight
N	newton
NAS	National Academy of Sciences
NFPA	National Fire Protection Association
NIOSH	National Institute for Occupational Safety and Health
nm	nanometre
o	ortho
OC	open cup
p	para
P_c	critical pressure
PEL	permissible exposure level
pH	measure of acidity/ alkalinity
ppb	parts per billion
ppm	parts per million
P_s	standard pressure
psi	pounds per square inch
s	second
STEL	short-term exposure limit
STIL	short-term inhalation limit
T_c	critical temperature
TC_{LO}	toxic concentration low
Td	decomposition temperature
TD_{LO}	toxic dose low
TL_m	median tolerance limit
TLV	Threshold Limit Value
Ts	standard temperature
TWA	time weighted average
UEL	upper explosive limit
UFL	upper flammability limit
VMD	volume mean diameter
v/v	volume per volume
w/w	weight per weight