SUMMARY OF GAS PIPELINE REGULATIONS IN ONTARIO: Using the Rhodes "Rs Safety Setback" to Plan Hazard Distances for Municipalities and Regional Governments

By Katharine Parsons, B.A. (Chem.), Executive Director, Global Environmental Action Group

NATURAL GAS PIPELINE RUPTURE/FIRE: Calculating safety setbacks from high-pressure gas lines

By Charles Rhodes, P. Eng., Ph.D.

PREPARED FOR KING TOWNSHIP
JANUARY 2010

SUMMARY OF GAS PIPELINE REGULATIONS IN ONTARIO: Using the Rhodes "Rs Safety Setback" to Plan Hazard Distances for Municipalities and Regional Governments

Figure 1 - Sunrise Propane Explosion

In general, internationally and in Canada, there are more regulations to protect "pipeline integrity" than legislation to protect the public. The Canadian Standards Association has some of the highest pipeline MAOP standards in the world, but those do not prevent the roughly 3,500 gas pipeline strikes every year in Ontario, more than 60% of which are caused by "external factors" such as construction.

LEGISLATION, ENVIRONMENTAL GUIDELINES AND REGULATIONS FOR GAS PIPELINE SETBACKS IN ONTARIO

The rules and regulations surrounding "hazard distances" in Provincial Legislation have cross references that makes it difficult to ascertain what these are. Four key documents relate to the location and construction of gas pipelines in Ontario.

1. Technical Standards and Safety Authority (TSSA) in its "Guidelines For Natural Gas Utilities Locating New Pipeline Facilities," **PI-98/01**, August 1998, indicates that the setbacks suggested are for pipelines designed to operate at hoop stresses of 40% or more of the specified minimum yield stress (SMYS). It does not specify pipeline diameter size. For example the 16 inch diameter pipeline proposed for King Township is expected to operate at less than the 40% of the specified minimum yield stress.

If the pipeline pressure was expected to cause a hoop stress exceeding 40% of SMYS, then a setback of 20 metres is proposed to individual dwellings and the guideline calls for a 200 metre setback from the "centerline of the pipeline to institutions where rapid evacuation may be difficult, such as hospitals, nursing homes, penal institutions, and institutions for the physically and mentally handicapped."

According to the Fuels Safety Division of the TSSA, schools do not come under this heading. Also the TSSA defines the large pipelines that are not transmission pipelines as "distribution pipelines (typically between 1 to 6 inches in diameter but they can be larger, up to transmission diameter of 36"). Distribution pipelines are allowed in road allowances/easements and do not require setbacks unless they operate at a pressure that causes the hoop stress to exceed 40% of SYMS.

The guideline goes on to allow that "Where these distances are not practicable" the setback for residences be reduced to 5 metres and the setback to institutions be reduced to 90 metres, providing both the type of pipeline used be changed to a different toughness AND the coverage over the pipeline be a minimum of 1.5 metres. Then, if that coverage over the pipeline is not "practicable," then the guideline calls for "suitable means of identifying and protecting the pipeline may be used as an alternative."

2. The second document ENVIRONMENTAL GUIDELINES FOR THE LOCATION, CONSTRUCTION AND OPERATION OF HYDROCARBON PIPELINES AND FACILITIES IN ONTARIO, Ontario Energy Board, 5th Edition, May 2003. Setbacks are not discussed but referred to the TSSA Guidelines[1] above only if that maximum pressure (40% SYMS) is exceeded. On page 28 of the OEB Guidelines, they write "**"**In urban settings, issues such as traffic safety, commercial business disruption, **proximity to institutions such as schools** and hospitals and the impacts on local residents may require increased attention during the routing and site selection stage. **Such information should be gathered as part of public consultation and incorporated into the social impact assessment so that it can be used as part of the routing and siting process**."

However the Guideline[2] does not insist upon identification for schools. It does so for other areas such as " "sensitive landforms," "heritage features," "watercourses," **"**fish habitat" and "occupied and vacant buildings adjacent to the ROW (Right Of Way) which may be affected by **construction activities."** (p.22)

The Guideline[2] continues: "Areas of important recreational potential should be avoided, including all known areas used for the purpose of organized outdoor education[2]." (p.34) Playgrounds of schools were specified as such.

3. The third document referenced is the "Land use planning for pipelines: A guideline for local authorities, developers, and pipeline operators," Canadian Standards Association, Plus 663, (August 2004). "This document proposes that, at a minimum, consultation take place if a proposed development is **within 200 m of the centreline of a pipeline**. This Guideline also **urges** that such consultation take place for development **beyond 200 m** of the centreline of a pipeline to the extent that a proposed development is still within a setback or emergency response planning zone associated with a given

pipeline (e.g., **some high-vapour-pressure** or sour natural **gas pipelines**).” (p.2 Section 1.2). That Guide does not address distribution lines 1 to 36” in diameter.

4. The fourth document is actually in two parts. The first is the “Oil and Gas Pipeline Systems – Code Adoption Document – Amendment – January 14, 2008[4] “ (Technical Standards & Safety Authority) that was adopted by Ontario Regulation 223/01 Codes and Standards Adopted by Reference[5] (Technical Standards and Safety Act, 2000), s. 8 (1).

The only one of these crucial documents that suggests setback is the “Guidelines for Natural Gas Utilities Locating New Pipeline Facilities,” but only if the pressure for the pipelines exceeds 40% SMYS.

GAS PRESSURE

The Maximum Allowable Operating Pressure (MAOP) for pipelines is established by the CSA Z662-03. The pressure varies in different sizes of pipelines. A 20-inch pipeline may have a MAOP of 700 psig but the local distributor may choose to operate it at 250 psig. A six-inch line can have an operating pressure of 720 psig.

INTERNATIONAL HAZARD DISTANCE LEGISLATION

In general, internationally and in Canada, there are more regulations to protect “pipeline integrity” than legislation to protect the public.

The Canadian Standards Association has some of the highest pipeline MAOP standards in the world, but those do not prevent the roughly 3,500 gas pipeline strikes every year in Ontario, more than 60% of which are caused by “external factors” such as construction.

United Kingdom

Hazard distances are calculated according to the pressure in the pipeline, the population density and the distance to those populations.

United States

The **State of California Department of Education** has a regulation that stipulates the proximity to a pipeline that a school can be built according to the pressure in that natural gas pipeline. If the pressure exceeds 80 pounds per square inch (psig), then schools can be no closer than 1,500 feet (approximately 500 meters). By comparison the proposed gas pipeline for King Township, Ontario is expected to operate around 650 psig and runs within 90 meters of a school. Pipeline companies in California have been looking at those distances when planning new lines. One risk assessment report was prepared by Wilson Geosciences (May 2007) for a pipeline (analyzed for 650 psi maximum pressure) proposed near four schools.

Various impact zones were calculated for the four schools (see example Figure 2 below).

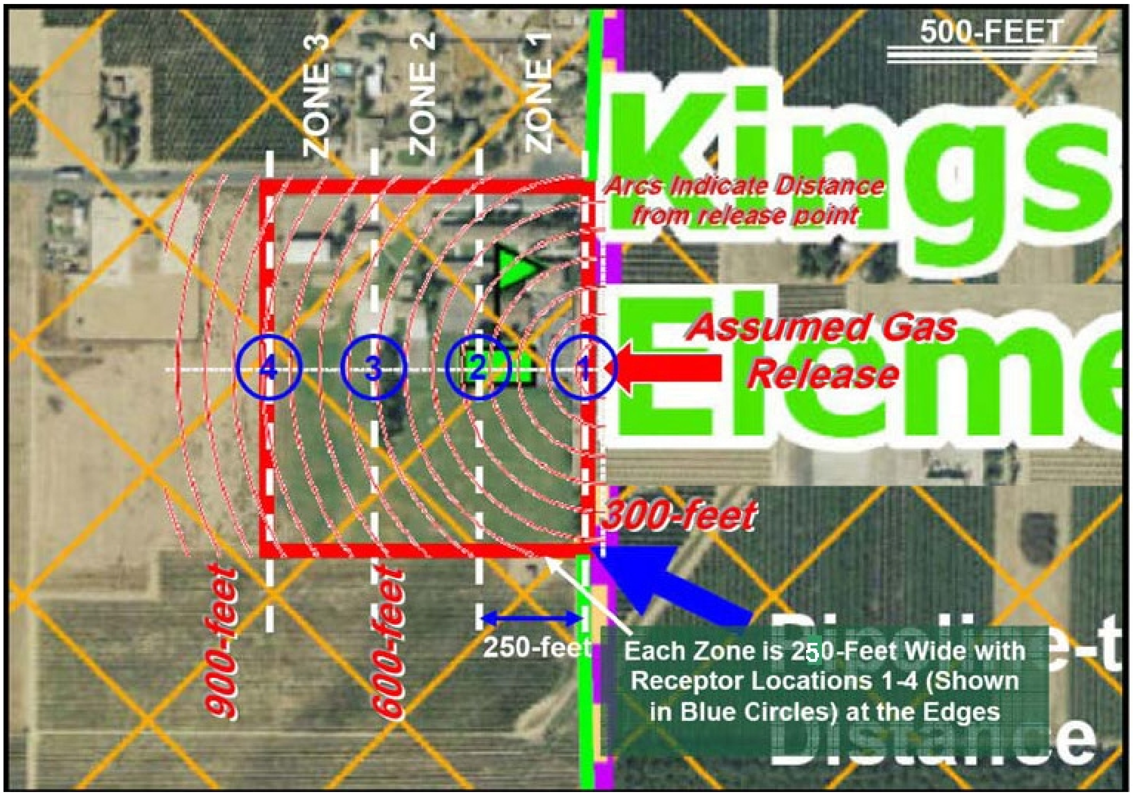

Figure 2 - School A

School A: 50 feet from proposed high-pressure pipeline (650 psig, 20 inch diameter) In the event of a pipeline rupture and ignition, the report calculated mortality in the blast zone 50 feet from the pipeline out to 300 feet to be 100% (i.e. the school location was not safe), and an additional 50% mortality within the zone 300 feet to 550 feet.

School B: 180 feet from proposed high-pressure pipeline (650 psig, 20 inch diameter) In the event of a pipeline rupture and ignition, the report calculated mortality from the pipeline from 180 feet to 520 feet (outside boundary) to be 50%, and 0% mortality from more than 520 feet away from the pipeline.

School C: 300 feet from proposed high-pressure pipeline (650 psig, 20 inch diameter) In the event of a pipeline rupture and ignition, the report calculated mortality from the pipeline from 300 feet to 580 feet (outside boundary) to be 40.5%, and 0% mortality more than 580 feet away from the pipeline.

School D: 1380 feet from proposed high-pressure pipeline (650 psig, 20 inch diameter). In the event of a pipeline rupture and ignition, the report calculated mortality from 1380 feet to 2700 feet (outside boundary) to be 0% (i.e. the school location was likely safe).

HAZARD DISTANCE LEGISLATION IN CANADA

ALBERTA

Alberta mandates setbacks for sour gas facilities according to population, facility, and potential release rate of sour gas from wells and pipelines. For the minimum setbacks in Alberta, the release rate of sour gas of 0.3 m^3/sec, there would be no additional setback to residences and schools beyond the usual easement or right-of-way for the pipeline (sometimes the recommended the 30 meters mentioned by the Canadian Standards Association is adhered-to). If the potential release rate of sour gas increases to 2 m^3/sec then the setback to residences increases to a mandated 100m and a mandated setback to rural schools of 500 meters. Once the sour gas volume-release rate increases to 6.0 m^3/sec, the mandated setback to urban centres and public facilities (such as schools) increases to 1,500 meters. In its application to the Ontario Energy Board, Enbridge stated that its maximum volume would be 136,000 cubic meters per hour (37.22 cubic meters per second).

BRITISH COLUMBIA

B.C. Refers to CSA Standard Z662 (the standard published by the Canadian Standards Association Oil and Gas Pipeline Systems). CSA Z662 refers to pipeline right-of-way as well as emergency planning widths around the ROW (usually 30 meters on either side of the pipeline). In addition to that, B.C. applies additional setbacks in its natural heritage areas, for example 200 meters from trumpeter swan nests, 100 meters from other nesting sites, 100 meters from mineral licks, 50 meters from beaver ponds and 50 meters from forest recreation sites and trails.

SASKATCHEWAN

Pressure testing according to CSA Standard Z662, *Oil and Gas Pipeline Systems.*

MANITOBA

The province distinguishes between high pressure (more than 700 kPa/101 psi) and low pressure (less than 700 kPa). Regulation determines setback according to the explosive capacity of gas pipeline in kg compared to TNT; if deemed non-explosive 15 m minimum setback. A “2 kg TNT equivalent” triggers a 32 m setback, up to 10 kg = 72 m setback.

NEW BRUNSWICK

Setbacks according to CSA Standard Z662, *Oil and Gas Pipeline Systems.*

RECENT CHANGES TO ONTARIO HAZARD DISTANCE LEGISLATION

Following the Sunrise Gas Explosion, the term “hazard distance” was introduced in the Ontario Regulations, but only as they applied to propane handling and storage issues. The Sunrise Propane Gas Explosion in Toronto August 10, 2008, which forced the evacuation of approximately 12,500 residents, caused widespread property damage and personal injury. The explosion has resulted in a $300 million class-action lawsuit against Sunrise Propane, the City of Toronto, and the provincial government. Residents had vocally questioned safety of the proximity of the facility to homeowners for years before the explosion. The resulting class-action lawsuit is what can occur as a result of lack of clear guidance documents and appropriate legislation.

The rules and regulations surrounding “hazard distances” in Provincial Legislation also have cross references that makes it difficult to ascertain what these are. For example, in the recent O.Reg 543/06 under The Planning Act, Official Plans and Plan Amendments, “hazard distance” is defined:

> ‘ "hazard distance" means the distance established as the hazard distance applicable to the propane operation referenced in a risk and safety management plan required under Ontario Regulation 211/01 (Propane Storage and Handling) made under the *Technical Standards and Safety Act, 2000*; ("distance de danger") ‘

Protection for Municipalities by Official Plans and Zoning Documents

The Province of Ontario is appearing to download the responsibility for safety setbacks and “hazard distances” onto the municipalities, for smaller diameter gas pipelines. In their Environmental Guideline[2] the Ontario Energy Board writes:

> “Planning Act, R.S.O. 1990, c. P. 13 Provides for official plans and zoning bylaws to control land use. However, **official plans do not control transmission lines approved by the Board**. (Appendix I, p. 4)”

The CSA Land Use Planning for Pipelines[3] defines “transmission lines” as:

> “Transmission pipelines typically range in size from 508.0 mm to 1219.2 mm (20 in to 48 in) in diameter. Transmission pipelines carry oil, natural gas, and natural gas liquids from the producing regions of the country to the marketplace. (A.2.2 p. 15).”

The TransCanada pipeline which is located on the west side of Highway 400 would be considered a “transmission line” according to the CSA.

Distribution lines are typically smaller:

> “Pipelines delivering natural gas from transmission pipelines to homes and businesses are called “distribution pipeline” systems. Distribution pipelines can be as large as 914.4 mm (36 in) in diameter. **However, most are much smaller, ranging in size from 33.4 mm to 168.3 mm (1 in to 6 in) in diameter. These pipelines generally operate at lower pressures than the**

> **transmission pipelines** and are owned and operated by local distribution companies (LDCs). Distribution pipelines are not specifically addressed in this Guideline."[3]

In local distribution lines the pressure may be as low as 3 psi or less. A two-inch line may have a pressure of 10-11 psi.

The natural gas pipeline that is proposed to supply the York Energy Centre, for example, would be defined as a "distribution line" as it is 16" in diameter, in spite of its 650 psi working pressure. Distribution lines are allowed by many jurisdictions but typically they are much smaller.

The Ontario Energy Board appears to have jurisdiction over pipelines over 20 inches in diameter. Therefore it may be appropriate to set hazard distances (setbacks) in municipal planning documents for pipelines over 6 inches in diameter based on the pipe diameter and the maximum rated working pressure.

Hazards and Risks of Natural Gas Pipelines

The proponents of natural gas pipelines will argue that the construction and operation of gas pipelines is the safest way to transport this flammable gas, and it is.

In his report "Matrix-Based Risk Assessment Approach for Addressing Linear Hazards, such as Pipelines[7]," F. Henselwood listed the cause of pipeline rupture as a result of external corrosion, for example, as only 2.58%.

However the *external causes* of pipeline breach are enormous by comparison. 69.35% of ruptures were caused by third-party damage and construction. These are often caused by back hoes, or by the pressure on the line by a boom truck. When the gas pipeline is built in a road right-of-way, as it is proposed for King Township, future road widening and construction may present hazards. Further, when road crews clear the snow from culverts in the spring with large construction shovels, it may be hazardous to do so if a pipeline is nearby. Often signage (such as the markers for gas pipelines) and landforms are obscured by large piles of snow.

CBC News investigated pipeline ruptures and learned that there are approximately 3,500 gas pipeline "strikes" every year in Ontario alone. Not all of these resulted in ignition/combustion.

In the above risk document, risk scores can be applied according to distance from the hazard. The terms "geographic risk estimates per hectare of land within 1 km of a pipeline," and "societal risk estimates per hectare of land within 1 km of a pipeline" were used. Further, if the value of a fatality is X, and one fatality is 1X, then two fatalities is 4X. In other words the formula applied to possible multiple fatalities is the number of fatalities raised to the power of two (i.e. squared).

Society tends to be able to handle the death of one or two people in a gas explosion in a reasonable way, but the death of multiple children in a school fire or explosion leaves a lasting mark on its population. The Oklahoma City terrorist bombing in 1995 claimed the lives of 168 people, which included 19 children in the daycare centre. The blast was the equivalent of 5,000 pounds (2,300 kg) of TNT. Fifteen years later, the most indelible image of one of the fatalities is that of a firefighter cradling the body of a toddler.

In Henselwood's study the "societal risk factors" dropped to zero 1 km from the hazard. It inched up slowly to 8% at 400 metres and then became 30% at 200 metres. This was not applied to specific land uses such as churches and schools. In other words, a 1000 meter distance from an explosion hazard is acceptable to the majority of the population irrespective of the land use.

Thermal radiation intensity with respect to distance resulting from a pipeline rupture/fire can be calculated according to the diameter and working pressure of a natural gas pipeline. In a recent document "Natural Gas Pipeline Rupture/Fire: Calculating safety setbacks from high-pressure gas lines**"** by Dr. Charles Rhodes, P. Eng., Ph.D., the calculated *minimum* "radiation safety distance" **Rs** from a 16" diameter 650 psi natural gas pipeline, such as that proposed for King Township (Ontario), would be 320 metres. He wrote:

> "All parties should clearly understand that the radiation emitted by a pipeline rupture/fire is so intense that the only practical strategy for a rural fire department is to let the fire burn itself out. It is also unrealistic to expect persons within radius (**Rs / 2**) of a pipeline rupture/fire to be rescued by volunteer fire department personnel. If possible the municipality should attempt to enforce a 300 m setback instead of a 200 m setback. There could easily be litigation related to injury and property damage in the 200 m to 300 m zone."

In the Township of King, where the 16 inch diameter 650 psi natural gas pipeline is proposed to service a 393 MW to 435 MW gas-fired peaking electricity generating station, it is contemplated that the pipeline will be built in the rural road allowance. The Kettleby Public School building, its school bus parking area and its playground are all within a 100 m radius of the pipeline. Even at Rs / 2 = 160 m the thermal radiation resulting from a pipe rupture/fire would be so intense as to ignite buildings and farm crops. At radii from the rupture/fire point less than Rs / 2 = 160 m the probability of human survival is remote.

Calculating Hazard Distances

Municipalities should give careful consideration to setbacks in rural areas, not simply to protect rural schools but also to allow for rural resources. Fire departments are often made up of volunteer firefighters. They may lack the training and equipment to fight the combustion consequences of a large delayed ignition natural gas explosion followed by sustained high levels of thermal radiation. Sources of water for firefighting are often limited to local wells, ponds, streams and water trucks.

In Alberta, for example, special consideration is given to setbacks from sour gas facilities in rural settings. If a 16” sour gas pipeline were to be built in Alberta today, the formula that the province applies for a rural school would result in a mandated setback of 1,500 metres from the ***property line*** of the school, and not just the structure. This recognizes the reality that children play outside in school yards. California has recognized this fact in its Department of Education regulations[10] with respect to distances from natural gas pipelines: it limits construction of new schools to no closer than 1,500 feet to high pressure gas pipelines of 80 psi and higher. The gas pipeline for the York Energy Centre will operate at a pressure of approximately 650 psi.

Rather than having a municipality assign risk factors to casualties, the following **Table 1** presents a sample of some setbacks for different types of gas pipelines and population types. It is based on Dr. Charles Rhodes’ “**Rs”** minimum safety setback[8]**,** the California risk documents[10-11], and the Province of Alberta’s directive for setbacks. Distances may be adjusted by rural municipalities if the limited resources for emergency management warrant up-sizing the setbacks (calculations are expanded in **Tables 2-5** following the population definitions).

TABLE 1
EXAMPLES OF SETBACKS BASED ON
“RHODES Rs” AND POPULATIONS

	TYPE OF DEVELOPMENT				
Type of gas pipeline	**Population 1 Individual Residences & Farms**	**Population 2 Unrestricted Country Development**	**Population 3 Public Facility**	**Population 4 Private Facility**	**Population 5 Urban Centre**
Distribution pipeline (typically “local” distribution systems) 101.6. mm (4 in) in diameter & 10 psi	Right-of-way of pipeline (if any)	Right-of-way of pipeline (if any)	Right-of-way of pipeline (if any)	Right-of-way of pipeline (if any)	Right-of-way of pipeline (if any)
Distribution pipeline 152.4 mm (6 in diameter) & 15 psi	18 meters	18 meters	18 meters	18 meters	18 meters
Distribution pipeline 304.8 mm (12 in. diameter) & 182 psi	177 meters	177 meters	177 meters (from property line) and prohibited within property	177 meters (from property line) and prohibited within property	177 meters
Distribution pipeline 406.4 mm (16 in. diameter) & 650 psi	**329 meters**	**329 meters**	**329 meters (from property line) and prohibited within property**	**329 meters (from property line) and prohibited within property**	**329 meters**

PIPELINES and POPULATIONS

Types of pipelines

Pipeline types from: "A guideline for local authorities, developers, and pipeline operators," Canadian Standards Association, Plus 663, August 2004[3]

Distribution pipelines

Pipelines delivering natural gas from transmission pipelines to homes and businesses are called "distribution pipeline" systems. **Distribution pipelines can be as large as 914.4 mm (36 in) in diameter.** However, most are much smaller, ranging in size from 33.4 mm to 168.3 mm (1 in to 6 in) in diameter. These pipelines generally operate at lower pressures than the transmission pipelines and are owned and operated by local distribution companies (LDCs).

Flowlines and gathering pipelines

Pipelines are referred to as "flowlines" and "gathering lines" when they connect wells or other facilities such as batteries or gas processing facilities.

> "**Flowline" pipelines.** Flowlines typically range in size from 60.3 mm to 114.3 mm (2 in to 4 in) in diameter.
> "**Gathering" pipelines.** Gathering pipelines range from 114.3 mm to 323.8 mm (4 in to 12 in) in diameter.

Feeder and transmission pipelines

Pipelines connecting oil and gas fields with transmission pipelines are called "feeder pipelines".

> **"Feeder" gas pipelines.** Typically, feeder pipelines range in size from 168.3 mm to 508.0 mm (6 in to 20 in) in diameter. There are more than 25 000 km of feeder pipelines in western Canada.
> **"Transmission" gas pipelines.** Transmission pipelines typically range in size from 508.0 mm to 1219.2 mm (20 in to 48 in) in diameter.

TYPES OF DEVELOPMENT

1. **individual residences and farms** is defined as individual buildings located out of urban centres and having *equal to or less than* 12 permanent dwellings per 100 hectares;

2. **unrestricted country development** is defined as any collection of permanent dwellings situated out of urban centres and having *more than* 12 permanent dwellings per 100 hectares;

3. **a public facility** is defined as a recreational area such as a campground, or a public building such as a rural school or hospital, situated out of urban centres; It may also include libraries, museums or other institutions;

4. **a private facility** is defined as an area where groups of people congregate such as churches or places of worship, daycare centres, rehabilitation centres or other institutions;

5. **an urban centre** is defined as a city, town, village, or other incorporated centre.

TABLE 2

PIPELINE SETBACKS BASED ON "RHODES Rs" FORMULA

For pipelines 4" to 48" in diameter
and
50 psi to 200 psi

Pipeline Diameter (inches)	Pipeline Diameter (meters)	Pressure (psi)	Rs setback (meters)
4	0.1016	50	**60**
6	0.1524	50	**60**
8	0.2032	50	**80**
10	0.2540	50	**100**
12	0.3048	50	**120**
14	0.3556	50	**140**
16	0.4064	50	**160**
18	0.4572	50	**180**
20	0.5080	50	**200**
30	0.7620	50	**300**
48	1.2192	50	**480**
Pipeline Diameter (inches)	**Pipeline Diameter (meters)**	**Pressure (psi)**	**Rs setback (meters)**
4	0.1016	100	**50**
6	0.1524	100	**75**
8	0.2032	100	**100**
10	0.2540	100	**125**
12	0.3048	100	**149**
14	0.3556	100	**174**
16	0.4064	100	**199**
18	0.4572	100	**224**
20	0.5080	100	**249**
30	0.7620	100	**374**
48	1.2192	100	**598**
Pipeline Diameter (inches)	**Pipeline Diameter (meters)**	**Pressure (psi)**	**Rs setback (meters)**
4	0.1016	200	**60**
6	0.1524	200	**91**
8	0.2032	200	**121**
10	0.2540	200	**151**
12	0.3048	200	**181**
14	0.3556	200	**212**
16	0.4064	200	**242**
18	0.4572	200	**272**
20	0.5080	200	**302**
30	0.7620	200	**454**
48	1.2192	200	**726**

TABLE 3

PIPELINE SETBACKS BASED ON "RHODES Rs" FORMULA

For pipelines 4" to 48" in diameter
and
350 psi to 600 psi

Pipeline Diameter (inches)	Pipeline Diameter (meters)	Pressure (psi)	Rs setback (meters)
4	0.1016	350	**70**
6	0.1524	350	**105**
8	0.2032	350	**140**
10	0.2540	350	**175**
12	0.3048	350	**210**
14	0.3556	350	**246**
16	0.4064	350	**281**
18	0.4572	350	**316**
20	0.5080	350	**351**
30	0.7620	350	**526**
48	1.2192	350	**842**

Pipeline Diameter (inches)	Pipeline Diameter (meters)	Pressure (psi)	Rs setback (meters)
4	0.1016	500	**77**
6	0.1524	500	**115**
8	0.2032	500	**154**
10	0.2540	500	**192**
12	0.3048	500	**231**
14	0.3556	500	**269**
16	0.4064	500	**308**
18	0.4572	500	**346**
20	0.5080	500	**385**
30	0.7620	500	**577**
48	1.2192	500	**923**

Pipeline Diameter (inches)	Pipeline Diameter (meters)	Pressure (psi)	Rs setback (meters)
4	0.1016	600	**81**
6	0.1524	600	**121**
8	0.2032	600	**161**
10	0.2540	600	**202**
12	0.3048	600	**242**
14	0.3556	600	**282**
16	0.4064	600	**323**
18	0.4572	600	**363**
20	0.5080	600	**403**
30	0.7620	600	**605**
48	1.2192	600	**968**

TABLE 4

PIPELINE SETBACKS BASED ON "RHODES Rs" FORMULA

For pipelines 4" to 48" in diameter
and
650 psi to 1000 psi

Pipeline Diameter (inches)	Pipeline Diameter (meters)	Pressure (psi)	Rs setback (meters)
4	0.1016	650	**82**
6	0.1524	650	**123**
8	0.2032	650	**165**
10	0.2540	650	**206**
12	0.3048	650	**247**
14	0.3556	650	**288**
16	0.4064	650	**329**
18	0.4572	650	**370**
20	0.5080	650	**412**
30	0.7620	650	**617**
48	1.2192	650	**988**

Pipeline Diameter (inches)	Pipeline Diameter (meters)	Pressure (psi)	Rs setback (meters)
4	0.1016	700	**84**
6	0.1524	700	**126**
8	0.2032	700	**168**
10	0.2540	700	**210**
12	0.3048	700	**252**
14	0.3556	700	**294**
16	0.4064	700	**336**
18	0.4572	700	**378**
20	0.5080	700	**419**
30	0.7620	700	**629**
48	1.2192	700	**1007**

Pipeline Diameter (inches)	Pipeline Diameter (meters)	Pressure (psi)	Rs setback (meters)
4	0.1016	1000	**92**
6	0.1524	1000	**138**
8	0.2032	1000	**184**
10	0.2540	1000	**230**
12	0.3048	1000	**276**
14	0.3556	1000	**322**
16	0.4064	1000	**367**
18	0.4572	1000	**413**
20	0.5080	1000	**459**
30	0.7620	1000	**689**
48	1.2192	1000	**1102**

TABLE 5

PIPELINE SETBACKS BASED ON "RHODES Rs" FORMULA

For pipelines 4" to 48" in diameter
and
1400 psi

Pipeline Diameter (inches)	Pipeline Diameter (meters)	Pressure (psi)	Rs setback (meters)
4	0.1016	1400	**100**
6	0.1524	1400	**150**
8	0.2032	1400	**200**
10	0.2540	1400	**250**
12	0.3048	1400	**300**
14	0.3556	1400	**350**
16	0.4064	1400	**400**
18	0.4572	1400	**450**
20	0.5080	1400	**500**
30	0.7620	1400	**750**
48	1.2192	1400	**1200**

References

1. Technical Standards and Safety Authority in its “Guidelines for Natural Gas Utilities Locating New Pipeline Facilities,” **PI-98/01**, August 1998

2. ENVIRONMENTAL GUIDELINES FOR THE LOCATION, CONSTRUCTION AND OPERATION OF HYDROCARBON PIPELINES AND FACILITIES IN ONTARIO, Ontario Energy Board, 5th Edition, May 2003.

3. Land use planning for pipelines: A guideline for local authorities, developers, and pipeline operators, Canadian Standards Association, Plus 663, August 2004

4. Oil and Gas Pipeline Systems – Code Adoption Document – Amendment – January 14, 2008 (Technical Standards & Safety Authority).

5. Ontario Regulation 223/01 Codes and Standards Adopted by Reference under the Technical Standards and Safety Act, 2000.

6. O.Reg 543/06 under The Planning Act, Official Plans and Plan Amendments.

7. A Matrix-Based Risk Assessment Approach for Addressing Linear Hazards, such as Pipelines, Fred Henselwood, Dendritic Consulting Ltd. (2004)

8. Natural Gas Pipeline Rupture/Fire: Calculating safety setbacks from high-pressure gas lines**”** by Dr. Charles Rhodes, P. Eng., Ph.D. (January 2010)

9. MINIMUM DISTANCE REQUIREMENTS SEPARATING NEW SOUR GAS FACILITIES FROM RESIDENTIAL AND OTHER DEVELOPMENTS, Interim Directive ID 81-**3**, Energy Resources Conservation Board, Province of Alberta.

10. Guidance Protocol for School Site Pipeline Risk Analysis, California Department of Education, URS Corporation February 2007 URS Corporation (February 2007). Volume 1, Section 1.

11. STAGE 2 ANALYSIS: 2007 CDE PROTOCOL NATURAL GAS PIPELINE RISK ASSESSMENT—FOUR SCHOOL SITES NEAR THE PROPOSED KINGS RIVER CONSERVATION DISTRICT COMMUNITY POWER PLANT 20-INCH DIAMETER HIGH-PRESSURE PIPELINE, SUMMARY REPORT AND APPENDIX: Based on 2007 CDE Guidance Protocol for School Site. Pipeline Risk Analysis, Wilson Geosciences, Inc. (May 2007)

~

Katharine Parsons is the Executive Director of the ***Global Environmental Action Group.*** Ms. Parsons is a researcher and environmentalist writing on health and science issues in Ontario. She can be reached at katharineparsons@gmail.com

~

January 28, 2010

NATURAL GAS PIPELINE RUPTURE/FIRE:
Calculating safety setbacks from high-pressure gas lines

By Charles Rhodes, P. Eng., Ph.D.
charles.rhodes@xylenepower.com

INTRODUCTION:
Major high pressure natural gas pipelines are generally designed for a maximum working pressure that causes an operating hoop stress of about 33% of the specified pipe material yield stress. A further margin of safety can be introduced by reducing the working pressure. However, practical material and operating cost considerations prevent a major reduction in working pressure.

Another means of improving safety is to ensure that no buildings are constructed within a specified setback distance from the natural gas pipeline center line. Similarly the pipeline route should be set back from outdoor locations where groups of people routinely assemble.

Usually major high pressure natural gas pipes are buried. The function of the soil cover is to protect the pipe and its coating from damage due to UV radiation, external impact, thermal stress and frost heaving. However, there are still real risks related to long term corrosion and to coating and impact damage by excavation equipment such as back hoes. In the winter, especially when snow is piled high, the operators of back hoes and similar mechanical equipment frequently damage other services, in spite of their best efforts to the contrary. The initial damage may be only a short scratch in the pipe's anti-corrosion coating. However, after a period of years corrosion at that scratch can lead to a sudden full bore pipe rupture.

From time to time major natural gas pipelines do rupture, and when they do the result is often spectacular.

If one makes a small hole (diameter less than twice the pipe wall thickness) in a high pressure natural gas pipeline the immediate result is a screaming hiss noise as natural gas leaks out. The leaking high pressure natural gas will blow away any soil cover in its path. The natural gas will mix with surrounding air and will form a cloud with concentrated natural gas at its center and dilute natural gas at its edges. If the edge of this cloud (natural gas concentration in the range 5% to 15%) encounters a source of ignition such as a spark made by an electrical switch, there will be a delayed ignition explosion followed by an ongoing localized fire. Fortunately, the size of the explosion and the size of the subsequent fire will be limited by the size of the original small hole in the natural gas line.

However, if a hole in a high pressure natural gas pipe has an axial length that exceeds about four times the pipe wall thickness, a very different sequence of events takes place. At the axial ends of the hole the local hoop stress will exceed the material yield stress. The pipe will immediately rip down its axis and bend back to form a rupture that has an open area several times the cross sectional open area of the pipe. The escaping gas will explosively blow away all the soil cover close to the rupture causing a large crater in the ground. The noise made by the escaping gas will be comparable to the sound made by a major jet aircraft on take-off. The rupture will be fed with high pressure natural gas from both the upstream and downstream pipes. This natural gas will mix with the surrounding air and will form a large cloud with concentrated natural gas at its center and dilute natural gas at its edges. When the edge of this cloud with a local natural gas concentration in the range 5% to 15% encounters a source of ignition such as a spark made by an electrical switch, there will be a huge delayed ignition explosion followed by an ongoing fire. The size of the delayed ignition explosion depends on the distance between the pipe rupture and the point of ignition. The larger this distance the larger the delayed ignition explosion. If the distance is large the pressure wave from the delayed ignition explosion may be comparable to the blast from a small tactical nuclear weapon. The subsequent fire will emit so much heat and thermal radiation that the only practical means of dealing with it is to valve off the gas pipe on both sides of the rupture and then wait for the fire to burn itself out.

Due to uncertainty regarding wind conditions and the position of the nearest point of ignition it is impossible to specify a practical safety setback distance that will ensure no damage or personnel injury from the delayed ignition explosion. However, the subsequent fire emits a quantifiable amount of thermal radiation for which a reasonable safety setback distance can be calculated.

This document develops a formula for the safe distance **Rs** from a natural gas pipe line required for personnel to avoid short term radiation skin damage from the steady state fire that likely follows a high pressure natural gas pipeline rupture. The formula is:

Rs = 17.71 Dp (Pa - Pb)^0.25 kg^-0.25 m^.25 s ^0.5
where:
Rs = radiation safety distance in metres
Dp = pipeline diameter in metres
Pa = pipeline working pressure in Pascals
Pb = atmospheric pressure in Pascals

It must be emphasized that the calculated safety setback applies to thermal radiation from combustion of clean natural gas. A delayed ignition explosion can cause blast damage beyond the calculated radiation safety radius. Toxic gases such as H_2S can cause loss of life beyond the calculated radiation safety radius. If the natural gas burns in combination with other substances such as oil, coal, asphalt, wood, plastic resins, etc., soot forms. That soot increases thermal radiation and could potentially double the required radiation safety radius.

The results of the formula (See: ***Formula Development*** below) developed herein are compared to the actual fire damage radius that occurred at Appomattox, Virginia where a 30 inch diameter buried high pressure natural gas pipeline ruptured and burned on September 14, 2008.

YORK ENERGY CENTRE PIPELINE, KING TOWNSHIP:

Dp = 16 inches = .406 m

Pb = 14.7 psia = 1 bar = 101 kPa = 1.01 X 10^5 newtons / m^2

Pa = 600 psia = 40.81bar = 4122.4 kPa = 41.22 X 10^5 newtons / m^2

Hence:
Rs = 17.71 Dp (Pa - Pb)^0.25 kg^-0.25 m^.25 s ^0.5

= 17.71 X .406 m X (40.21 X 10^5 newtons / m^2)^0.25 kg^-0.25 m^.25 s ^0.5

= 17.71 X .406 m X 402.1^0.25 X 10 (kg m s^-2 m^-2)^0.25 kg^-0.25 m^.25 s ^0.5

= 321.97 m

APPOMATTOX (see Figures 1 - 3):

On September 14, 2008 a 30 inch diameter buried natural gas pipeline that normally operates at a pressure of 800 psi ruptured and burned in a farmer's field near the intersection of Highway 26 and State Route 677 just north of Appomattox, Virginia. There was a modest delayed ignition explosion. Overhead news photographs showing the area where the crop burned were compared to distance calibrated overhead photographs from Google maps. It was found that with reference to the pipe rupture crater the area burned extended **311 m** to the south-west and **275 m** to the north-east.

Application of the formula for the radiation safety distance Rs gives:
Dp = 30 inch X .0254 m / inch = 0.762 m
Pa = 800 psi X 101 X 10^3 Pa / 14.7 psi = 549.66 X 10^4 Pa
Pb = 101 X 10^3 Pa = 10.1 X 10^4 Pa
Rs = 17.71 Dp (Pa - Pb)^0.25 kg^-0.25 m^.25 s ^0.5
= 17.71 X 0.763 m X (539.56 X 10^4 Pa)^0.25 kg^-0.25 m^.25 s ^0.5
= **651.25 m**
Thus the area in which the crop and buildings spontaneously burned was the area where Rz < (Rs / 2).

CONCLUSIONS:
When a high pressure natural gas pipeline operating at its rated working pressure develops a crack or hole more than about four pipe wall thicknesses in axial length the result is a sudden full cross section pipe rupture. Some time after the pipe rupture there is a delayed ignition explosion followed by a steady state fire. This fire emits a high level of thermal radiation that makes it difficult to approach with conventional fire fighting equipment.

One can define a radiation safety distance Rs from the fire at which distance the radiation level is similar to the radiation level in the middle of the Sahara desert at noon on a very hot day. The formula is:
Rs = 17.71 Dp (Pa - Pb)^0.25 kg^-0.25 m^.25 s ^0.5
where:
Rs = radiation safety distance in metres
Dp = pipeline diameter in metres
Pa = pipeline working pressure in Pascals
Pb = atmospheric pressure in Pascals

Application of this formula to the York Energy Centre pipeline gives a radiation safety distance of about:
Rs = 321 metres. At Rz = 160 metres the radiation level will be four times as high and will cause spontaneous combustion of buildings and farm crops.

There is additional danger if the natural gas fire triggers combustion of other materials that form soot. If large amounts of soot mix with the natural gas combustion air the soot could increase the radiant heat output four fold which would double the safety radius Rs.

Given the limited resources of rural fire departments it is reasonable to assume that in the event of a high pressure natural gas pipeline rupture/fire they will simply ensure that the pipe is valved off on both sides of the rupture and then let the fire burn itself out**. It is also reasonable to conclude that crops, buildings and other combustibles within a distance (Rs / 2) of the pipeline rupture/fire will spontaneously ignite and will be totally destroyed.**

It should be emphasized that the above calculation applies to thermal radiation from steady state combustion of clean natural gas. The damage radius from a delayed ignition explosion could easily be larger. Based on eyewitness reports from Appomattox the sequence of events at that pipeline rupture/fire was a delayed ignition explosion followed by steady state combustion. The same sequence of events is expected to occur elsewhere.

The above calculation shows that even if someone is fortunate enough to survive the initial delayed ignition explosion, the temperature within the radiation safety radius Rs of the flame will rapidly rise past the point of human tolerance.

The principal objective of emergency services must be to immediately evacuate humans from inside the radiation safety radius Rs. It can safely be assumed that inside the radiation safety radius Rs damage to property will be extensive and inside (Rs / 2) most people will die and almost all property will be destroyed. **Most municipal fire departments are not equipped to function within the high thermal radiation levels that will occur inside (Rs / 2). Insurance coverages should reflect this reality.**

I strongly urge that in the case of the York Energy Centre pipeline **a minimum 200 metre setback** should be maintained from the pipeline center line to all human occupied structures and to all places of routine outdoor human assembly. This is an ongoing setback requirement that should be actively enforced by municipal authorities for the life of the pipeline. All parties should clearly understand that the radiation emitted by a pipeline rupture/fire is so intense that the only practical strategy for a rural fire department is to let the fire burn itself out. It is also unrealistic to expect persons within radius (Rs / 2) of a pipeline rupture/fire to be rescued by volunteer fire department personnel. If possible the municipality should attempt to enforce a 300 m setback instead of a 200 m setback. There could easily be litigation related to injury and property damage in the 200 m to 300 m zone.

With reference to Fuels Safety Division publication PI-98/01 “Guidelines For Locating New Oil and Gas Pipeline Facilities” all the specified setbacks except the 200 m setback are totally inadequate for major high pressure natural gas pipelines. With respect to large diameter pipelines even the specified 200 metre setback is inadequate.

The Fuels Safety Division of TSSA should review document PI-98/01 with a view to **making minimum setbacks from natural gas pipelines a function of pipeline diameter and operating pressure** as set out herein. Code enforcement authorities should be realistic with respect to their expectation of volunteer emergency personnel working within high thermal radiation zones. In the event of a major natural gas pipeline rupture/fire the available emergency personnel will likely attempt to save human lives but in so doing they will likely sustain extensive personal skin damage. **They will**

then be unable to extinguish fires.

***FORMULA DEVELOPMENT*:**
Consider a long straight natural gas pipeline that is subject to a sudden rupture that opens the full cross section of the pipe. To calculate the radiant heating consequences if there is a fire it is necessary to first find the natural gas mass flow rate out of the rupture. In reality there are two flows, because the pipeline on both sides of the rupture discharges gas into the rupture. We will calculate one of these gas flows and then double the result to obtain the total mass flow out of the rupture.

Pa = the pressure in the pipeline distant from the rupture

Pb = the pressure at the point of rupture after the rupture. Normally Pb is atmospheric pressure.

Let Dp = pipeline inside diameter

Let Pi = 3.14159

Let Rma = gas density at pressure Pa

Let Rmb = gas density at pressure Pb

Let Rm(X) = gas density at linear position X.

The pipe cross-sectional area Ac is:
Ac = Pi (Dp / 2)^2

The mass of gas contained between X and X + dX is:
dM = Rm(X) Ac dX

Within the pipe but near the point of rupture the gas pressure drops and the gas expands. The linear velocity along the pipe increases. The energy contained in the compressed gas becomes linear kinetic energy. The linear velocity at the point of rupture is Vb.
The mass flow rate from one pipe at the point of rupture is:
Rmb Ac Vb

Let X indicate linear position along the pipe.

Let T = time

Then:
V(X) = (dX / dT) = gas linear velocity

The gas kinetic energy between X and X + dX is:
(dM / 2) (dX / dT)^2

Let P = pressure at X

Let P + dP = pressure at X + dX

Conversion of pressure energy into kinetic energy as gas flows along the pipe gives:
-dP Ac dX = d[(Rm(X) Ac dX) (dX / dT)^ 2 / 2]
or
-dP = d[(Rm(X) (dX / dT)^ 2 / 2]

Integrating from Pa to Pb gives:
-(Pb - Pa) = [Rm (dX / dT)^ 2 / 2]b - [Rm (dX / dT)^ 2 / 2]a
or
(Pa - Pb) = [Rm (dX / dT)^ 2 / 2]b - [Rm (dX / dT)^ 2 / 2]a

Assume that as a result of the pipe rupture the natural gas supervisory control system closes valves distantly upstream and downstream from the pipe rupture. Then the initial condition at the location of each of these valves is no flow, or expressed mathematically in terms of the gas stream:
[dX / dT]a = 0

Hence:
(Pa - Pb) = [Rm (dX / dT)^ 2 / 2]b
or
[dX / dT]b = [2 (Pa - Pb) / Rmb]^0.5

Fm = exiting gas mass flow rate from one pipe
= Rmb Ac [dX / dT]b
= Rmb Ac [2 (Pa - Pb) / Rmb]^0.5
= **Ac [2 (Pa - Pb) Rmb]^0.5**

Let Ec be the combustion heat release per unit mass of natural gas.

Then the total combustion heat release per unit time H is given by:
H = 2 Fm Ec
where the 2 reflects the fact that the rupture is fed by two pipes.

Let **Fr** be the fraction of this heat that is emitted via radiation.

Let **Rz** = radius from the center of the flame to a surface subject to radiation damage.

Assume that the radiation is evenly distributed over a sphere with radius **Rz** and surface area **4 Pi Rz^2**

Then at radius Rz the radiation intensity / unit area = **(H Fr) / (4 Pi Rz^2)**

Assume that to avoid skin damage the radiation intensity should be less than the most intense possible solar radiation incident on the Earth's surface.(**1365 W / m^2**)

Hence, in terms of radiant energy, the safe distance Rs from the center of the flame is defined by:

(H Fr) / (4 Pi Rs^2) = 1365 watts / m^2
or

Rs = [(H Fr) / (4 Pi X 1365 watts / m^2)]^0.5
= **[(2 Fm Ec Fr) / (4 Pi X 1365 watts / m^2)]^0.5**

where Fm is given by:

Fm = Ac [2 (Pa - Pb) Rmb]^0.5

= **Pi (Dp / 2)^2 [2 (Pa - Pb) Rmb]^0.5**

Combining these two formulas gives:
Rs = [(2 Fm Ec Fr) / (4 Pi X 1365 watts / m^2)]^0.5
= [(2 Pi (Dp / 2)^2 [2 (Pa - Pb) Rmb]^0.5 Ec Fr) / (4 Pi X 1365 watts / m^2)]^0.5
= Dp (Pa - Pb)^0.25 [([2 Rmb]^0.5 Ec Fr) / (8 X 1365 watts / m^2)]^0.5

The value of Fr can be found from a paper by J. P. Gore et al titled Structure and Radiation Properties of Large-scale Natural Gas/Air Diffusion Flames, published in Fire and Materials, Vol. 10, 161-169 (1986).
These authors found that the radiation emission from a 207 MW natural gas flame measured at ground level about 11.9 m from the flame center was 6.37 kW / m^2.

The surface area of that sphere was:
4 Pi (11.9 m)^2 = 1778.62 m^2

Hence the emitted radiation was:
6.37 kW / m^2 X 1778.62 m^2 = 11330 kW = 11.330 MW
Hence:
Fr = 11.330 MW / 207 MW **= .0547**

NUMERICAL SIMPLIFICATION:

Pi = 3.1415928

Rmb = 16 gm / 22.4 lit
= 16 X 10^-3 kg / 22.4 X 10^-3 m^3
= **.714 kg / m^3** = density of natural gas at standard temperature-pressure

Ec = (10.4 kWh / m^3) X (1 m^3 / .714 kg) X 3600 s / h **= 52437 kJ / kg**

Hence:
Rs = Dp (Pa - Pb)^0.25 [([2 Rmb]^0.5 Ec Fr) / (8 X 1365 watts / m^2)]^0.5

= Dp (Pa - Pb)^0.25 [([2 X .714 kg / m^3]^0.5 X 52437 kJ / kg X .0547) / (8 X 1365 watts / m^2)]^0.5

= Dp (Pa - Pb)^0.25 [[1.428 kg / m^3]^0.5 X .26266 kJ m^2 / kg-watts X 1000 J / kJ]^0.5

= Dp (Pa - Pb)^0.25 [1.195 kg^0.5 m^-1.5 X 262.66 J m^2 / kg-watts]^0.5

= Dp (Pa - Pb)^0.25 X 17.71 kg^0.25 m^-.75 m (J / kg-watts)^0.5

= 17.71 Dp (Pa - Pb)^0.25 kg^0.25 m^-.75 m (watt s / kg-watts)^0.5

= 17.71 Dp (Pa - Pb)^0.25 kg^-0.25 m^.25 s ^0.5

Units Check:
(newtons/ m^2)^0.25 = (kg m s^-2 m^-2)^0.25 = kg^0.25 m^-.25 s^-0.5

Dr. Charles Rhodes, P. Eng.

Dr. Rhodes taught electrical engineering at the University of Toronto and then spent 30 years in private industry. His expertise ranges from application of energy storage systems to developing high efficiency boilers and co-generation systems for major buildings. In recent years Dr. Rhodes applied astrophysical data to quantification of climate change. He has intervened at Ontario Energy Board hearings relating to electricity rates and to the OPA Integrated Power System Plan.. He currently lives in East Gwillimbury, Ontario and can be reached at charles.rhodes@xylenepower.com.

APPOMATTOX, VIRGINIA
September 14, 2008
Natural Gas Pipeline Explosion

Figure 1 Appomattox blast area

Figure 2   30-inch gas pipeline crater

Figure 3 House in blast area