BEFORE THE

PENNSYLVANIA PUBLIC UTILITY COMMISSION

MEGHAN FLYNN	:	
ROSEMARY FULLER	:	
MICHAEL WALSH	:	
NANCY HARKINS	:	
GERALD MCMULLEN	:	DOCKET NOS. C-2018-3006116
CAROLINE HUGHES and	:	P-2018-3006117
MELISSA HAINES	:	
Complainants	:	
v.	:	
	:	
SUNOCO PIPELINE L.P.,	:	
Respondent	:	

DIRECT TESTIMONY OF

JEFFREY D. MARX

ON BEHALF OF

FLYNN COMPLAINANTS

<u>JEFF MARX Q&A</u>

I. <u>Voir Dire and Background</u>

Q. Mr. Marx, what do you do for a living?

A. I am a process safety engineer.

Q. **And by whom are you employed?**

A. Quest Consultants.

Q. **Would you tell the Court your educational background?**

A. I have a Bachelor's Degree in Mechanical Engineering from the University of Oklahoma, and a Master's Degree in Mechanical Engineering from Georgia Institute of Technology.

Q. **Do you have in front of you a copy your curriculum vitae, marked as Exhibit Marx-1?**

A. Yes.

Q: Is this a current copy of your CV?

A: Yes, it is.

We offer Flynn Complainants' Exhibit Marx-1 into evidence

Q. **Now, I note that even before you got your mechanical engineering degree in 1993, you already were working as an engineer trainee at Quest doing consequence analysis studies. What is consequence analysis study?**

A. Consequence analysis study is the evaluation of the potential hazards or impacts from generally, in our business, hazardous chemicals or waste.

Q. **And you've been doing this now for how long?**

A. I've been employed as a full time engineer for over 26 years now.

Q. **Now, in your undergraduate engineering program at the University of Oklahoma, did you take courses such as fluid mechanics, statistics, and other things that have a bearing ultimately today on pipeline analysis work?**

A. Yes, things like fluid mechanics and thermodynamics, they work into the modeling, the consequence analysis that we do for prediction events from pipelines and other hazardous chemical facilities.

Q. **Now, with respect to your work at Georgia Tech from 2002, how long were you in that program?**

A. I think it was about five years, because I was doing a distance learning program.

Q. **Did you also take courses there, at that time, which have a bearing on your ability to do pipeline analysis today?**

A. Yes, it would be the same topics in engineering, such as thermodynamics, heat transfer, fluid dynamics - those topics that do have application in pipeline hazards analysis.

Q. **Can you take a few minutes now to go through your CV and just highlight for Judge Barnes some of your professional publications that have a bearing on issues that you will testify about today?**

A. We have done quite a few studies over the years. I've probably been involved in hundreds of studies that involve consequence and/or risk analysis, and risk analysis always involves consequence analysis. One of the major topics in recent years has been building siting analysis, and many of the facilities we dealt with processed, stored, transferred, handled HVLs, which we'll be talking about, I'm sure, and we have done quantitative risk analysis in that framework. We have also done consequence analysis and quantitative risk analysis for many other facilities including refineries and gas plants and other projects, including pipelines.

Q. **Have you done work for the government?**

A. Yes, we have.

Q. **What agencies have you worked with?**

A. The primary one that we have worked with is PHMSA, and that work has been through the LNG Group in Washington, D.C.; we consult directly to them on LNG issues. LNG would be liquified natural gas. We have also worked for various government entities over the years on smaller projects throughout Quest's history, some of those in other countries. We've also worked for, for example, the Department of Energy in the U.S. and government entities in Canada.

Q. **On the second page of your resume, your C.V., do you see where you've identified you facilitated team meetings for hazardous operations studies?**

A. Yes

Q. **I note that you mentioned Williams Pipeline. Is that the petroleum distribution company?**

A. Yes. From memory, I don't recall what that particular job was, but the description in my resume appears to be natural gas pipeline systems.

Q. **And I see also you did some work with Bechtel on several different projects?**

A. Yes.

Q. **And you worked with SemGas. What kind of a company is SemGas?**

A. SemGas is a smaller pipeline and midstream company out of Tulsa. They were building natural gas plants and pipelines. They also have crude oil lines.

Q. Now, having reviewed your CV myself, is it fair to say that most of your work for the last 25 years has been in the field of quantitative risk analyses, consequence analysis studies involving refineries or refinery units, toxic and flammable gas pipeline systems, oil and natural gas production systems, LPG import/export terminals, gas treatment and processing plants, reinjection systems, and road and rail transportation systems? Is it fair to say most of your work has involved those things?

A. Yes, it did.

Q. Again, looking, at your CV, is it fair to say that your work in doing those projects included data gathering, accident selection, analysis structuring, consequence calculations, frequency analysis, risk mapping, and risk assessment?

A. Yes.

Q. Jeff, have you ever done any teaching or training in the areas that you've talked about?

A. Yes, I have.

Q. **Could you elaborate on that a little bit?**

A. Quest, for most of its existence, conducted a training class for PHMSA, the Pipeline and Hazardous Safety Administration, Hazardous Materials Safety Administration, regarding LNG, so we consulted with them on a yearly basis for that class. We have given classes, or I have given classes on quantitative risk analysis and consequence analysis and other topics such as process hazard analysis leadership, liquified gas hazards and other custom courses that clients have asked us to put together. Those courses ranged from just one day of education to a full week.

Q. **I see from your CV that you were the co-inventor of a patented community response guideline device. Would you tell the Judge exactly what that is?**

A. Years ago, we were trying to come up with a method that chemical plants or hydrocarbon processing plants could use to give themselves or local emergency responders a quick way to assess a situation and determine the impact there might be. The basis of the tool was that ision – two decisions were made very quickly in the emergency response time frame. One of them was a determination whether the event is a large release or a moderately sized release. The second decision is what are the weather conditions, which would include breezy or close to calm. This, together with general wind direction, form the inputs for a physical device consisting of a laminated card with a little dial that you could spin. On the card was a map of the facility and the dial shows the potential area impacted based on the magnitude of the hazard, the wind conditions, and wind direction. We put this out there and patented it; we thought it was a good idea. We fabricated these for a few facilities, and even for a few pipelines. The pipeline version did not have the dial; we showed the hazard zone as hazard corridors on a map.

Q. Did you also have some involvement in the development of risk quantification software?

A. Yes, I did. We also, since the inception the company, have had both consequence analysis software called CANARY by Quest®, and a risk analysis package that uses CANARY and brings in all of the probabilities and the various parameters that you would consider in a quantitative risk analysis. I have been involved in the development and application and support of those software packages ever since I've worked here. Many of the modules in CANARY and in our risk package I had direct responsibility for, often with assistance from a programmer for the code. The CANARY program is actually commercially available, and so we, the engineers at Quest, provide support for the users. The risk analysis package is an in-house tool; we don't market that.

Q. **Did you use the CANARY software in development of the Mariner Pipeline quantitative risk analysis report that you released last year?**

A. Yes, we did.

Q. **Did you use the software in connection with the analysis that you performed leading up to today's testimony?**

A. Yes.

Q. **Now, the complainants in this proceeding have asked you to comment on several points they raised their petition for interim emergency relief. Have you read and understood that petition as best you can?**

A. Yes.

Q: I am going to read to you a list of topics and then ask you, based upon your education, training and experience, if you believe you are professionally equipped to render an opinion on those topics to a reasonable scientific certainty. Here are those topics:

- **Characteristics of hazardous liquids and HVLs in particular**
- **Review of accidents involving HVL pipelines**
- **Review of vulnerable sites along mariner pipelines in Chester and Delaware Counties**
- **Event timing that leads to fires, explosions, etc.**
- **Implications for emergency response**
- **Consequence assessment for leaks/explosions in Chester and Delaware Counties**
- **Implications of your testimony for Sunoco's public awareness flyers**

A: Yes, I believe can so testify.

Flynn Complainants offer Jeffrey Marx to render his professional opinion as a process safety engineer on the following matters raised in the Second Amended Complaint:

- **Characteristics of hazardous liquids and HVLs in particular**
- **Review of accidents involving HVL pipelines**
- **Review of vulnerable sites along Mariner pipelines in Chester and Delaware Counties**
- **Event timing that leads to fires, explosions, etc.**
- **Implications for emergency response**
- **Consequence assessment for leaks/explosions in Chester and Delaware Counties**
- **Implications of your testimony for Sunoco's public awareness flyers**

Q: **Mr. Marx, do you understand that complainants in their Second Amended Complaint are alleging that (1) Mariner East HVL pipelines are being built and operating too close to their homes, places of work, and other facilities in Chester and Delaware Counties; that (2)**

Sunoco's public awareness program is inadequate; and that (3) Mariner East 1 and the 12-inch bypass pipeline are not being properly maintained?

A: Yes, I understand those are their allegations.

Q: **Are you aware that complainants contend that (a) Sunoco's public awareness program fails to comply with applicable law and in fact that (b) Sunoco cannot possibly comply with applicable law.**

A: Yes, I am aware of the contentions of the complainants.

Q: **Are you aware also that complainants are here today to ask that the PUC enter permanent relief directing Sunoco to cease operations of the Mariner Pipeline Project?**

A: Yes

Q: **So far as you know, is it true that Sunoco does own pipelines, terminals, and other assets used in the purchase, transfer and sale of: crude oil; refined products such as gasoline, diesel, and jet fuel; and also-called natural gas liquids ("NGLs") including propane, ethane and butane?**

A: Yes

Q: **So far as you know, is it true that Sunoco's Mariner East is a pipeline project in Pennsylvania, Delaware, Ohio, and West Virginia designed to transport NGLs such as propane, ethane, and butane to the Marcus Hook Industrial Complex in southeastern Pennsylvania and Delaware and other access points for distribution to other places?**

A: Yes

Q: So far as you know, is it true that the Mariner East 1 pipeline is an 8 inch pipeline built in the 1930's that previously transported hazardous liquids but was repurposed in 2014 and is now transporting hazardous *volatile* liquids—HVLs?

A: Yes

Q: So far as you know, is it true that Sunoco has proposed to modify the plans for its Mariner East 2 pipeline in certain sections where it is unable to drill and build as planned by connecting it to an existing 12 inch pipeline also built in the 1930's to transport non-volatile liquids?

A: Yes

Q: You've seen in the Second Amended Complaint that complainants are referring to this hybrid pipeline as "the workaround" pipeline?

A: Yes

Q: Mr. Marx, as you understand it, is it true that if the workaround pipeline becomes operational it would increase the volume of hazardous, highly volatile liquids being transported near homes, schools, businesses, senior living facilities, and other densely populated areas?

A: Yes

II. Executive Summary

Q: So far as you know, what is the reason Quest was retained in this proceeding?

A: Quest was retained to assess the potential consequences associated with the Mariner East pipeline project in Chester and Delaware Counties, Pennsylvania. The objective of this work was to leverage a previous work completed by Quest, along with an understanding of highly volatile liquid (HVL) release properties and the associated hazards, in order to form a better understanding of the potential consequences to persons in the vicinity of the Mariner East pipeline project (s).

Q: Would you give the judge some background on your company?

A. Quest is an engineering consulting company, formed in 1989, that specializes in consequence and risk analysis for hazardous materials, such as HVLs. Quest's clients include many companies in the oil and gas or petrochemical business, as well as regulatory agencies and citizen's groups. Quest has completed many consequence and risk analysis studies for pipelines near residential areas or other sensitive locations, such as schools, for various locations in the USA, as well as several foreign countries.

Q: What are the topics covered in your analysis?

A: This work covers the following topics:

- *Hazard Analysis*: defining the HVL release scenarios, pipeline parameters and site properties
- *Consequence Analysis*: Application of Quest's proprietary software, CANARY, for calculations of exposure areas to fire or vapor cloud explosion effects that have a potential for impacts to the public. Property damage was not evaluated.
- *Assessment:* evaluation of the potential consequences and the means by which they could be realized to inform a set of findings related to potential pipeline accidents

Q: What were your key findings as a result of your work on this project?

A: Key findings from this assessment, within a reasonable degree of professional certainty, include the following points:

- There exists sufficient publicly available information in order to generate reasonably accurate calculations of both hazards and risk from potential Mariner East pipeline releases.
- The worst hazard zones are realized in the first few minutes of an HVL pipeline accident due to loss of inventory and pressure decay.
- Predicted fatal impacts of accidental pipeline rupture events were found to extend up to about 2,100 feet from the pipelines or their associated equipment. Moderate holes could create hazard zones extend up to about 1,000 feet from the pipeline.
- In the event of a pipeline release, persons in the vicinity of the pipeline may have difficulty escaping unharmed.
- The maximum hazards following an HVL pipeline rupture will be realized before the operator can affect any meaningful measures to shut down the release.
- It is extremely unlikely that emergency response activities will be activated before the maximum hazards of an HVL pipeline rupture are realized.
- It is difficult to define the proper public response to a pipeline incident (i.e., shelter in place or evacuate) due to the variability of the event magnitude and various possible hazards.
- First responders can help to extinguish secondary fires or to evacuate persons who have found shelter from the pipeline impacts.

Q: Explain briefly your methodology and the focus of your study.

A: Risk- and consequence-based methodologies have been employed by Quest in many studies for pipelines near residential areas or other sensitive locations, such as schools. These studies have been completed for various locations in the USA, as well as several foreign countries. On several occasions, the quantitative risk analysis (QRA) results were presented to government or regulatory officials.

The emphasis of this study was on suburban population areas along the pipeline route. The study was comprised of four general tasks:

Task 1. Hazards Identification: Determine the potential hazards associated with an HVL pipeline;

Task 2. Failure Cases: Define potential release scenarios that could result in significant impacts to persons in the vicinity of the pipeline, including the mode and characteristics of release scenarios;

Task 3. Hazard Zone Analysis: Perform consequence analysis calculations to define the potentially lethal hazard zones associated with release scenarios; and

Task 4. Assessment: Evaluate the potential accident scenarios associated with the pipeline(s) to inform further decision-making regarding the pipeline(s).

Q: What are the hazards associated with the Mariner East pipelines?

A: The potential hazards associated with the Mariner East pipelines are common to other HVL pipelines and are a function of the material being transported as well as the transport conditions and pipeline parameters. The hazards that are likely to exist are identified by the physical and chemical properties of HVLs and the pipeline operating conditions. HVLs, while transported as liquid, will quickly turn to vapor when released to the atmosphere. Because of this behavior, they are a category of materials that is potentially more hazardous than other pipeline products such as natural gas, gasoline, or crude oil. For the pipelines considered in this study, the common hazards (see definitions) are

- Jet fires;
- Pool fires;
- Flash fires; and
- Vapor cloud explosions.

These hazards form the primary contributors to the risk of injury or fatality following an accidental release from an HVL pipeline. Other hazards that are highly localized, such as initial explosion projectiles and asphyxiation (due to oxygen displacement) were not evaluated in a detailed manner for this analysis.

III. Characteristics of hazardous liquids and HVLs in particular

A. In General

Q: **Mr. Marx, what does the term "natural gas" refer to?**

A: Natural gas is the portion of typically naturally-occurring hydrocarbons that after extraction and clean-up are transported as a gas and are used for fuel or chemical feedstocks.

Q: **What is a natural gas liquid?**

A: Natural gas liquids is label given to the portion of extracted hydrocarbons that, typically, are liquid under pressure but gas at ambient conditions, and normally excludes the heavier hydrocarbons that are characterized as crude oil, natural gasoline, naphtha or condensate.

Q: **How are natural gas liquids produced?**

A: They are extracted from the ground with natural gas and the liquid hydrocarbons are separated by various processing means, so that the natural gas, as well as crude oil or condensates, can be transported independently. Natural gas liquids are sometimes further separated in to specific products such as ethane, propane, and butane.

Q: **How do you understand the term "hazardous liquid?"**

A: Within the context of pipelines, hazardous liquids are the class of materials transported as a liquid, and include crude oil, refined products (such as gasoline, jet fuel, diesel), and natural gas liquids, among other products such as ammonia or carbon dioxide.

Q: **Are some hazardous liquids highly volatile and others not highly volatile?**

A: Correct.

Q: **What are hazardous highly volatile liquids (HVLs)?**

A: HVLs are a class of materials that are gases at ambient conditions but are stored or transported as liquid by pressure. They are labelled "highly volatile" because upon loss of pressure, they quickly change from liquid to gas. For this reason, these materials are also referred to as liquefied gasses.

Q: **And is it a correct use of terminology to refer to ethane, propane and butane as HVLs?**

A: Yes

Q: **For present purposes then, is it fair to distinguish between methane on the one hand and ethane, propane and butane on the other hand?**

A: Yes

Q: **Can you explain what happens when HVLs such as ethane, propane and butane are released from a pipeline?**

A: Yes. In the initial instants of the release, liquid within the pipeline will be ejected at high velocity due to the pressure in the pipeline. There is a thermodynamic behavior called "flash" that describes how a portion of a liquefied gas instantly changes from liquid to vapor. During the flash process, the density of the material decreases several hundred times, and so the volume increases significantly. This process breaks up the remaining liquid into droplets, many of which are carried in the vapor stream that is mixing with air. This mixture is called an aerosol. There may also be some liquid that reaches the ground.

As this release from the pipeline process occurs, there is also a significant drop in temperature. This is called the Joule-Thompson effect, and is a characteristic of most materials: when the pressure drops, so does the temperature. Thus, the released material consists of an airborne cold aerosol (vapor plus liquid drops) and perhaps a pool of cold liquid on the ground. As air mixes with the aerosol, it quickly heats up the mixture, vaporizing the droplets. In the same way, any liquid that reaches the ground will be heated by the ground and will quickly vaporize.

This process puts a great deal of material into the atmosphere very quickly. But as the pressure in the pipeline decreases, the mass release rate also decreases. In addition, some material could begin to flash inside the pipe, restricting the flow of material out the hole. Overall, unless the loss of containment event is very small, is a rapid decline in release rate over time.

In a pipeline HVL release scenario, released material has a significant amount of momentum due to the velocity imparted by the pressure of the system. This material, as it mixes with air, slows down, but has the capacity to travel a significant distance due to its initial velocity.

Q: How does a release from a natural gas transmission line differ from a release from an HVL pipeline?

A: A release of natural gas, primarily methane, is a compressed gas in the pipe, and will be gas once released. In addition, methane at ambient conditions (typical atmospheric temperature and pressure) is lighter than air. HVLs begin as liquid in the pipeline and transition to vapor after release. HVL materials such as ethane, propane, and butane are naturally heavier than air at ambient conditions, and even more when they are cold and/or in aerosol forms. So the released material tends to slump toward the ground and remain there. After the momentum of the release is dissipated, they spread due to gravity effects, being heavier than air. In this way, HVLs do stay near grade level as they disperse, and tend to move downhill as well as downwind.

A material is released from a pipeline, it depressurizes. For a natural gas pipeline, this does take some time. But for and HVL pipeline, the material must change to vapor as it depressurizes. Accordingly, when comparing the same length, diameter, and starting pressure of natural gas pipeline to an HVL pipeline, the HVL will take longer to depressurize due to the larger amount of material in the pipeline.

Q: Can you give us some working definitions to understand your work better?

A: Yes, here are some definitions relevant to the hazards we consider:

Definitions - Hazards
Explosion – a sudden release of energy
Jet fire – an ignited release of gas or gas plus entrained liquids that forms a velocity-driven fire
Pool fire – a collection of released liquids on the ground that forms a pool, and when ignited forms a vertical flame column
Flash fire – the ignition of a released flammable material that has mixed with air to form a flammable vapor cloud
Vapor cloud explosion – the ignition of a flammable vapor cloud (flash fire) that forms a damaging blast wave. The strength of the blast depends on fuel reactivity, confinement, or enveloping repeated small obstacles
Asphyxiation – the state of being deprived of oxygen which can result in symptoms ranging from dizziness to death; in the context of pipeline releases, displacement of air by the released pipeline material

Q: How about failure cases?

A: Potential HVL release events are determined from a combination of past history of releases from similar pipelines, including previous reports, accident data, and engineering analysis.

Definition
Failure Case – An accident scenario involving a release of hazardous material, which is developed and defined as a part of a consequence or risk analysis study

The release conditions that are used to define a failure case include:

- Fluid composition, temperature, and pressure
- Release rate and duration
- Location and orientation of the release

Q: What are hazard zones and vulnerability zones?

A: First, some formal definitions:

Definitions
Hazard Zone – The area or zone that is predicted to be affected by a defined hazard *Vulnerability Zone* – The area or zone that could be affected by a given hazard zone when any potential wind direction is considered (a vulnerability zone appears as a circle when a fixed source is evaluated, or a corridor when a linear source is evaluated)

The release conditions (e.g., pressure, composition, temperature, hole size, inventory, etc.) from the failure case definitions are valuated to produce a set of hazard zones for each failure case. We use our CANARY computer software hazards analysis package to produce hazard zones for the fire and vapor cloud explosion (VCE) hazards associated with each failure case. In each calculation, the models account for:

- Thermodynamic and physical properties of the HVL materials
- Pipeline transport conditions such as temperature, pressure, and flow rate

- Ambient weather conditions (wind speed, air temperature, humidity, atmospheric stability)

Q: When you refer to an "assessment" in this context, what are you talking about?

A: Failure case information and consequence analysis are combined to provide a more developed understanding of the potential impact of a pipeline release. This information can be used to inform emergency response, public education, or legislative aspects of pipeline accident evaluation.

Q: Can you give us an overview of the Mariner East Pipelines?

A: The Mariner East (ME) project is composed of up to three pipelines that are intended for transportation of HVLs from the Marcellus Shale areas to Marcus Hook, Pennsylvania for export to market. Figure 1 shows the pipeline route (in red) through Chester and Delaware counties. The pipelines are being constructed by Sunoco Pipeline, a division of Energy Transfer Partners.

The three pipelines are:

- ME1 – an existing 8-inch diameter pipeline currently in service
- ME2 – a 20-inch diameter pipeline currently under construction
- ME2X – a 16-inch diameter pipeline currently under construction

For the most part these pipelines share the same right-of way as they traverse Chester and Delaware counties. There are exceptions where the ME1, ME2 and ME2X pipelines are routed in different right-of-way corridors. All three pipelines are intended for transportation of ethane, propane, or butane, all of which are HVL materials. In addition to the above pipelines, Sunoco has proposed to connect completed portions of the ME2 pipeline by using an existing 12-inch hazardous liquids line. This connection will bypass certain locations where the ME2 pipeline construction has been delayed. This analysis does not evaluate the 12-inch line or its effects on the consequences or risk imposed by ME2.

Figure 1
Mariner East Pipeline Route in Chester and Delaware Counties
(Image from Google Earth®)

The maximum operating pressure of each of the pipelines was originally modeled at 1,480 pounds per square inch gauge (psig). ME1 is fed by the Berks County pump station, approximately 30 miles upstream of the Chester/Delaware county line. ME2 and ME2X, in their initial operating state will be fed by the Middletown pump station in Dauphin County, approximately 75 miles upstream of the Chester/Delaware county line. Since Quest's QRA work on these pipelines, it has been reported that pressures of up to 2,100 psig may be seen in the pipeline(s).

IV. <u>Mariner's Leak and Rupture Detection System</u>

Q: **Like other petroleum products pipeline systems, the Mariner East Project in broad terms can be thought of as consisting of pipes, pump stations and valve stations.**

A: Yes

Q: **HVLs are pumped at pressures that are higher at some locations than other locations.**

A: Yes

Q: **Explain what a leak is.**

A: A leak would be a characterization of a loss of containment that is a "pinhole," or crack, or similar small hole in the pipeline.

Q: **Explain what a puncture is.**

A: A puncture is a loss of containment event that is characterized by a moderate hole, in the range of 1 inch or 2 inches diameter. This might be formed by something such as a backhoe tooth in an excavation accident.

Q: **Explain what a rupture is.**

A: "Rupture," while not a definite term, is generally interpreted as a full diameter or "full-bore" failure of the pipeline but can also be any large hole in the pipeline. In this context, large would be a hole approaching or equal to the diameter of the pipeline. A rupture generally represents a loss of containment event that is the largest potential event associated with a pipeline.

Q: **Explain how operators monitor for leaks and ruptures.**

A: The operator, at a remote monitoring facility, watches the flow rate of product and its pressure, and potentially other parameters, at various locations along the pipeline. This will certainly include each pump station and delivery points, and likely includes many or all of the pipeline valve stations. As product is being moved, the conditions are expected to be consistent in flow rate along the line, with decreasing pressure, due to frictional losses, between pump stations. When unexpected fluctuations in flowrate (up or down) or unexpected drops in pressure are seen, the operator must identify the event and initiate a shutdown, which involves shutting down the supply pumps and closing valves.

Q: **Are fluctuations in pressures within a particular range normal?**

A: Yes, but those fluctuations should in general always be a decrease in pressure as you move down the pipeline from a pump station.

Q: **Operators have the ability to note changes in pressure in any given pipeline section between valve stations. In the Mariner system, the distance is typically what? About 5 miles?**

A: To the best of my knowledge, the valve spacing is approximately every 5 to 10 miles.

Q: **Describe range of leaks in accordance with amount of pressure lost in any given event.**

A: Proceeding with the general loss of containment categories discussed a few moments ago, we can start with a leak. This would release an amount of product that is small compared to what we refer to as the "normal" flow rate in the pipeline. I would not expect a leak, as previously defined, to be detected as a drop in pressure along the line, or as a drop in flow rate. In other words, leaks would probably not be detected by monitoring equipment.

Moving to punctures, these events represent a significant loss of containment that should be detected. I would expect that detection and decision making may require a few minutes.

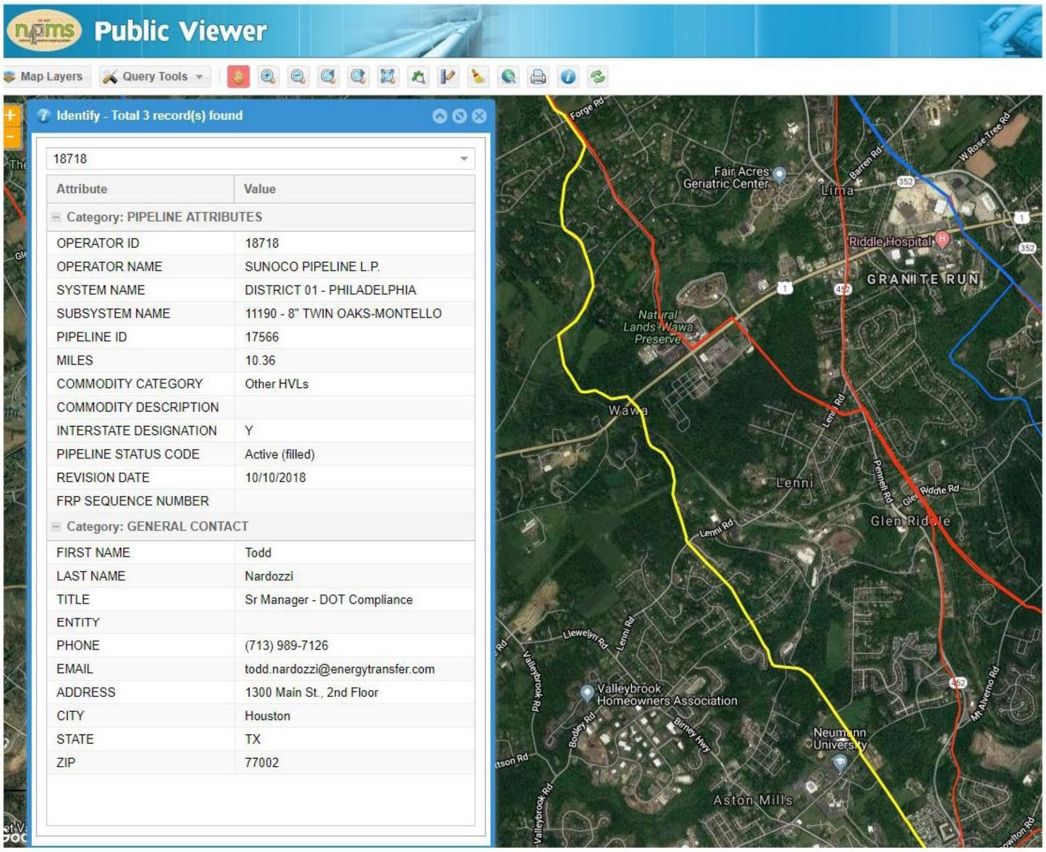
Ruptures will definitely be detected within seconds of the event initiation, and the pipeline parameters should clearly indicate that a full shut down is immediately necessary.

V. Mariner Pipeline Information

Q: For purposes of your work, how difficult is it to get Mariner pipeline information?

A: Obtaining general pipeline location information is relatively straightforward. The National Pipeline Mapping System (NPMS) provides information about pipelines and their locations. Figure 2 provides a screen shot from the viewer shows part of the Mariner East pipeline in Delaware County.

Other publically available sources provide additional pipeline details. For example, as part of the regulatory filings with the Pennsylvania Department of Environmental Protection (DEP), specific pipeline parameters, pipeline routing, valve station locations, and alignment drawings, and HDD boring information, are provided as public record. Some of the graphical information (maps or drawings) available for the Mariner East Pipelines(s) are shown in Figures 3 and 4.



Attribute	Value
Category: PIPELINE ATTRIBUTES	
OPERATOR ID	18718
OPERATOR NAME	SUNOCO PIPELINE L.P.
SYSTEM NAME	DISTRICT 01 - PHILADELPHIA
SUBSYSTEM NAME	11190 - 8" TWIN OAKS-MONTELLO
PIPELINE ID	17566
MILES	10.36
COMMODITY CATEGORY	Other HVLs
COMMODITY DESCRIPTION	
INTERSTATE DESIGNATION	Y
PIPELINE STATUS CODE	Active (filled)
REVISION DATE	10/10/2018
FRP SEQUENCE NUMBER	
Category: GENERAL CONTACT	
FIRST NAME	Todd
LAST NAME	Nardozzi
TITLE	Sr Manager - DOT Compliance
ENTITY	
PHONE	(713) 989-7126
EMAIL	todd.nardozzi@energytransfer.com
ADDRESS	1300 Main St., 2nd Floor
CITY	Houston
STATE	TX
ZIP	77002

Figure 2
NPMS Pipeline Routing

Figure 3
Overview of Pipeline Route and Valve Stations in Chester and Delaware Counties
(Image from Google Earth®)

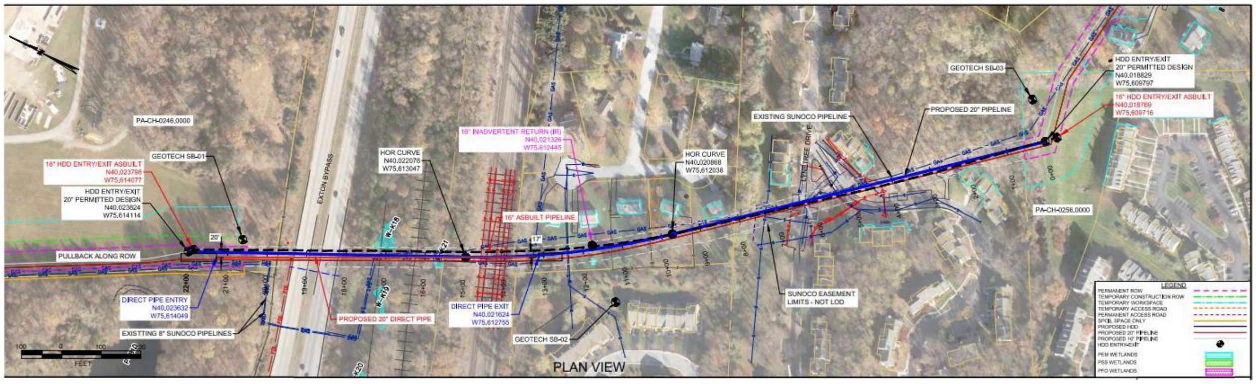


Figure 4
Example HDD Location and Specification Details

Q: Are pipeline accidental release scenarios available from publicly available sources?

A: Yes. Many of the necessary parameters used in modeling pipeline accidental release scenarios are also available from publicly available sources. Some of the basic pipeline information can be found on the Energy Transfer Partners Website concerning the Mariner East pipelines. Included here are piping diameters, reports about the 12-inch line "re-purpose" project with associated pipeline parameters.

The DEP website also has permit applications for pump stations. For example, the Mariner East pump station in Berks County application lists several pieces of information:

- The material: "Light Hydrocarbon – NGL Mix of Ethane and Propane @ 100F (Max)"
- The intended operating pressures: "Suction Pressure = 579 PSIG, Discharge = 1435 PSIG, Product Vapor Pressure of 531 PSIA"
- Maximum operating pressure of 1,480 psig

VI. Mariner Pipeline Hazards

Q: Can you explain the hazards analysis in the context of an HVL pipeline?

A: Yes. Potential releases of HVLs were considered for the Mariner East pipelines. Each potential release may result in one or more of the following hazards:

- Fire radiation occurs when released HVLs are ignited as either a jet fire or pool fire. The fire releases the energy of combustion as heat, light, and thermal radiation. Thermal radiation is what is felt by an observer of a fire. The impact depends upon the duration and intensity of thermal radiation. For example, consider a fire in a home's fireplace. Stand across the room and you can see the fire, but not feel it; stand a few feet away and you can feel the warmth of the fire; put your hands a few inches away from the fire and you feel heat, then pain, and if you stay there long enough your hands will receive burns. Likewise, if exposed to an HVL fire with thermal radiation intensity high enough and long enough, a person will receive burns that could result in injuries that may be fatal.
- The flash fire hazard develops from a dispersing release of HVL with a delayed ignition. As the released fluids mix with air and are carried downwind, a flammable mixture of HVL in air is created. As this continues, the vapor cloud is assumed to grow to its maximum size before finding an ignition source. When ignited, everything within the flammable vapor cloud zone is enveloped in flame. The fire burns out quickly because it has no continuing source of fuel, except the area near the release point, where the flash fire transitions into a continuous jet or pool fire. Fatality is assumed for all persons with the flash fire zone.
- In some instances, a flammable vapor cloud will have dispersed into an area of confinement or congestion. Confinement is a condition where a flash fire's combustion products cannot expand in all directions. Congestion is the presence of repeated small obstacles, and in this work, comes in the form of forested areas. As the flame front moves past these obstacles, it wraps around them, increasing the surface area of the flame and thus increasing the burning rate. In the case of either confinement or congestion, there is a build-up of pressure due to the combustion event. That build-up of pressure is called overpressure, which travels out from the explosion source in the form of a blast wave. A blast wave, depending on its strength, can damage structures, or result in injury or fatality to persons in the area.

- There also exists a non-zero probability that a hydrocarbon pipeline release will not be ignited. In this case, the end results is dissipation of the flammable material. However, in the immediate area of the release the hazard of asphyxiation does exist, which is displacement of oxygen in air that is breathed, to the point of injury or death. This can only occur, in the context of a pipeline release, if a person is very close to the release point and does not take corrective action. In all cases, the flammable hazard zones are much larger than the asphyxiation hazard zone.

Q: Please talk about you define the scenarios that could lead to these hazards.

For an impact from any one of the hazards inherent to the Mariner East pipelines, there must first be a loss of containment (LOC) event. If the material normally contained within the pipeline is released and ignited, the resulting consequences can be described by modeling. Thus, the first step in modeling involves defining the failure cases, or release event scenarios.

For all releases from conventionally buried piping, it is typically assumed that the pipe is buried at a conventional depth of 3-4 feet. Upon release, there is sufficient energy from the HVL depressurization that a crater will be formed above the release location. This allows for a free jet of material to be released to the atmosphere.

The Mariner East pipelines feature several locations where Sunoco is completing the pipeline installation through the use of horizontal directional drilling (HDD). This method bores a long tunnel and then pulls the pipe back into it before tying it into the conventional bury sections. The following concepts were applied in this work for HDD sections:

- The pipeline can be 30-150 feet below grade in HDD sections, making it extremely improbable that a pipeline failure would result in a surface crater.
- The probability of external damage from digging or heavy machinery in the HDD sections is extremely low.

- Because the HDD sections come back to the surface at the entry and exit points, these locations are viewed as the points where a release to atmosphere will manifest itself. Thus, the hazards for HDD sections are often located at the entry or exit points.

This approach effectively assumes that the released HVL, following a failure of the pipeline within the HDD zone, will travel along the HDD bore, which is assumed to be the path of least resistance to the surface. While it is possible for the released material to follow geological fissures or other natural or man-made conduits, the pipeline borehole is viewed as the "easiest" path to the surface for most locations.

At the valve stations, the equipment (piping, valves, instruments, etc.) is 2-3 feet above local grade. Thus, there will be no crater formed for these segments of the pipeline. Failures of the piping or associated equipment result in releases directly to atmosphere.

Q: Please explain Quest's consequence analysis models

A: To describe the hazards for any equipment handling or transporting hazardous materials, release scenarios are developed to simulate the potential LOC events. This first requires calculations of material release rates and the properties of the material following release. Following these calculations, hazard models are applied to describe the extent of a flammable vapor cloud (flash fire), jet fire radiation, pool fire radiation, or blast wave (from a VCE). Potential impacts can be determined from the results of these calculations.

When performing site-specific consequence analysis studies, the ability to accurately model the release, dilution, and dispersion of gases and aerosols is important if an accurate assessment of potential exposure is to be attained. For this reason, Quest has developed, and uses, a modeling package, CANARY by Quest®, that contains a set of complex models that calculate release conditions, initial dilution of the vapor (dependent upon the release characteristics), and subsequent dispersion of the vapor introduced into the atmosphere. The models contain algorithms that account for thermodynamics, mixture behavior, transient release rates, gas cloud density relative to air, initial velocity of the released gas, and heat transfer effects from the surrounding atmosphere and the substrate. The release and dispersion models contained in the QuestFOCUS package (the predecessor to CANARY) were reviewed in a United States Environmental Protection Agency (EPA) sponsored study and an American Petroleum Institute (API) study . In both studies, the QuestFOCUS software was evaluated on technical merit (appropriateness of models for specific applications) and on model predictions for specific releases. One conclusion drawn by both studies was that the dispersion software tended to overpredict the extent of the gas cloud travel, thus resulting in too large a cloud when compared to the test data (i.e., a conservative approach).

A study prepared for the Minerals Management Service (MMS) reviewed models for use in modeling routine and accidental releases of flammable and toxic gases. MMS recommends CANARY for use when evaluating toxic and flammable gas releases. The specific models (e.g., SLAB) contained in the CANARY software package have also been extensively reviewed.

CANARY also contains models for jet fire and pool fire radiation. These models account for material composition, target height relative to the flame, target distance from the flame, atmospheric attenuation (includes humidity), wind speed, and atmospheric temperature. The models are based on information in the public domain (published literature) and have been validated with experimental data.

In addition, Quest has designed and published a VCE model called QMEFS (Quest model for estimation of flame speeds) to model VCEs from confined and congested areas . This model is contained within the CANARY consequence modeling package.

VI. <u>HVL Pipeline Release Scenarios</u>

Q: **Did you apply your model to determine the physiological effects from HVL release scenarios?**

A: Yes, we did. The recent consequence analysis, as well as the QRA performed on the Mariner East pipelines, involved the evaluation of many unique potential hazardous material release scenarios. Each potential release may result in one or more of the hazards listed above. In order to compare the risks associated with each type of hazard, a common measure of consequence must be defined. In risk analysis studies, a common measure for such hazards is their impact on humans. However, when comparing a fire radiation hazard to a VCE hazard, the magnitude of the hazard's impact on humans must be identically defined. It would not be meaningful to compare human exposure to a nonlethal blast wave to human exposure to lethal thermal radiation.

In the QRA study, risk was defined as the potential exposure of humans to lethal hazards (i.e., radiant heat or VCE blast wave) that have the potential to occur as a result of accidents originating along the pipeline route. The QRA defined all hazard effects to be based on fatality for consistency within the analysis and to set up the study so that it may be compared to other forms of fatality, as well as international risk criteria, which are based on fatal exposures. For consequence analysis studies, injury impacts are often evaluated also. Injury effects result in larger impact zones than are predicted for fatality effects.

One of the initial tasks in modeling the potential impacts from a pipeline accident is to understand the release rate, or how quickly material in the pipeline is released to atmosphere. Most HVL pipeline accidents begin as an explosion – a sudden release of energy – due to the pressurized fluid in the pipeline. This initial explosion is accompanied by a very high release rate of material. As the first seconds of the release pass, fluids accelerate within the pipeline to flow toward the point of lower pressure (outside the pipe). But as the release scenario continues, the higher velocity flow, as well as thermodynamic effects, create pressure drop in the piping that restricts the flow of material to the break point. The result of this is a constantly decaying release flow rate, as demonstrated in Figure 5.

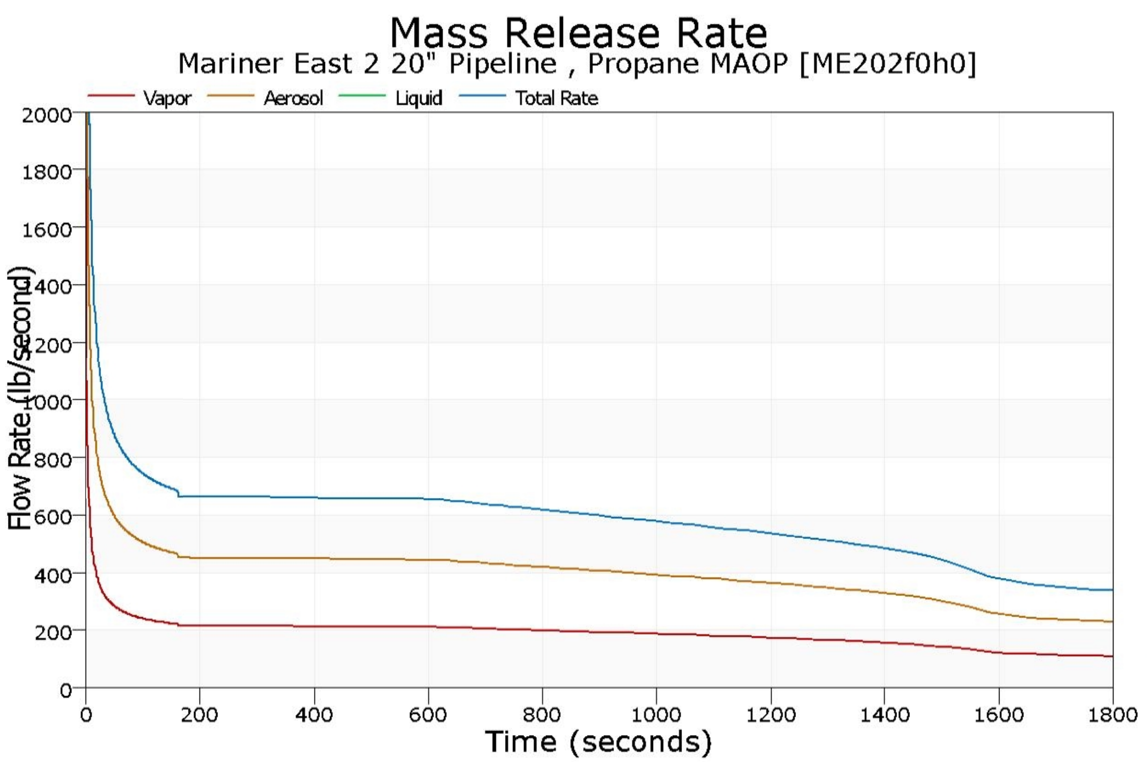


Figure 5
Mass Release Rate for ME2 Propane Pipeline Rupture

As shown in Figure 5, the first few seconds involve very high rates that decay quickly. After about two minutes, the release flow rates settle into a slowly decaying behavior. After about ten minutes, the release rate begins to decay more quickly, but persists for several hours for this pipeline (only the first 30 minutes are shown in Figure 5).

This behavior, typical for HVL pipeline releases, demonstrates that the maximum hazards are realized within the first few minutes of the release. The release rate, and therefore the hazard extents, get smaller as time passes and the pressure in the pipeline decays. While this may be altered by pump station shutdowns or valve closures along the pipeline, these are not expected to affect the release rate in the first few minutes where the maximum hazards are defined.

Q: **How do you factor in the matter of ignition timing?**

A: We evaluate loss of containment events for flammable materials through consideration of ignition timing. First, there is immediate ignition. This is characterized by ignition that occurs within the first seconds of the event. It can be initiated by the failure mechanism itself, for example, puncture by a backhoe tooth could cause a spark; or, a pipeline rupture might involve the collision of segments of the pipeline with each other such that a spark ignites the releasing material. The hazard in this case is a fire. For HVLs, this will be a jet fire, sometimes called a torch fire, as the material being released is at high pressure and will typically have a large velocity as it is expelled from the pipe. In some cases, there may also be a pool fire due to thermodynamic effects that result in liquid accumulation on the ground.

The second scenario is that of what we call delayed ignition. This means that the loss of containment event continues for some time, typically measured in minutes, before the released material reaches an ignition source. As the material is released, it mixes with air and in certain combinations of air plus vaporized HVL, the mixture is flammable, or able to be ignited. The hazard here is, first, the burning of that flammable vapor cloud. This is often called a flash fire.

Beginning at the ignition point, the released material that has mixed with air to a flammable state burns relatively quickly, finding its way back to the release point where the material that is still coming out of the pipe forms a jet fire, or possibly a pool fire. In some cases, where the flammable cloud envelops a region of confinement (walls) or congestion (obstacles), a vapor cloud explosion can result. With sufficient conditions, this explosion can create a damaging blast wave.

The last scenario is non-ignition. This is certainly more common for leaks than ruptures. The only hazard in this case is the potential for asphyxiation, which is displacement of oxygen in air that is breathed, to the point of injury or death. This can only occur, in the context of a pipeline release, if a person is very close to the release point and does not take corrective action.

Q: **Mr. Marx, complainants in their Second Amended Complaint claim to have identified three actual historical catastrophic events caused by pipeline leaks or ruptures. Would you take a look at pars. 49, 50 and 51 of the Second Amended Complaint?**

A: OK

Q: **Have you reviewed available public records and determined whether or not the three descriptions are accurate**

A: Yes.

Q: **Would you take a minute and read into the record what the Second Amended Complaint says happened in each of the three cases: I will read directly from the Second Amended Complaint.**

49. On November 1, 2007, a 12-inch-diameter pipeline transporting liquid propane ruptured in a rural area near Carmichael, Mississippi. The resulting gas cloud, formed from the 430,626 gallons of liquid propane that were released, expanded over nearby homes, forming a low-lying cloud of flammable gas. The gas found an ignition source about 7 1/2 minutes later. Witnesses miles away reported seeing and hearing a large fireball and heavy black smoke over the area. In the ensuing fire, two people were killed and seven people sustained minor injuries. Four houses were destroyed, and several others were damaged. About 71.4 acres of grassland and woodland were burned. This accident occurred in a sparsely populated area, with only about 200 people living within a 1-mile radius (about 3 square miles) of the location of the pipeline failure. A similarly sized area in Chester or Delaware Counties (about 3 square miles) might contain thousands of people. The National Transportation Safety Board identified the inadequacy of the pipeline operator's public education program as a factor that contributed to the severity of the accident.

50. On Saturday, August 24, 1996, at about 3:26 p.m. near Lively, Texas, an 8-inch pipeline transporting butane ruptured. The material volatilized into colorless, odorless, extremely flammable gas that stayed close to the ground as it drifted across the surrounding residential area. Danielle Smalley and Jason Stone, both 17 years old, ran to a pickup truck intending to warn neighbors. As they sped away, their truck ignited the vapor. Both suffered fatal thermal injuries. The fire continued to burn until about 6 p.m. the next day, which was how long it took the operator to isolate the failed section.

51. On December 9, 1970, in Franklin County, Missouri, an 8-inch pipeline transporting propane ruptured. Twenty-four minutes later, "the propane-air mixture exploded, destroyed all buildings at the blast origin, extensively damaged 13 homes within a 2-mile radius

[approximately 12 and a half square miles], sheared telephone poles, snapped tree trunks, smashed windows 12 miles away, and registered its impact on a seismograph in St. Louis, 55 miles distant. An expert from the United States Department of the Interior, Bureau of Mines, determined that the "detonation and initial fire consumed [only] 756 barrels of propane, giving rise to an estimated explosive force of 100,000 pounds of TNT." There were no fatalities due to the fact that accident occurred in a sparsely populated area while people were awake, and the few people in the area used the twenty-four minutes between the release and the explosion to self-evacuate themselves with expedition.

Q: How does your model deal with the matter of hazard distances?

A: As part of the QRA work, a significant set of hazard zones were calculated for varying hole sizes, release orientations, and weather conditions. The range of hazard distances achieved by potential flash fires, jet fires, and pool fires following releases from the Mariner East pipelines were calculated in this work.

For purposes of defining the largest potential impacts, ruptures of the Mariner pipelines when operating at their maximum operating pressure (MOP) of 1480 psig were considered. Release orientations for the largest impacts occur for horizontally or nearly horizontal events.

A summary of the maximum calculated hazard distances (generally resulting from the pipeline rupture scenario, and often associated with the aboveground equipment) is presented for the ME1, ME2, and ME2X pipelines, along with the variation of transported material (ethane, propane, or butane) in Table 1. As seen in Table 1, the fatal hazard zones predicted in this analysis are limited to a range of 2,135 feet from the pipeline; this distance results from a rupture of the ME2 pipeline at an above-ground valve station, where a horizontally-oriented release could occur. In all cases, the maximum distances reported are represented by:

- Flash Fire: Downwind extent of the flammable vapor cloud defined by the a gas concentration in air equal to the lower flammable limit
- Jet/Pool Fire: Downwind extent of thermal radiation sufficient to cause fatality in the most vulnerable portions of the population (the 1% fatality level, assuming a 30 second exposure)

Table 1
Maximum Hazard Distances for the Mariner East Pipelines

Pipeline	Product	Maximum Hazard Zone Distance [feet] for	
		Flammable Vapor Cloud (LFL)	Jet Fire
ME1	Ethane	900	375
	Propane	1,035	420
	Butane	1,095	375
ME2	Ethane	1,800	955
	Propane	2,135	1,055
	Butane	2,130	900
ME2X	Ethane	1,420	645
	Propane	1,640	700
	Butane	1,680	645

An example of a maximum fatal hazard distance is illustrated in Figure 6. This figure shows:

- The maximum flammable vapor cloud (LFL) hazard footprint associated with a rupture of the ME2 pipeline when carrying propane – *the orange shaded area*.
- The vulnerability zone associated with this maximum hazard zone – *the blue shaded area*. A vulnerability zone is created by rotating a hazard footprint around its point of origin, creating a circular area where the location of impact is dependent on the wind direction.

- The vulnerability corridor along the ME2 pipeline – *the yellow shaded area*. A vulnerability corridor is similar to a vulnerability zone, except that it "slides" along the pipeline route to indicate the area that could be affected by the hazard footprint, depending on wind direction and release location.

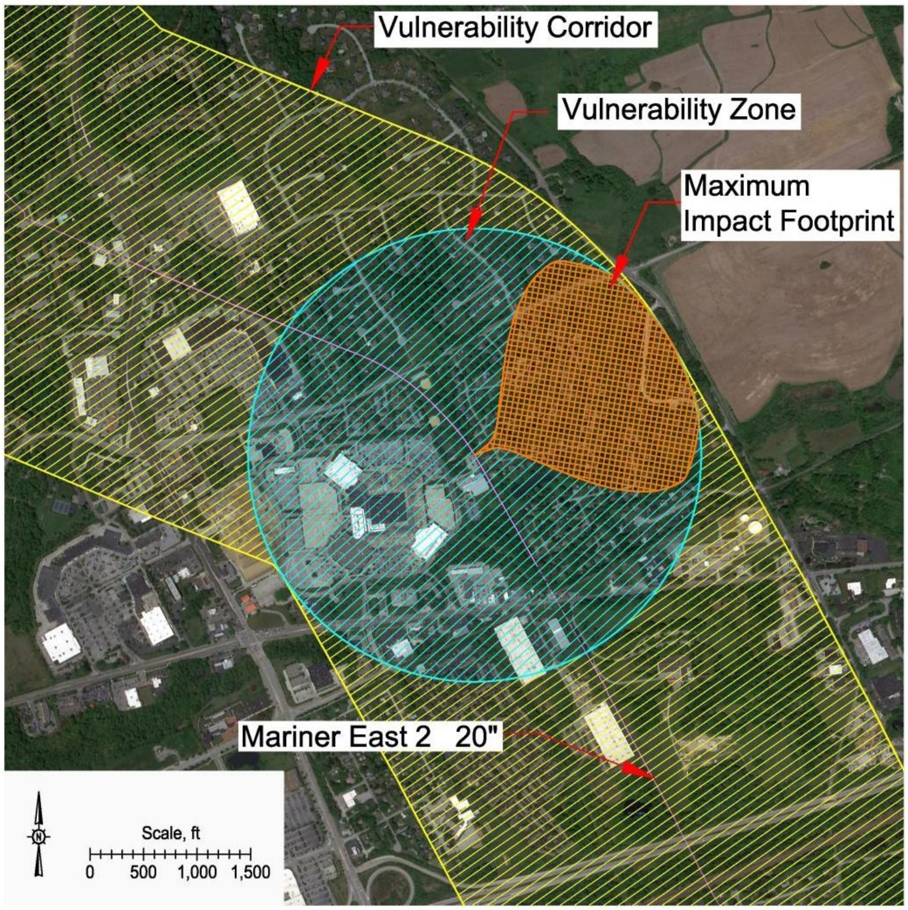


Figure 6
Maximum Hazard Footprint, Vulnerability Zone, and Vulnerability Corridor for a Rupture of the ME2 Pipeline - Chester County Library Area

Q: Were you able to do a comparison between natural gas and HVL events?

A: Yes. To provide a point of comparison, consider a local natural gas transmission pipeline. The Texas Eastern Pipeline runs across Pennsylvania to supply natural gas to the New York City area. A lateral line extends through Chester and Delaware counties toward the Philadelphia International Airport. The MOP of this 8" pipeline is 870 psig.

Results for this pipeline are as follows:

Maximum Flammable Vapor Cloud (Flash Fire) Extent:	115 feet
Maximum Jet Fire Thermal Radiation Extent (`1% fatality from burns)	175 feet

Q: You were asked to investigate the possibility of escape from the impacts of pipeline release events, is that correct?

A: Yes. Quest investigated the possibility of escaping the potential impacts of pipeline rupture events, with the assumption that the release is immediately ignited and forms a jet fire. This evaluation investigates the ability of people near the pipeline to escape injury or fatal effects during a pipeline incident.

For comparison, two similar pipelines were evaluated: (1) The 20" Mariner East 2 (ME2) pipeline, transporting propane, and (2) a hypothetical 20" natural gas transmission (NGT) pipeline. While the natural gas pipeline does not exist in Chester or Delaware Counties, this comparison was established so that the potential escape consequences could be based on pipelines of similar diameter and operating pressure.

The pipelines were each assumed to be operating at pressures of 1,480 psig and 2,100 psig. The analysis is based on escape from the fire at three escape speeds: 3, 4, and 5.6 mph. These are (effectively) walking or jogging speeds, but represent a range of ambulatory ability for potentially exposed persons.

The evaluation evaluated both receiving burns to exposed skin, and being fatally burned, by the radiation from an immediately ignited jet fire. The modeled jet fire represents the first minute of the incident; after this time the flame recedes as the release rate from the pipeline decays. While exposure to the fire's radiation is certainly possible after this first minute, the effects will be less severe. It is assumed that persons would have reached a safe place after about one minute, so this analysis is focused on the potential impacts in the first minute of the event.

The summary of the results presented in Tables 2 and 3 represent three possible impacts, based on starting distance from the pipeline and escape speed:

- Escape from the flame without skin burns
- Burns to exposed skin
- Fatality due to excessive skin burns

In each case, a dose-response relationship was used to calculate the time when either effect was reached, assuming an escape speed and starting point relative to the release location. The results in Table 2 assume that the person is traveling along the axis of the flame, away from it, but in the direction the flame is pointed. The results in Table 3 assume that the person is traveling perpendicular to the axis of the flame. Large jet fires such as this often orient themselves due to the high velocity of the released hydrocarbons. In some cases, the wind will affect a flame, and if so, Tables 2 and 3 can be thought of as escaping downwind or crosswind, respectively. For those entries in Tables 2 and 3 labeled "escape," it was found that a person moving away from the flame could escape both burns and being fatally burned.

The escape effects assume a starting point. These distances are in relationship to the pipeline rupture location, either along the flame axis or perpendicular to it. For distances within about 500 feet, there is no escape in either of these two directions. For locations "behind" the flame, or in the upwind direction, the impacts are significantly less, but were not calculated.

Further details regarding this investigation are provided in Appendix A.

Table 2
Impacts for Potential Escape Away from Flame

Pipeline	Operating Pressure [psig]	Starting Distance [ft]	Predicted Impact for Escape Speed [mph]		
			3	4	5.6
ME2	1480	500	Fatality	Fatality	Fatality
		700	Fatality	Burns	Burns
		1100	Burns	Burns	Escape
	2100	500	Fatality	Fatality	Fatality
		700	Fatality	Fatality	Fatality
		1100	Burns	Burns	Burns
Natural Gas Trans-mission	1480	500	Fatality	Fatality	Fatality
		700	Burns	Burns	Burns
		1100	Escape	Escape	Escape
	2100	500	Fatality	Fatality	Fatality
		700	Fatality	Burns	Burns
		1100	Burns	Escape	Escape

Table 3
Impacts for Potential Escape Perpendicular to Flame

Pipeline	Operating Pressure [psig]	Starting Distance [ft]	Predicted Impact for Escape Speed [mph]		
			3	4	5.6
ME2	1480	500	Fatality	Fatality	Fatality
		700	Fatality	Burns	Burns
		1100	Burns	Burns	Burns
	2100	500	Fatality	Fatality	Fatality
		700	Fatality	Fatality	Fatality
		1100	Burns	Burns	Burns

Natural Gas Trans-mission	1480	500	Burns	Burns	Burns
		700	Burns	Burns	Burns
		1100	Escape	Escape	Escape
	2100	500	Fatality	Fatality	Burns
		700	Burns	Burns	Burns
		1100	Escape	Escape	Escape

The results in Tables 2 or 3 assume a fully open escape area with no sheltering from the fire radiation. It is expected that in most cases, persons can evacuate to some type of shelter (behind trees or a car, behind or inside a home, etc.) within the first minute of the event (but likely within 20-30 seconds at most).

Q: Can you now discuss the matter of emergency response to pipeline release events?

A: In the event of a pipeline accident, as was presented in the previous sections of this report, there are two primary things that should happen: (A) the pipeline operator would recognize the event, begin shutting down the pipeline, and notify local responders, and (B) local responders will converge upon the release location to mitigate the effects of the accident.

It is helpful to consider the timeline of an event, beginning with the initiation of accident. For larger, energetic releases such as punctures or ruptures, the initial moments of the event can be characterized as an explosion – a sudden release of energy as the pressurized fluid begins to escape. If this is a conventional buried pipeline, the escaping material will blow away the overburden and form a crater, eventually resulting in a free jet of material. This initial release will be audible, easy to see, and will begin to create a large white cloud, which is characteristic of all HVL releases. This occurs because the released material becomes very cold due to the drop in pressure. Upon mixing with air, this cold material condenses water vapor in the air, similar to the natural formation of clouds in the sky or your breath on a cold morning.

Pipeline operators, typically at a remote monitoring facility, watch the product flow rate and pressure at various locations along the pipeline. Monitoring points include each pump station, as well as delivery points, and may include pipeline valve stations. As product is being moved, the conditions are expected to be consistent in flow rate along the line, with decreasing pressure, due to frictional losses, between pump stations. In the time frame of several seconds to a few minutes following a pipeline rupture or puncture, the pipeline operators will notice pressure or flow differentials. When unexpected fluctuations in flowrate (up or down) or unexpected drops in pressure are seen, the operator must (1) identify the event and its location, (2) initiate a shutdown, which involves stopping the supply pumps and closing valves, and (3) notify local responders.

Once local responders are notified, it may require between five and 30 minutes to mobilize and reach the area. A phone call from the pipeline operator initiates a chain of communication that mobilizes people and equipment, typically from several different agencies. These responders must then locate the accident site and determine the best way to approach the scene, keeping in mind the potential hazards to themselves and their equipment that may be present. Initial efforts will involve personnel coordination, command post establishment, and immediate fire response activities. As an understanding of the event develops, evacuation and other response activities can commence.

Q: Can you run through the chronology of an HVL pipeline rupture event?

A: Sure. As an example, consider a *hypothetical* HVL pipeline **rupture** event:

- The pipeline ruptures, and ignites immediately, forming a large jet fire.
- The remote monitoring operator recognizes the incident within a few seconds of the

rupture.

- The operator assesses the data and begins shutdown activities within 1-2 minutes. Pump stations are given the command to shut down and after an appropriate delay, automated valves are closed (often requires an additional 3-4 minutes for shutdown sequences to develop).
- The operator calls local responders, based on an assessment of where the rupture has occurred.
- The operator calls pipeline personnel for notification, and potentially to shut down pipeline valves that are not automated.
- Public in the area of the rupture call 911 reporting an explosion followed by a large fire.
- Local responders arrive at the scene 10-15 minutes after the rupture, set up a command post ½ mile upwind of the rupture site, and begin extinguishing secondary fires. The jet fire from the pipeline is unapproachable and inextinguishable.
- After 20 minutes, the pipeline operator notifies emergency responders that the pipeline has been isolated around the rupture site – 3 miles upstream and 8 miles downstream.
- After about 14 hours, the pipeline inventory is depleted and the fire is declared controlled.

Q: Can you run through the chronology of an HVL pipeline puncture event?

A: Consider a second example, involving a *hypothetical* **2-inch diameter hole** in an HVL pipeline:

- A small corrosion hole in the pipeline begins to release HVL and the hole quickly grows to approximately 2 inches in diameter in the weakened area. The force of the released material results in a crater being formed between the pipeline and the surface.
- Local residents hear the event, but aren't sure what it was.
- As the HVL mixes with air, a flammable vapor cloud develops, spreading over the immediate area, and is transported downwind, settling in low-lying and forested areas.

- Approximately 5 minutes later, a local resident out walking her dog, sees the vapor cloud. Because the weather conditions were not favorable for fog at that time, she realizes this is not a natural occurrence, and calls 911 to report the event.
- The 911 operator dispatches local responders to the area. After further conversation with the resident, the operator determines that is likely a pipeline release due to the proximity of the HVL pipeline, and places a call to the pipeline operator.
- At about 10 minutes into the event, the pipeline operator begins shutdown and isolation activities. Pump stations are given the command to shut down and after an appropriate delay, automated valves begin closing (often requiring an additional 3-4 minutes for shutdown sequences to develop).
- Local responders arrive and begin to assess the situation. After about15 minutes of assessment, a command post is set up about ¼ mile from the release point. Based on responder reports, the county emergency response office decides to activate its reverse 911 capability to warn residents and recommend evacuation.
- A few minutes later, a car drives through what appears to be a foggy area at a creek crossing about 800 feet from the release site. The car stalls. As the driver attempts to re-start the car, the flammable vapor cloud is ignited. The flash fire burns across the roadway and into the surrounding forest. The flames accelerate through the forest, resulting in a vapor cloud explosion that sends a blast wave out in all directions. The flammable cloud burns all of the available material, and forms a jet fire at the release site where HVL material is still being released from the pipeline.
- As responders begin to assess the event, they find that the driver of the car was fatally injured, several responders were injured from the blast, and there are multiple homes in the area that are now on fire. Many more homes were damaged by the blast, from broken windows to moderate structural failure.
- Although a 9-mile segment of the pipeline around the release point has been isolated, an inextinguishable jet fire continues to burn at the release location. Several secondary and structure fires continue to burn within about 500 feet of the release location.
- After about 3 hours into the event, firefighters have the secondary and structure fires under control and have begun recovery operations. Several victims are found in or

around homes that were within the flammable vapor cloud or close enough to be damaged by the vapor cloud explosion.

- After about 48 hours, the pipeline inventory is depleted and the fire is declared controlled.

Q: **Given the discussions we have had concerning HVL pipeline failures and the potential hazards, please explain the implications for emergency response.**

A: It is helpful to consider the timeline of an event, beginning with the initiation of the leak, puncture, or rupture. For now, we'll leave out leaks as they are less energetic and less severe. The initial moments of the event can be characterized as an explosion – a sudden release of energy as the pressurized fluid begins to escape. Provided that this is a conventional buried pipeline, the escaping material will blow away the overburden and form a crater, eventually resulting in a free jet of material. This initial release will be audible, easy to see, and will begin to create a large white cloud. In the time frame of several seconds to a few minutes, the pipeline operators will notice pressure or flow differentials and should initiate shutdown procedures, as well as communicating with local emergency responders. It will of course take responders several to tens of minutes to mobilize and reach the area. After arriving at the scene, fire response and evacuation activities are carried out. However, the release from the pipeline has likely already subsided as the pressure in the pipeline decreases and it de-inventories.

Q: **You mentioned a large white cloud. What is that and how does it relate to HVL releases?**

A: The large, white vapor cloud is characteristic of all HVL releases. This occurs because the released material becomes very cold due to the pressure drop. Upon mixing with air, this cold material creates condensation of the water vapor in the air. This is very similar to the natural formation of clouds that we see in the sky. It is useful because it makes what is normally a colorless gas a highly visible dispersing vapor cloud. As a rule of thumb, the visible cloud approximately represents the flammable cloud – but this is only approximate as this is not a scientific statement and varies with the HVL, its release characteristics, and the ambient humidity.

Q: **How does this compare to the accident history of HVL pipelines?**

A: As a generalization, it matches up well. Let's consider emergency response in light of an example scenario: the Carmichael, MS incident which is detailed in an NTSB report.

- The pipeline rupture occurred at 10:35 in the morning
- The remote operator recognized the pressure reduction as a loss of containment and began shutdown activities about 1 minute later
- 3 minutes into the event, local field personnel were called to respond
- 4 ½ minutes into the event, the first 911 call was made. A resident reported an "explosion" and could see a white cloud ("smoke") and could smell gas. This came from a house that was about 500 feet from the pipeline and was the location of one of the two fatalities.
- A second 911 call came in during the 1st, about 5 minutes into the event, reporting an explosion and "smoke."
- At about 6 minutes into the event, another resident called the toll-free number provided by Dixie pipeline to report the incident.
- Seven minutes into the event, emergency responders were dispatched.
- 7 ½ minutes into the event, the gas cloud was ignited. Ignition source unclear. The cloud area was described as approximately 950 feet by 1,250 feet.
- About 2 hours into the event, manual isolation valves were closed and the pipeline considered fully shut in.
- 30 hours into the incident, the fire was declared extinguished

In this particular accident, the takeaway from the report is the following:

1. I would characterize this as delayed ignition event. In the 7.5 minutes between rupture and ignition, a significant amount of propane was released.
2. Even prompt action by well-trained operators may not be sufficient to protect the public from disaster. In this incident, operators took action quickly, but they cannot quickly end the release of propane from the pipeline due to the inventory in the pipe.
3. Evacuation of the area was not be feasible in such a short time frame. Emergency responders could not get to the location before ignition occurred.
4. Residual propane in the affected pipeline continues to burn for several hours until the material is depleted. In this time, the hazard zone from the propane fire is diminishing, but secondary fires could spread.
5. Even timely, well executed and effective actions by law enforcement, fire departments and other agencies may not be sufficient to save lives in the event of a pipeline rupture. The hazards develop too quickly and are most severe at the beginning of the event.

Q: **What are the possible consequences following a HVL pipeline failure in Chester and Delaware counties?**

A: All or nearly all of the Mariner pipelines are in high consequence areas, meaning, in this case, that there is a significant population around the pipeline route or routes. A large leak, or a puncture or rupture at any location along the ME1 or the workaround pipeline has the potential to cause a fatality. The accident histories cited in the Second Amended Complaint involved fatalities due to the pipeline failure, but were all in rural or sparsely populated areas. Of course there have been many HVL pipeline accidents over the years that did not involve fatalities, but the population density surrounding the pipeline route increases the likelihood of public impact.

Q: **Can you identify and describe some specific locations that you are familiar with in Chester or Delaware counties that may be particularly vulnerable?**

A: Yes. I was able to go see several locations along the Mariner pipeline route in Delaware and Chester counties. One interesting location was at the northern edge of Delaware County where the Andover neighborhood is located. The pipeline route runs along one edge of that neighborhood, within 100 feet of several houses. Also in that area is a restaurant and bar, called "Duffers" that is within about 30 feet of the pipeline route and one of the valve stations. The outdoor seating area actually has a good view of the valve station. An accident in that area could endanger the restaurant, its patrons, and many persons in the Andover neighborhood.

Another location is the Wellington at Hershey's Mill, a senior living center in West Chester. The multi-story buildings there are all between about 80 and 500 feet from the Mariner pipeline route. This type of facility raises some interesting issues with the potential consequences of a pipeline failure, emergency response, and any evacuation that may be required, due to the number of persons in proximity to the pipeline, and the potential physical limitations of residents, which would make evacuation more difficult.

I also visited the Chester County Library in Exton, where the Mariner pipeline route is within 20 feet of that building, and within about 30 feet of residences on the other side of the easement.

An additional site I visited is Glenwood elementary in Delaware County. The school is about 600 feet away from the Mariner pipeline route, so only a very large event could affect the school. But if such an event occurred while children were present, there are concerns that have been voiced regarding evacuation – if that is the proper response – or shelter in place if that is the better action.

Q: **What do you know about the complainants' locations in relation to the Mariner pipelines?**

A: I have been to Carolyn Hughes' residence and have seen where that is in relation to the pipeline route. For the other complainants, I can only assume that the relative locations as to where they live, work, or where their children attend school are accurate.

Q: **Explain impact zones and effect of distance from source.**

A: The impact or vulnerability zones of course vary according to several parameters, primarily release hole size. Earlier, when discussing the event timelines I deferred the discussion of leaks. Leaks could be so small as to go undetected for days, or could be quickly identified by a hissing sound and perhaps a jet of material emanating from the ground. In this case, the vulnerability zone is very small and in individual would have to be in the pipeline right-of-way to be affected. As hole sizes grow larger, the vulnerability zone grows larger, from tens of feet to hundreds of feet, to one thousand or more.

Q: **Explain some of the factors that have a bearing on outcomes**

A: The primary factor is hole size, which we have discussed. Beyond that, issues such as release orientation, ignition timing (immediate, delayed or none), and weather conditions can have an impact on the vulnerability zone that is realized in a unique event.

Q: **Please explain to me what could happen at one of the Complainant's locations if a pipeline release were to occur. For example, let's say the ME1 pipeline ruptures. What kind of vulnerability zones could be expected?**

A: Based on the modeling we did for our QRA study, the maximum vulnerability zone around ME1 is approximately one-quarter of a mile. Within this distance, a flammable vapor cloud could envelop persons and houses, and if ignited, those people or houses would be within a flash fire. At a shorter distance, about 400 feet, is the extent of fatal burns from an ignited jet fire, with injuries possible at greater distances. At distances longer than about ¼ mile, residents could be expected to be evacuated after a pipeline event, although they would normally be outside of the immediate vulnerability zone.

Q: Mr. Marx, within a reasonable degree of professional certainty, please state the major findings of your analysis.

A: They can be summarized as follows:

- Although some information concerning the Mariner East Pipeline(s) project has not been made public, there exists sufficient publicly available information in order to generate reasonably accurate calculations of both hazards and risk from potential pipeline releases.
- Due to loss of inventory and pressure decay, the release rate from an HVL pipeline incident decreases with time. Consequently, the worst hazard zones are realized in the first few minutes of the pipeline accident.
- Predicted fatal impacts of accidental pipeline rupture events were found to extend up to greater than 2,000 feet from the Mariner pipelines or their associated equipment. Moderate holes could create hazard zones extend up to about 1,000 feet from the pipeline.
- Depending on the pipeline size and operating conditions, and the magnitude of the release scenario, persons in the vicinity of the pipeline may have difficulty escaping unharmed.
- The potential impacts of an HVL pipeline rupture are more severe than those for a natural gas transmission pipeline rupture at the same line diameter and operating pressure.

- The potentially lethal hazards associated with the Mariner pipelines are significantly larger than those associated with the natural gas transmission pipelines in Chester and Delaware Counties.

Q: Mr. Marx, within a reasonable degree of professional certain, please state the major implications for emergency response and public awareness that can be extracted from your analysis.

- In the event of an HVL pipeline loss of containment, especially a rupture event, the maximum hazards will be realized before the operator can affect any meaningful measures to shut down the release.
- In the event of an HVL pipeline loss of containment, especially a rupture event, it is extremely unlikely that emergency response activities can provide assistance before the maximum hazards are realized (and perhaps not even activated before the maximum hazards are realized).
- While pipeline shutdown and emergency responder activities are important, and can help to mitigate impacts in the range of tens of minutes after the event begins, there are no actions that can affect the hazards realized in the first minutes of the event.
- For members of the public in the vicinity of the Mariner pipelines, it is difficult to know what the proper reaction (i.e., shelter in place or evacuate) to a pipeline incident may be due to the variability of the event magnitude, various hazards that are possible, and timing of ignition.
- First responders can help to extinguish secondary fires, evacuate persons who have sheltered in place (e.g., in a home), or evacuate persons who have escaped the pipeline impacts by finding shelter.

Q: Mr. Marx, have all of your opinions above been given within a reasonable degree of professional certainty?

A: Yes.

Q: Mr. Marx, would you agree that if additional information becomes available it is conceivable you would have to review that information to determine whether it affects your opinion in this case.

A: Yes, of course.

APPENDIX A
ESCAPE ANALYSIS DETAILED RESULTS

Table A-1
Impacts for Potential Escape Away from Flame

Pipeline	Operating Pressure [psig]	Starting Distance [ft]	Escape Speed [mph]	Time to Burns [s]	Time to Fatality [s]
ME2	1480	500	3	2	8
			4	2	8
			5.6	2	9
		700	3	6	50
			4	7	escape
			5.6	7	escape
		1100	3	45	escape
			4	51	escape
			5.6	escape	escape
	2100	500	3	1	3
			4	1	3
			5.6	1	3
		700	3	3	16
			4	3	17
			5.6	3	19
		1100	3	20	escape
			4	21	escape
			5.6	23	escape
Natural Gas Trans-mission	1480	500	3	3	15
			4	3	18
			5.6	3	27
		700	3	19	escape
			4	21	escape
			5.6	26	escape
		1100	3	escape	escape
			4	escape	escape
			5.6	escape	escape
	2100	500	3	1	6
			4	1	6
			5.6	1	6
		700	3	6	51
			4	6	escape
			5.6	6	escape
		1100	3	6	escape
			4	escape	escape
			5.6	escape	escape

Table A-2
Impacts for Potential Escape Perpendicular to Flame

Pipeline	Operating Pressure [psig]	Starting Distance [ft]	Escape Speed [mph]	Time to Burns [s]	Time to Fatality [s]
ME2	1480	500	3	4	18
			4	4	20
			5.6	4	22
		700	3	8	55
			4	8	escape
			5.6	8	escape
		1100	3	30	escape
			4	32	escape
			5.6	35	escape
	2100	500	3	2	11
			4	2	11
			5.6	2	12
		700	3	5	26
			4	5	28
			5.6	5	32
		1100	3	16	escape
			4	16	escape
			5.6	17	escape
Natural Gas Trans-mission	1480	500	3	11	escape
			4	12	escape
			5.6	12	escape
		700	3	28	escape
			4	30	escape
			5.6	36	escape
		1100	3	escape	escape
			4	escape	escape
			5.6	escape	escape
	2100	500	3	7	48
			4	7	58
			5.6	8	escape
		700	3	15	escape
			4	16	escape
			5.6	17	escape
		1100	3	escape	escape
			4	escape	escape
			5.6	escape	escape