Del-Chesco United for Pipeline Safety

October 19, 2018

To the Citizens, Municipalities, School Districts, and Members of the General Assembly of Pennsylvania

Final Report of the Citizens Risk Assessment of the Sunoco Mariner East Project

Del-Chesco United for Pipeline Safety hereby conveys to you the Citizens Risk Assessment Final Report of Sunoco's proposed Mariner East pipeline project, completed by Quest Consultants of Norman, Oklahoma. While we recognize that there are areas worthy of further investigation, this Report represents an important contribution to a public understanding of the safety risks associated with the transport of hazardous, highly volatile liquids through densely populated "high consequence" areas. In addition, the public-private partnership between Del-Chesco United for Pipeline Safety, impacted residents, and municipal governments that produced this work was nothing short of historic in its scope.

Del-Chesco United recognizes the important contributions of those who made this project possible. First and foremost, we are indebted to Pennsylvania state Senator Andy Dinniman, whose tireless work on behalf of his constituents and all Pennsylvanians led to the original concept that became the Citizens Risk Assessment. Sen. Dinniman's bold leadership inspired us to conduct this investigation of public safety risk after both state agencies and the Pennsylvania executive branch of government declined to do so.

Municipal governments also rose to the occasion. Del-Chesco United acknowledges the financial contributions of East Goshen Township; Uwchlan Township; West Whiteland Township; Westtown Township; and Willistown Township, all located in Chester County. East Goshen Township's Board of Supervisors deserves special recognition for being the first township to recognize the importance of this work with a financial contribution to the Citizens Risk Assessment.

Del-Chesco United thanks the West Chester Area School District for providing the use of the Fugett Middle School Auditorium on August 28, 2018 for the public presentation of the preliminary results of the Citizens Risk Assessment. The superintendents of West Chester Area School District, Downingtown Area School District and Rose Tree Media School District have repeatedly expressed concern for the safety of the students committed to their care each school day, in light of the continuing lack of information about the magnitude of the risks associated with Mariner East, as well as the lack of adequate leak response plans.

Chester County's Department of Emergency Services provided space at its West Chester facility for training in the use of the CANARY consequences modeling software, a license for which was procured by Del-Chesco United. Representatives of Chester County Emergency Services, East Goshen Township, Uwchlan Township, Willistown Township, and the Downingtown Area School District participated in this important training. Senior representatives of the Chester County Department of Emergency Services were helpful in advancing our understanding of the limitations of emergency notification and response capabilities. Del-Chesco United also recognizes Delaware County Council, whose Director of Emergency Services reviewed Quest's capabilities, pronouncing the company "fully qualified." This review added credibility to the Citizens Risk Assessment, and hastened its initiation.

Finally, the leadership team of Del-Chesco United salutes every person who donated your hard-earned money to this project. We understand the economic hardships imposed on our communities by Sunoco's proposed project, and humbly thank each of you for your contribution. The name of every person who donated to the Citizens Risk Assessment in defense of our shared American values is recorded in the history of this project. To everyone named above, and to anyone we failed to mention, thank you.

Del-Chesco United for Pipeline Safety

For Immediate Release
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FINAL REPORT RELEASED

CITIZENS RISK ASSESSMENT OF SUNOCO'S MARINER EAST PIPELINE COMPLETED

CHESTER COUNTY and DELAWARE COUNTY, Pennsylvania, October 19, 2018—Today, Del-Chesco United for Pipeline Safety announces the release of the Quantitative Risk Assessment Final Report of Sunoco's proposed Mariner East hazardous, highly volatile liquids export pipeline project. The Risk Assessment was completed by Quest Consultants of Norman, Oklahoma, under a contract executed in June 2018. Clean Air Council, one of Pennsylvania's oldest environmental nonprofit organizations, served as fiscal agent for the project. Tim Boyce, Director of the Delaware County Emergency Services Department reviewed Quest's abilities as part of a Risk Assessment proposal Quest presented to Delaware County Council. Mr. Boyce reported that Quest was "fully qualified" to perform such work.

Funding for the Citizens Risk Assessment was obtained through a historic public-private partnership of impacted Pennsylvania municipalities; nonprofit corporations such as homeowner's associations; and from an unprecedented, crowd-sourced outpouring of contributions from individuals across Pennsylvania.

Del-Chesco United has also acquired a temporary lease of the CANARY consequences modeling program, a proprietary tool developed by Quest Consultants. CANARY was used to model accidents on Mariner East for the Citizens Risk Assessment, and Del-Chesco United is willing to operate CANARY for any interested municipality, school district, or emergency response agency. Del-Chesco United is currently seeking additional funding in order to purchase a perpetual license for CANARY.

As part of the project, members of the Citizens Risk Assessment project team had an opportunity to interact with both the senior Quest engineer assigned to the project as well as personnel from Chester County's Department of Emergency Services. The implications that the Del-Chesco team gleaned from these interactions and the Final Report results included the following.

- ***Risk*** can be assessed as the product of *consequences* and *probability*.

- Predicted consequences of a release of hazardous, highly volatile liquids from the proposed 20-inch diameter "Mariner East 2" pipeline extend up to 2,135 feet. This is a modeled result and not an upper limit.

- Valve sites are points where there is significantly heightened likelihood of release. Due to the equipment present, and the aboveground placement of this equipment, pipeline valve stations represent the highest risk locations. The risk of fatality near valve sites was found to be in excess of the tolerable limit when compared to international criteria.

- "Horizontal directional drill" (HDD) entry and exit points are locations of significantly heightened likelihood of release. In the event of a breach along a deeply buried segment, gas will flow along the path of least resistance, which is likely to be the HDD entry exit points. Gas may also be released through fissures or cracks that may have been created during loss-of-drilling-fluid events ("frac-outs").

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- The presence of two pipelines approximately doubles the probability of an accident over a single pipeline. Three pipelines triples the probability, and so on. A doubling of probability represents a doubling of risk.

- There is a threshold rate of release below which the operator is unable to detect a leak is occurring. This threshold release rate is large enough that it could produce very serious consequences including injuries, death, or property damage.

- Even the smallest leak of highly volatile liquids from a transmission pipeline has potentially deadly consequences.

- Should there be a leak or rupture of a particular segment that IS identified by the operator, it will take many minutes (even under best possible circumstances) to close block valves. Even with block valves closed, highly volatile liquids will continue to vent from the breach until the failed segment is substantially emptied.

- Wooded areas serve to increase the surface area of a gas cloud and act to worsen the consequences of a vapor cloud explosion. In cases modeled using CANARY, the presence of trees increased the blast radius beyond what it would have been without trees.

- Any confinement of a combustible vapor cloud can produce explosive effects. Examples of potential confinement include low-lying area surrounded by higher terrain, densely developed areas, and buildings into which gas may find its way.

- Should county emergency services departments be informed of a leak, they intend to operate their "reverse 911" systems to notify residents via phone of the need to self-evacuate or other instructions. However, the federal pipeline regulator advises against the use of telephones and cell phones, warning "these can ignite airborne gases."

- The Final Report indicates that, under some circumstances, being inside a building may provide protection from death or injury from fire radiation or explosive effects. However, Sunoco's one-size-fits all guidance recommends immediate on-foot self-evacuation, in the correct upwind direction. In all cases, Sunoco recommends leaving the building if you are in one. Sunoco has not provided any information about to determine when it may be safer to remain indoors; how to find wind direction; or how to recognize when a "safe location" has been reached. Sunoco also has failed to provide guidance about actions that should be taken by people of limited mobility such as seniors, young children, or those with disabilities, particularly at night or during inclement weather.

# # #

Del-Chesco United for Pipeline Safety is a nonpartisan, fact-based, grassroots coalition of locally-based safety groups, made up of concerned Pennsylvanians from across our Commonwealth. Our mission is to unite people through education and to encourage our elected officials to make informed policy decisions for the safety and well-being of our communities.

QUANTITATIVE RISK ANALYSIS FOR THE MARINER EAST PIPELINE PROJECT

Prepared For

Del-Chesco United for Pipeline Safety
and
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QUANTITATIVE RISK ANALYSIS FOR THE MARINER EAST PIPELINE PROJECT

EXECUTIVE SUMMARY

Del-Chesco United for Pipeline Safety, with the Clean Air Council acting as fiscal agent, retained Quest Consultants Inc.® (Quest) to investigate the risk associated with the Mariner East pipeline project in Chester and Delaware Counties, Pennsylvania. The objective of the study was to compute the level of risk posed to the public by potential releases of highly volatile liquid (HVL) products from the Mariner East pipeline project(s). This work was done as a quantitative risk analysis (QRA), which means that quantitative measures of the consequences of pipeline release events and the probability that those events will happen are combined to produce numeric measures of risk.

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. The QRA methodology used in this work has been employed by Quest in many 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.

In this work, risk is expressed as the location-specific individual risk of fatality, due to accidental releases from the Mariner East (ME) pipelines, which include the 8-inch ME1, the 20-inch ME2, and the 16-inch ME2X. The emphasis of the study was for three areas along the pipeline route: near Glenwood Elementary in Delaware County, near the Chester County Library in Exton, PA, and near the Chester/Delaware Counties line. The end product is a description of risk that can be compared to other forms of individual risk or international criteria for individual risk. Neither the U.S.A. nor Pennsylvania have adopted individual risk criteria for such applications.

The methodology applied in the QRA covers the following:

- Hazard Analysis: defining the HVL release scenarios, pipeline parameters and site properties
- Frequency Analysis: DOT pipeline failure rates for buried HVL pipelines; aboveground equipment failure rates; local probabilistic weather data
- Consequence Analysis: Application of Quest's proprietary software, CANARY by Quest®, for calculations of exposure areas to fire or explosion effects that have a potential for fatal impacts (injury impacts and property damage were not evaluated)
- Risk Calculation and Assessment: Combination of frequency and consequence analysis results to develop continuous occupancy, location-specific individual risk of fatality contours for the areas around the pipelines; comparison of those results to other forms of individual fatality risk or international criteria for individual fatality risk.

Key findings from the analysis include the following:

- Predicted fatal impacts of accidental pipeline release events were found to extend up to 2,135 feet from the pipelines.
- Due to the equipment present, and the aboveground placement of this equipment, the pipeline valve stations represent the highest risk locations, where the risk is approximately equal to being fatally involved in a motor vehicle accident. The risk level at these valve stations was found to be in excess of the tolerable limit when compared to international criteria.
- The risk was found to be elevated where the ME1, ME2, and ME2X are co-located along the pipelines' route. The risk is *about* 10% as likely as being fatally involved in a motor vehicle accident, where the ME1, ME2, and ME2X are co-located and all in operation. This risk is also about 150 times as likely as getting struck by lightning.
- As a generalization, areas further than about 600 feet from the pipeline or pipelines are predicted to have an individual fatality risk level that is generally interpreted as tolerable or acceptable.
- The risk above the horizontal directional drill (HDD) sections is significantly less than above the conventional, shallow-bury sections of the pipeline. However, the side-effect is that risk is concentrated at the HDD entry and exit points.
- Generally, the calculated fatality risk due to the Mariner East pipelines is highest at the aboveground pipeline valve stations, followed by the HDD entry/exit points or at locations where the ME1, ME2, and ME2X pipelines are co-located. Risk is generally lower along the pipeline route where there are only one or two pipelines, lower above the ME1 line only, and lowest above locations where there are pipelines installed by HDD (deep bury).

QUANTITATIVE RISK ANALYSIS FOR THE MARINER EAST PIPELINE PROJECT

Table of Contents

1.0 INTRODUCTION AND OVERVIEW

Del-Chesco United for Pipeline Safety, with the Clean Air Council acting as fiscal agent, retained Quest Consultants Inc.® (Quest) to investigate the risk associated with the Mariner East pipeline project in Chester and Delaware Counties, Pennsylvania. The objective of the study was to compute the level of risk posed to the public by potential releases of highly volatile liquid (HVL) products from the Mariner East pipelines.

In this work, risk is expressed as the location-specific individual risk of fatality, due to accidental releases from the Mariner East pipelines. Within the study objective, the end product is a description of risk that can be compared to other forms of individual risk or international criteria for individual risk. Neither the U.S.A. nor Pennsylvania have adopted individual risk criteria for such applications, although a few jurisdictions in the U.S.A. have attempted to develop such criteria for industrial projects. The measures of risk developed in this work do not address the impacts to groups of people, which is defined as societal risk. Societal risk calculations are a different measure for risk that is not within the scope of this work.

The emphasis of the study was for three areas along the pipeline route: near Glenwood Elementary in Delaware County, near the Chester County Library in Exton, PA, and near the Chester/Delaware Counties line.

The study, a quantitative risk analysis (QRA), was composed of four distinct tasks:

- Task 1. Determine potential releases that could result in fatal impacts to persons in the vicinity of the pipeline.
- Task 2. For each potential release identified in Task 1, derive the annual probability of the release.
- Task 3. For each potential release identified in Task 1, calculate the potentially lethal hazard zones.
- Task 4. Using a consistent, accepted methodology, combine the probabilities from Task 2 with the potential release consequences from Task 3 to arrive at measures of risk posed by the pipeline.

This methodology has 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.

1.1 Hazards Identification

The potential hazards associated with the Mariner East pipelines are common to other HVL pipelines and are a function of the material being transported. 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 are jet fires, pool fires, flash fires, and vapor cloud explosions. These hazards form the primary contributors to the risk of fatality following an accidental release from an HVL pipeline.

Definitions
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

There are other hazards that are highly localized and were not included in this analysis:

- A potential initial explosion at the failure location due to the energy being released from the pipeline, causing a blast wave and overburden projectiles; and
- Asphyxiation due to oxygen displacement in the immediate area around an HVL release.

1.2 Failure Case Definition

The 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

This step in the analysis defines the various release sources and conditions of release for each failure case. The release conditions include:

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

1.3 Failure Frequency Definition

The frequency with which a pipeline or its components are expected to fail can be defined by historical data from similar pipelines.

The pipeline failure rates used in this analysis were extracted from the U.S. Department of Transportation (DOT) Pipeline and Hazardous Materials Safety Administration (PHMSA) incident database for liquids pipelines. So that the analysis would be specific to HVL pipelines, PHMSA's data for HVLs was extracted from the liquids pipelines database and applied in this work.

Failure frequencies for aboveground equipment were extracted from a commonly-used hydrocarbon processing equipment database, as their failure frequencies could not be reliably determined from the PHSMA data set.

1.4 Hazard Zone Analysis

The release conditions (e.g., pressure, composition, temperature, hole size, inventory, etc.) from the failure case definitions are then evaluated, using the best and most appropriate hazard quantification technology, to produce a set of hazard zones for each failure case.

Definition
Hazard Zone – The area or zone that is predicted to be affected by a defined hazard

The CANARY by Quest® computer software hazards analysis package is used to produce profiles for the fire and explosion hazards associated with each failure case. For this work, the models that are used 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)

1.5 Risk Quantification

The methodology used in this study has been successfully employed in many QRA studies that have undergone regulatory review in countries worldwide.

The result of the analysis is a prediction of the risk posed by the HVL pipeline(s). Risk may be expressed in several forms (e.g., risk contours, average individual risk, societal risk, etc.). For this analysis, the focus was on the prediction of site-specific individual risk contours.

Definitions
Site-specific Individual Risk – The measure of the annual probability of fatality of a hypothetical individual, who is present at a single location point, 24 hours a day, 365 days a year *Societal Risk* – A cumulative measure of fatality risk to specific groups of persons in locations around a source of hazardous materials accidents

1.6 Risk Assessment

Risk indicators enable an evaluation of the fatality risks associated with the pipeline by comparison to risk standards developed by international agencies, as well as to other forms of fatality risk.

Definition
Risk Assessment – The evaluation of a risk analysis for the purpose making judgements of acceptability or tolerability

2.0 THE MARINER EAST PIPELINES

The Mariner East (ME) project is composed of up to three pipelines that are intended for transportation of highly volatile liquids (HVLs) from the Marcellus Shale areas to Marcus Hook, Pennsylvania for export to market. Figure 2-1 shows the nominal pipeline route (in red) through Chester and Delaware counties. The pipelines are being constructed by Sunoco Pipeline, a division of Energy Transfer Partners.

Figure 2-1
Mariner East Pipeline Route in Chester and Delaware Counties (Image from Google Earth®)

2.1 Pipeline Data

The three pipelines[1] 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 several exceptions to this, however, 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.

[1] https://marinerpipelinefacts.com/mariner-east/mariner-east-faq/
http://www.dep.pa.gov/Business/ProgramIntegration/Pennsylvania-Pipeline-Portal/Pages/Mariner-East-II.aspx

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.

The maximum operating pressure of each of the pipelines is 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.

2.2 Meteorological Data

A QRA study utilizes meteorological data that describe the range of conditions that could occur in the geographical area where the study is focused. The data must describe a range of conditions, as well as provide the frequency at which each condition occurs. Meteorological conditions are used in the consequence modeling for the QRA, influencing the dispersion of released HVLs and the impacts of a fire if the released materials are ignited.

For this study, hourly meteorological data for wind speed and wind direction for the Philadelphia area, for the years 2008-2018 (more than 143,000 data points) was obtained from the U.S. National Centers for Environmental Information (NCEI)[2]. A Pasquill-Gifford atmospheric stability class distribution was developed from this weather data. A summary of the meteorological data used in this study is presented in Figure 2-2 as wind rose data for all atmospheric stability classes. The length and width of a particular arm of the rose define the frequency and speed at which the wind blows from the direction the arm is pointing.

Interpreting the Wind Rose
Reviewing Figure 2-2 shows that the most common winds blow from westerly directions. For example, winds **from** the west-northwest (WNW) represent about 8% of all observations. Within that direction classification, lighter winds (0-3 and 4-6 knots classifications in the original data set) represent slightly less than 5% of the total observations.

Since the weather data is developed from data over many years, seasonal changes in wind magnitude, direction, etc., are already factored into the wind rose.

Annual average values of air temperature and relative humidity extracted from the NCEI data were applied to this analysis.

2 https://www.ncdc.noaa.gov/cdo-web/

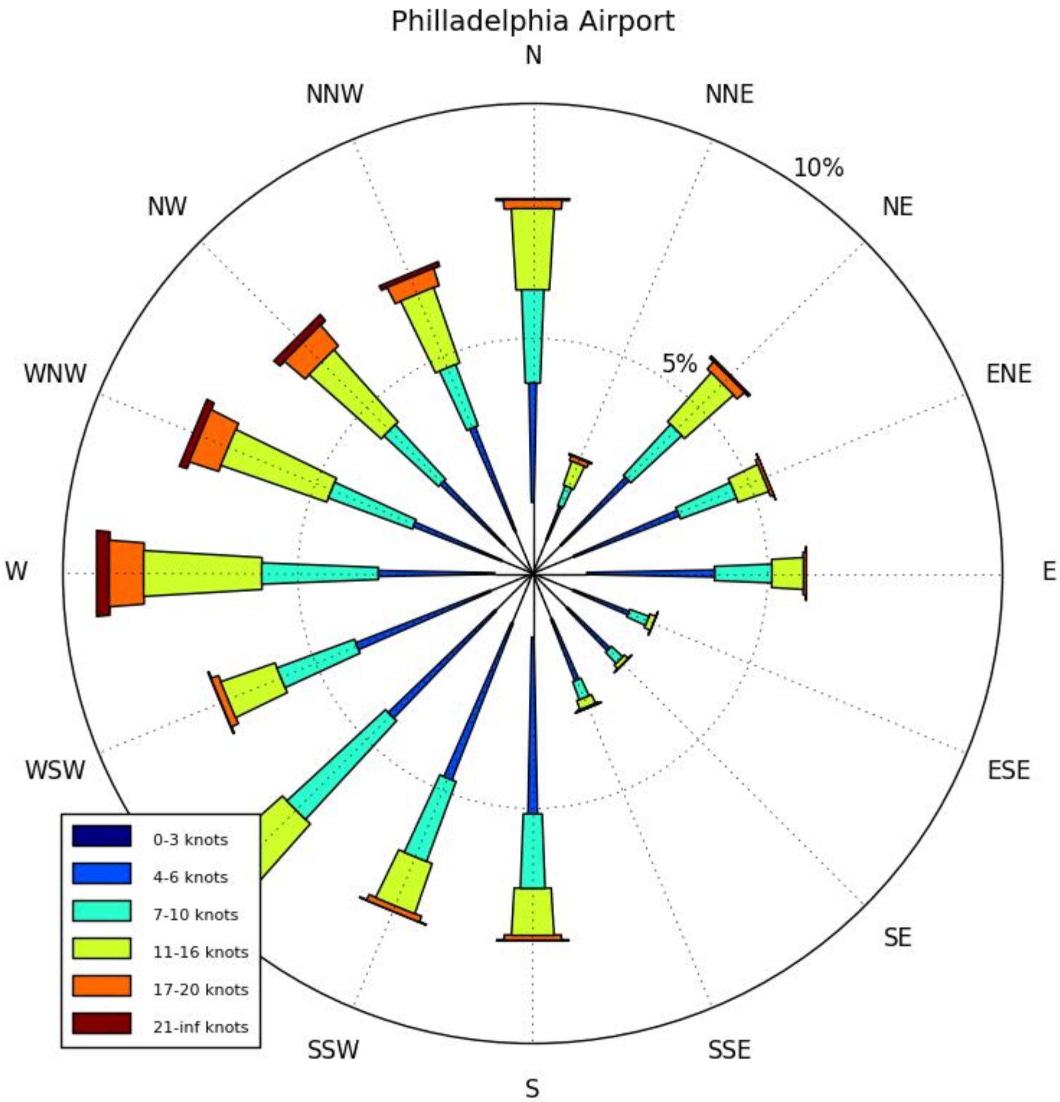

Figure 2-2
Wind Rose Data for All Stability Classes for the Chester/Delaware Counties Area
[Data from the Philadelphia Airport Weather Station 2008-2018]

3.0 FREQUENCIES AND PROBABILITIES

The quantification of risk involves determination of how often accidental (fatal) events might occur, in addition to defining their magnitude or area affected. For each portion of a system that could involve an accidental release of hazardous material, a numerical value of how often that may occur must be assigned.

3.1 Numerical Terminology

The risk that an individual is potentially fatally impacted as a result of events that could originate due to the pipeline can be represented by a numerical measure. This numerical measure represents the chance, or probability that an individual will be exposed to a fatal hazard during a year-long period. These numbers have their basis in the frequency of occurrence for accidental events.

For example, a value of one chance in 1,000,000 (one million) per year can be expressed in scientific notation as 1.0 x 10^{-6}/year (or 10^{-6} in shorthand notation). Table 3-1 lists the numerical value, the short-hand representation of that value as it is used in this report, and the value expressed in terms of chances per year.

Table 3-1
Frequency/Probability Terminology and Numerical Values

Numerical Value	Shorthand Notation	Chance
1.0 x 10^{-3}	10^{-3}	One chance in 1,000 per year
1.0 x 10^{-4}	10^{-4}	One chance in 10,000 per year
1.0 x 10^{-5}	10^{-5}	One chance in 100,000 per year
1.0 x 10^{-6}	10^{-6}	One chance in 1,000,000 per year
1.0 x 10^{-7}	10^{-7}	One chance in 10,000,000 per year
1.0 x 10^{-8}	10^{-8}	One chance in 100,000,000 per year

3.2 Buried Pipeline Releases

Data for the frequency of releases from a pipeline is available from the DOT/PHMSA[3]. PHMSA keeps a database for both natural gas pipelines and hazardous liquids pipelines. The HVL materials covered in this analysis fall into the liquids pipeline category.

To be compliant with PHMSA's regulations, pipeline operators must report the mileage of pipe they operate each year, as well as details concerning pipeline accidents (incidents) that may occur. A pipeline accident is defined as a failure of a pipeline and a release of hazardous liquid, where:

- There is an explosion or fire;
- There is a release of 5 gallons or more of a hazardous liquid (with some exceptions);
- The release results in the death of any person;
- The release causes a personal injury necessitating hospitalization; OR
- The estimated property damage, including clean-up, recovery, lost product, pipeline damage, and damage to other property, exceeds $50,000.

[3] https://www.phmsa.dot.gov/data-and-statistics/pipeline/source-data

Given these criteria, all pipeline releases of significance are required to be reported to PHMSA with supporting information so that the PHMSA database is complete.

Periodically, PHMSA changes the reporting criteria, such that the failures database cannot easily be combined with previous versions. The most recent database began service in 2010. Thus, it has eight full years of data (through 2017) that can be applied. For this work, that database was used, and has been considered sufficiently comprehensive and representative of pipeline failures that may occur in the near future.

Hazardous liquid pipeline releases were analyzed based on data from PHMSA from 2010-2017. In this time frame there were a total of 1,539,182 mile years of onshore hazardous liquid pipeline. Releases of hazardous liquids were filtered by the following methodology:

1. Incidents that only involved an intentional release of product (by the pipeline company) were removed;
2. Incidents that did not involve a release of hazardous liquid were removed;
3. Pipeline accidents that involved offshore (not land-based) pipelines were removed; and
4. Any pipeline accidents that involved above-ground equipment were removed (more information on this distinction is presented in Section 3.3).

With those constraints, there were found to be 986 accidental releases from buried, onshore pipelines.

Data for pipeline mileage was also downloaded from PHMSA. This set of data allows the generation of a failure rate per mile, which is what is required for QRA analyses.

Table 3-2 provides a summary of the PHMSA pipeline data that was considered in this analysis, as well as the calculated values of pipeline failures that result.

Table 3-2
2010-2017 PHMSA Liquids Pipeline Data and Resulting Event Frequencies: All Operators

Commodity	Releases	Total Mile Years of Pipeline	Release Rate Per Mile of Pipeline, Per Year	One Release for Every ___ Miles of Pipe Per Year
Biofuel / alternative fuel (including ethanol blends)	0	125	--	--
CO_2 (carbon dioxide)	17	40,203	4.23×10^{-4}	2,365
Crude oil	492	483,241	1.02×10^{-3}	980
HVL or other flammable or toxic fluid which is a gas at ambient conditions	184	510,305	3.61×10^{-4}	2,770
Refined and/or petroleum product (non-HVL) which is a liquid at ambient conditions	293	505,308	5.80×10^{-4}	1,725
Total liquids pipelines	986	1,539,182	6.41×10^{-4}	1,560

Based on the data presented above, the HVL-specific pipeline failure rates were selected for this analysis, as there is sufficient data to describe HVL pipelines as opposed to all hazardous liquids pipelines. To develop a numeric failure frequency (FF), the following is applied:

$$FF = \frac{Number\ of\ accidents}{Number\ of\ equipment\ years}$$

Example
The PHMSA database reported 184 HVL pipeline accidents in the 2010-2017 period. During that time, there were a total of 510,305 mile years of HVL pipe in service. Thus, $$FF_{HVL} = \frac{184\ accidents}{510{,}305\ mile\ years} = 0.00036057 = 3.61 \times 10^{-7}\ \frac{accidents}{mile\ year}$$

The same liquids pipeline database was also analyzed for accidents attributable to Sunoco (or related companies). While Sunoco has a significant history in crude oil and refined products pipelines, they began operating HVL pipelines in 2014. There was found to be insufficient numbers of buried pipeline accidents (many recent accidents have involved above-ground equipment), few miles of pipe, and only a few years of service for HVL pipelines. This does not provide a statistically significant data set to develop a failure rate for Sunoco HVL pipelines. Thus, for the Mariner pipelines in this analysis, the failure rate using industry-wide PHMSA data for HVL pipeline accidents and the associated mileage of pipelines, based on all operators, was applied.

3.3 Aboveground Equipment Releases

Pipeline valve stations were also evaluated in this analysis. While the data presented in the PHMSA database for liquids pipelines does record accidents involving equipment such as valves, tanks, fittings, and instrumentation, there are no equipment counts associated with these pieces of equipment. Following the formula in section 3.2, a value for the number of accidents could be found, but the number of equipment-years is not reported. For example, PHMSA does not collect the number of valves along the liquids pipeline, only the numbers of miles of pipe. Thus, there is insufficient data in the PHMSA pipeline accidents database to develop a failure rate for aboveground equipment such as valves, instrumentation connections, and gasketed joints.

To provide a failure frequency for the specific locations along the Mariner pipeline(s) where aboveground equipment exists, an alternate database must be applied. Data from the UK Health and Safety Executive (HSE) Hydrocarbon Release Database (HCRD)[4] for the years 2002 through 2012 were used to develop failure rates for each type of aboveground equipment. For each, the number of failures (and the corresponding release hole size), as well as the number of equipment-years of service were recorded. In addition to overall failure rates, it is also possible to derive a hole size distribution from the information presented in the HCR database. For the equipment types considered in this QRA, Table 3-3 presents the annual failure rates that were applied.

[4] HSE HCRD (2017), Hydrocarbon Releases System, Health and Safety Executive. https://www.hse.gov.uk/hcr3

Table 3-3
Failure Rate Data for Aboveground Equipment

Equipment	Annual Failure Rate
Flanged connections	2.58×10^{-5}
Instrument connections	3.84×10^{-4}
Valves	1.35×10^{-4}

3.4 Probability

The numbers presented in Sections 3.2 and 3.3 are frequencies of failures (that represent releases of hydrocarbon to the atmosphere) based on historical data. A QRA uses probabilities to describe risk. Some examples of often-used probabilities are:

- For a coin flip: the probability is ½ for "heads" for each flip
- Flooding: a "100-year flood" is equivalent to a 100-year recurrence interval, which means that flood has a probability of 1 in 100 for any given year (0.01 or 1.0×10^{-2} per year)
- For being struck by lightning, based on 27 deaths in 2015 within the U.S. population, the probability is about one chance in 11,904,370 per year (a probability 8.4×10^{-8} of per year)

In the QRA study, equipment failure frequencies are calculated from failure rate databases, as described in the previous sections. Failure frequencies only statistically describe how often a pipeline fails, but does not provide the probability needed to describe a complete scenario. Because of this, conditional probabilities must be applied to the analysis.

Conditional probabilities describe the chance (as a percentage between zero and 100) of something happening.

Example
Consider an event whose probability is one in ten per year (1.0×10^{-1} per year). If we are interested in how often that event may occur AND the day is sunny, we need a conditional probability. The probability of a sunny day in the Philadelphia area is 56.7% (207 sunny days per year[5]). This value is applied as a conditional probability to the original probability for a resulting probability of 5.67×10^{-2} per year, or one chance in about 18 per year.

The conditional probabilities, as percentages, for several variables were applied in this analysis are listed in Table 3-4. The conditional probabilities of the various release hole sizes were developed from the PHMSA liquids pipeline database.

[5] https://www.bestplaces.net/climate/city/pennsylvania/philadelphia

Table 3-4
Conditional Probabilities

Variable	Value	Conditional Probability (%)
Hole Size	¼ inch diameter	55
	¾ inch diameter	23
	2 inch diameter	12
	6 inch diameter	7
	Full Rupture	3
Release Orientation	Horizontal or near-horizontal (19° for buried lines[6])	50
	45°	25
	Vertical	25
Weather Conditions	Varies over 6 wind speeds, 6 atmospheric stability classes, 16 wind directions	See Section 2 and wind rose
Ignition	Immediate Ignition[7]	Varies based on release magnitude
	Delayed ignition[8]	Varies based on ignition sources encountered by flammable vapor cloud
	No ignition	Remainder

The final event probabilities applied in the QRA are then a combination of a release frequency (based on historical data) and modified by several conditional probabilities. In this QRA, there are thousands of unique events that are described by combinations of these variables.

Example
For a 2-inch diameter release from a one-foot length of HVL pipeline (see Section 3-2 and Table 3-4), oriented vertically, during stable atmospheric conditions with a 3 mph wind from the north results in a 1.18×10^{-11} per year probability. Expressed another way, there is 1 chance in 89,513,494,000 per year (89 billion) of this unique event happening.

Probabilities in the QRA are expressed as *annual* probabilities so that there is a common basis for the frequency and probability values. In addition, this allows comparison to other statistics and international or regulatory risk criteria, which are both expressed in annual terms (See also Section 5.0).

6 HSE (2009), Comparison of Risks from Carbon Dioxide and Natural Gas Pipelines. Prepared by the Health and Safety Laboratory for the Health and Safety Executive 2009. Research Report RR749.

7 TNO (1999), Guidelines for Quantitative Risk Assessment (First Edition), the Purple Book. CPR 18E, the Netherlands Organization for Applied Scientific Research, Committee for Prevention of Disasters, The Hague, Netherlands, 2005.

8 UKOOA (2006), Ignition Probability Review, Model Development and Look-Up Correlations, IP Research Report, January 2006.

4.0 POTENTIAL CONSEQUENCES

One of the primary tasks of a QRA is to define the hazards that are associated with a particular system or facility, as well as defining the potential extent of any impacts should an accidental release occur. The impacts are defined by consequence analysis, which describes the area that is potentially impacted.

4.1 Hazard Identification

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.

Potential releases of HVLs were considered for the Mariner East pipelines. Through the selection of a range of failure cases, the QRA involved the evaluation of many potential hazardous events. Each potential release may result in one or more of the following hazards:

1) Fatal exposure to thermal radiation following ignition of an HVL release, in the form of a jet fire, or in some cases, a pool fire;
2) Fatal exposure to a direct flame from the ignition of a flammable cloud (a flash fire, as defined by the extent of the lower flammable limit (LFL) of the released material as is disperses in air); or
3) Fatal exposure to a blast wave following the ignition of a flammable cloud and an explosion.

These three hazards can be explained further as follows, within the context of accidental releases of HVLs from a pipeline:

- 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 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 that back at 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.
- 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.

4.2 Consequence Analysis Models

Quest uses its proprietary software, CANARY by Quest®, for most consequence modeling.

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 vapor cloud explosion). 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 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 by Quest®) were reviewed in a United States Environmental Protection Agency (EPA) sponsored study[9] and an American Petroleum Institute (API) study[10]. 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)[11] 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.

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[9] TRC (1991), Evaluation of Dense Gas Simulation Models. Prepared for the U.S. Environmental Protection Agency by TRC Environmental Consultants, Inc., East Hartford, Connecticut 06108, EPA Contract No. 68-02-4399, May, 1991.

[10] Hanna, S. R., D. G. Strimaitis, and J. C. Chang (1991), Hazard Response Modeling Uncertainty (A Quantitative Method), Volume II, Evaluation of Commonly-Used Hazardous Gas Dispersion Models. Study cosponsored by the Air Force Engineering and Services Center, Tyndall Air Force Base, Florida, and the American Petroleum Institute; performed by Sigma Research Corporation, Westford, Massachusetts, September, 1991.

[11] Chang, Joseph C., Mark E. Fernau, Joseph S. Scire, and David G. Strimaitis (1998), A Critical Review of Four Types of Air Quality Models Pertinent to MMS Regulatory and Environmental Assessment Missions. Mineral Management Service, Gulf of Mexico OCS Region, U.S. Department of the Interior, New Orleans, November, 1998.

In addition, Quest has designed and published an explosion model called QMEFS (Quest model for estimation of flame speeds) to model vapor cloud explosions from confined and congested areas[12]. This model is contained within the CANARY consequence modeling package.

4.3 Physiological Effects of Fires and Explosions

This QRA performed on the Mariner East pipelines involved the evaluation of hundreds of 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 an explosion 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 (e.g., breaking windows) to human exposure to lethal thermal radiation (e.g., 37.5 kW/m^2 for five seconds).

In this study, risk is defined as the potential exposure of humans to lethal hazards (i.e., radiant heat or explosion blast wave) that have the potential to occur as a result of accidents originating along the pipeline route. The lethal exposure levels for the various hazards, considering the vulnerability of persons outdoors, are listed in Table 4-1. Table 4-2 lists the lethal exposure levels for the various hazards, considering the vulnerability of persons indoors.

Table 4-1
Consequence Analysis Lethal Exposure Levels – Outdoors Exposure

Hazard	Fatality Endpoints
Thermal radiation from a jet fire or pool fire, assuming a 30 second exposure time[13]	1% fatality – 7.28 kW/m^2 50% fatality – 14.4 kW/m^2 99% fatality – 28.4 kW/m^2
Exposure to an ignited flammable gas cloud[14]	100% fatality – for persons outdoors and within a flammable vapor cloud (as defined by the LFL) 0% fatality – for persons outside of the flammable vapor cloud
Overpressure from a blast wave following a vapor cloud explosion	1% fatality – 2.4 psi 50% fatality – 13.1 psi 99% fatality – 72.0 psi

In all cases, the hazard effects are 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.

Injury effects may result in larger impact zones than are predicted for fatality effects. However, this study did not evaluate injury impacts.

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[12] Marx, J.D. and B.R. Ishii (2017), "Revisions to the QMEFS Vapor Cloud Explosion Model". 2017 AIChE Spring Meeting & 13th Global Congress on Process Safety, San Antonio, TX, March 26 29, 2017.

[13] Tsao, C. K., and W. W. Perry (1979), Modifications to the Vulnerability Model: A Simulation System for Assessing Damage Resulting from Marine Spills. U.S. Coast Guard Report CG-D-38-79, Washington, D.C., March, 1979.

[14] TNO (1999), Guidelines for Quantitative Risk Assessment (First Edition), the Purple Book. CPR 18E, The Netherlands Organization for Applied Scientific Research, Committee for the Prevention of Disasters, The Hague, Netherlands, 1999.

Table 4-2
Consequence Analysis Lethal Exposure Levels – Indoors Exposure

Hazard	Fatality Endpoints
Thermal radiation from a jet fire or pool fire[15]	Above 25 kW/m^2 – 100% fatality Below 25 kW/m^2 – 0% fatality
Infiltration of a flammable gas cloud into a building[16]	100% fatality – for indoors gas concentration reaching the lower flammable limit
Building damage from an overpressure blast wave following a vapor cloud explosion[17]	1% fatality – 0.88 psi 50% fatality – 2.6 psi 99% fatality – 5.9 psi

4.4 Releases from Buried Piping

For all releases from conventionally buried piping, it was assumed that the pipe was located at a 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, where the minimum angle is set at 19° (see Table 3-4).

4.5 HDD Sections

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 will manifest itself. Thus, the hazards for every HDD section were located at the entry or exit points, with each point receiving a probability of release equal to that of a length of pipe that is half of the HDD distance.
- At the entry and exit points, the HDD releases were modeled identically to those along the conventionally buried sections.

This approach effectively assumes that the released HVL (following a failure of the pipeline within the HDD zone) will follow the path of least resistance to the surface. While it is possible for the released material to follow geological fissures or other natural conduits, the pipeline borehole is viewed as the "easiest" path to the surface.

[15] HSE (2011), "Indicative Human Vulnerability to the Hazardous Agents Present Offshore for Application in Risk Assessment of Major Accidents". Health and Safety Executive, Version No. 3, SPC/Tech/OSD/30, November 1, 2010.
[16] TNO Green Book (1989), Methods for the Determination of Possible Damage to People and Objects Resulting from Releases of Hazardous Materials. The Netherlands Organization of Applied Scientific Research, Voorburg, The Netherlands, December, 1989.
[17] DOD (2009), "Approved Methods and Algorithms for DOD Risk-Based Explosives Siting". Technical Paper No. 14, Revision 4. Department of Defense Explosives Safety Board, Alexandria, VA, July 21, 2009.

4.6 Release from Aboveground Equipment

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. See Table 3-4.

4.7 Parametric Analysis

In order to better understand the maximum hazards that could be present in the Chester and Delaware County areas, a parametric study of pipeline parameters was conducted. This served to explore the conditions that were important and, perhaps, those that were not, with the end goal of simplifying the analysis to the point where a representative set of conditions was applied to produce, in general, larger impacts. Table 4-3 presents the parametric study results.

Table 4-3
Consequence Analysis Parametric Study

Parameter	Variants	Finding
Ambient Conditions	Annual average (57°F. 63% R.H.) Summer (77°F. 61% R.H.) Winter (37°F. 65% R.H.)	Small differences between these options; annual averages applied
Distance along pipeline from pump station	70, 78, 84, 90 miles	Consequences decrease as distance from pump station increases; 5% variance in results over these distances; 78 miles applied as the base case (approximately the distance from the pump station to Chester-Delaware county line)
Pumping discharge pressure	1480 (MOP), 1400, 1600, 1200, 1100, 1000 psig	Consequences decrease as pump discharge pressure increases; used MOP as the base case
Transported material	Ethane, propane, butane	Propane creates the largest consequences
Release angle	15° to 90° from horizontal in 5° increments	Consequences decrease as release angle increases; 3 angles applied, see Section 3
Pumped flow rate (ME2, propane)	275, 250, 225, 200, 150, 100, & 50 thousand barrels per day (bpd)	Very little difference in consequences between the various flow rates; applied 275,000 bpd as the base case
Pumped flow rate (ME2X, propane)	Iterative variance	170,000 bpd was found to be the approximate maximum sustainable flow rate
Pumped flow rate (ME1, propane)	Iterative variance	40,000 bpd was found to be the approximate maximum sustainable flow rate

4.8 Maximum Hazard Distances

The range of hazard distances achieved by potential flash fires, jet fires, and pool fires following releases from the Mariner East pipelines are presented in the following tables. 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)

As an example, consider the ME2 (20") buried pipeline transporting propane. Table 4-4 shows the range of results for a leak from the pipeline (modeled as a ¼-inch diameter hole); Table 4-5 provides the results for a 2-inch diameter hole, and Table 4-6 provides the results for a pipeline rupture. (3/4-inch diameter and 6-inch diameter holes were also modeled, but are not shown in these tables.) These represent the maximum hazard distances for the presented hole sizes, given a near-horizontal release from a buried pipeline.

Table 4-4
Maximum Hazard Zone Distances for a Leak from the Buried ME2 Pipeline Transporting Propane

Wind Speed [mph]	Maximum Downwind Distance of Hazard Zone [feet]							
	Flammable Vapor Cloud (LFL)						Immediate Ignition Jet Fire	Delayed Ignition Jet Fire
25			<5	7			55	55
23			<5	7			55	55
16			7	10			55	55
10		<5	7	13	<5		59	59
6	7	7	10	80	85	90	62	62
2	45	45	95	80		120	62	62
Stability Class:	A	B	C	D	E	F		

Note: existing wind speed/stability combinations are enclosed by the heavy line.

Table 4-5
Maximum Hazard Zone Distances for a 2-inch Diameter Hole in the Buried ME2 Pipeline Transporting Propane

Wind Speed [mph]	Maximum Downwind Distance of Hazard Zone [feet]							
	Flammable Vapor Cloud (LFL)						Immediate Ignition Jet Fire	Delayed Ignition Jet Fire
25			35	55			345	345
23			35	55			345	345
16			45	70			355	355
10		35	60	85	510		365	365
6	50	50	75	515	815	900	380	380
2	415	430	690	845		1,090	385	385
Stability Class:	A	B	C	D	E	F		

Note: existing wind speed/stability combinations are enclosed by the heavy line.

Table 4-6
Maximum Hazard Zone Distances for a Rupture of the Buried ME2 Pipeline Transporting Propane

Wind Speed [mph]	Maximum Downwind Distance of Hazard Zone [feet]							
	Flammable Vapor Cloud (LFL)						Immediate Ignition Jet Fire	Delayed Ignition Jet Fire
25			95	150			915	675
23			100	155			920	680
16			120	185			940	700
10		100	155	985	1,600		1,005	725
6	405	130	1,035	1,425	1,850	1,980	1,055	750
2	1,040	1,085	1,410	1,650		2,115	1,055	750
Stability Class:	A	B	C	D	E	F		

Note: existing wind speed/stability combinations are enclosed by the heavy line.

A summary of the maximum 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 4-7. As seen in Table 4-7, the 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.

Table 4-7
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 hazard distance is illustrated in Figure 4-1. 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.

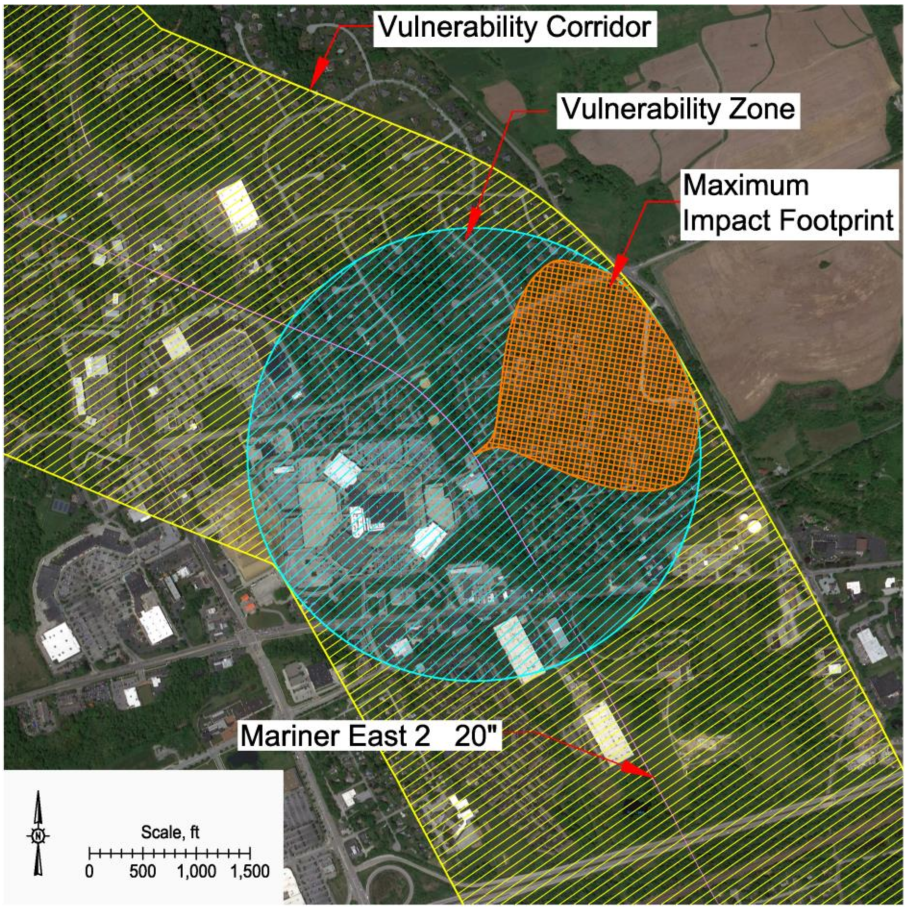

Figure 4-1
Maximum Hazard Footprint, Vulnerability Zone, and Vulnerability Corridor for a Rupture of the ME2 Pipeline - Chester County Library Area

5.0 RISK

This section presents the results of the quantitative risk analysis. The QRA was set up to calculate the annual probability of fatality to an individual, based on their proximity to the pipeline(s). The calculated level of fatality risk can then be compared to a set of statistical values of fatality risk and several available international criteria that have been used in determining the acceptability of public fatality risk.

Many of our everyday decisions involve an analysis or assessment of risk, although most of them do not involve issues of fatality. But for those that do, and those that might involve injury, everyone tolerates some risk in their lives.

Definition
Tolerable Risk – A level of risk deemed acceptable by society. Typically an increase in risk is associated with some particular benefit or functionality. Sometimes higher levels of risk may be tolerated given that the risk has been evaluated and is being managed.

5.1 Risk Presentation

Once each release event has been fully assessed (frequency of occurrence and consequences of that occurrence), the results can be presented in a concise manner. The risks due to all possible unique accidents can be combined to produce a measure of risk to the public in the surrounding area. The combined risk is graphically presented in the form of location specific individual risk (LSIR) contours. Risk contours define the summation of all hazard zones for each unique accident combined with their respective probabilities as a function of location around the pipeline(s). A contour line represents a specific risk value and bounds an area of magnitude. For example, the calculated contour associated with a one-in-one million per year (or 10^{-6}) risk defines the locations of 1.0 x 10^{-6} per year risk.

If a risk level such as 1.0 x 10^{-6}/year is predicted to occur at a location due to all potential releases from the pipeline, the risk level represents the annual chance of fatality, assuming continuous occupancy.

Definition
Continuous Occupancy – The presence of an individual at a location 24 hours per day, 365 days per year

All risk measures in this study assume continuous occupancy, even though it is understood that most persons in the vicinity of the Mariner East pipelines will not be at one location near to the pipeline 24 hours a day, for 365 days in a year. If a given person's presence cannot be defined as continuous occupancy, that person's risk is reduced when they are not present.

5.2 Study Results

The risk contours for the Mariner East pipelines are presented graphically for the following locations:

- Glenwood Elementary School area – The Mariner East pipeline route that passes approximately 600 feet from the school's playground area (and further from the school buildings), and includes one pipeline valve site as well as HDD segments to the north and south.

- Chester/Delaware County line area – The Mariner East pipeline route near the county line which is characterized by rural residences, a neighborhood, a local restaurant in close proximity to a pipeline valve site, and HDD segments of the pipeline.
- Chester County Library area – The segment of the Mariner East pipeline route in Exton that passes adjacent to the library, and close to residential and commercial areas including the Exton mall.

In each case, the risk to the public is based on continuous occupancy (persons assumed to be in the area 24 hours per day, 365 days per year). The following figures are presented along with a short interpretation of the risk.

- Figure 5-1 – Glenwood Elementary School area, ME2 pipeline, continuous outdoor exposure
- Figure 5-2 – Glenwood Elementary School area, ME2 pipeline, continuous indoor exposure
- Figure 5-3 – Chester/Delaware County line, ME1 pipeline, continuous outdoor exposure
- Figure 5-4 – Chester/Delaware County line, ME1 pipeline, continuous indoors exposure
- Figure 5-5 – Chester/Delaware County line, ME1 + ME2 pipelines, continuous outdoor exposure
- Figure 5-6 – Chester/Delaware County line, ME1 + ME2 pipelines, continuous outdoor exposure
- Figure 5-7 – Chester County Library area, ME1 pipeline, continuous outdoor exposure
- Figure 5-8 – Chester County Library area, ME1 pipeline, continuous indoor exposure
- Figure 5-9 – Chester County Library area, ME1 + ME2 + ME2X, continuous outdoor exposure
- Figure 5-10 – Chester County Library area, ME1 + ME2 + ME2X, continuous indoor exposure

The risk contours illustrate the annual fatality risk to persons near the pipeline as a function of their distance from the pipeline. Any level of risk shown by a risk contour is the risk of fatal exposure to hazards associated with all the pipeline release scenarios. For example, the contour labeled 1.0×10^{-6} in Figures 5-1 through 5-10 represents one chance in one million per year, for a person either outdoors or indoors, 100% of the year, being exposed to a fatal hazard from the possible releases of flammable material from the Mariner East 1, 2, or 2X pipelines, or combinations of these pipelines.

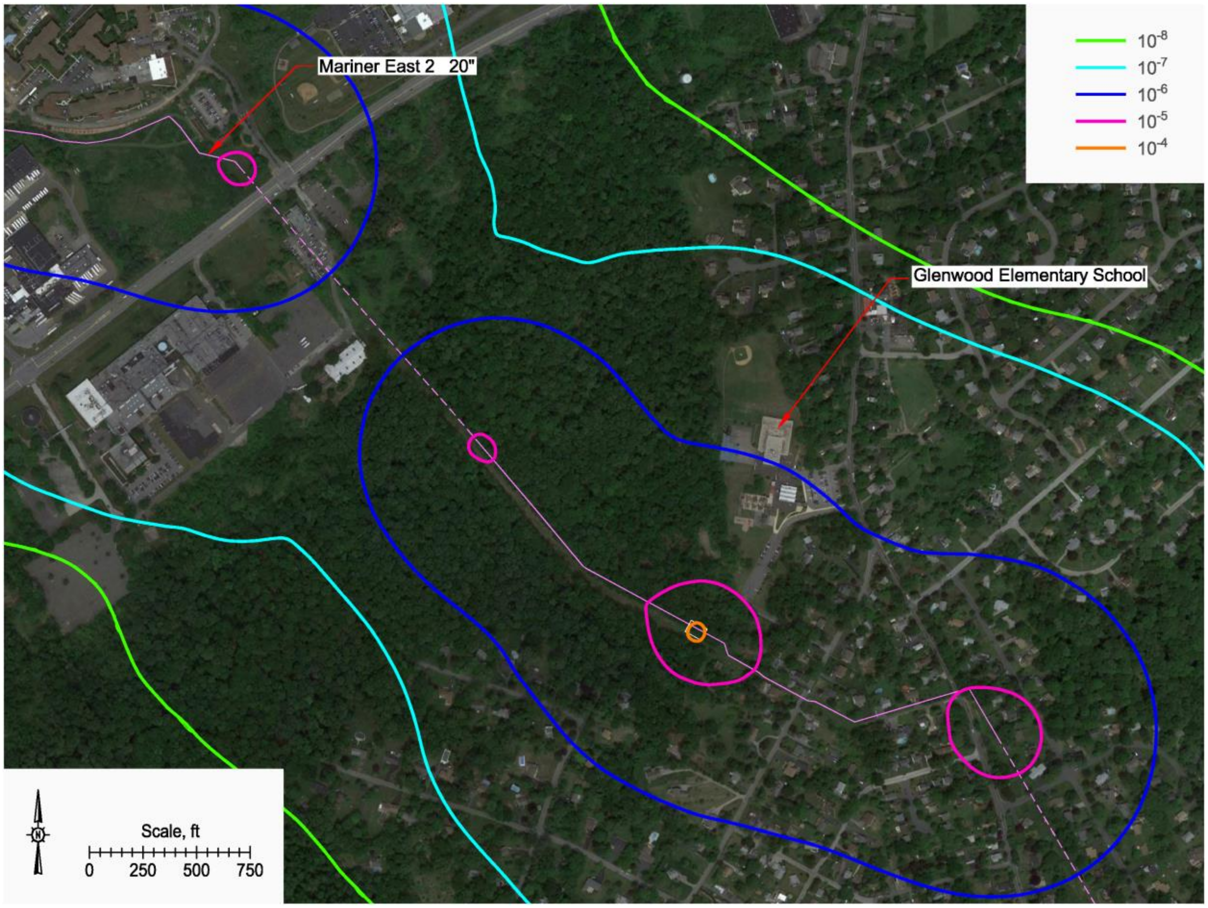

Figure 5-1
Risk Contours for the *Outdoor* Public Due to the Mariner East 2 Pipeline Transporting Propane Glenwood Elementary School Area

Interpreting the Results – ME2, Glenwood Area, Outdoor
In Figure 5-1, the area directly above the pipeline valve site (near the center of the picture) is predicted to have an individual fatality risk level of about 1.0 x 10^{-4} per year, assuming continuous occupancy (the orange contour in the plot). This is equivalent to a chance of fatality of one in ten thousand per year, assuming a person stays in that location 24 hours/day, 364 days/year. The risk is at or above 1.0 x 10^{-5} per year near the HDD entry/exit points (the magenta contours in the plot; one chance in one-hundred thousand per year), and less than 1.0 x 10^{-6} per year (one chance in one million per year) above the HDD sections (the dashed line portion of the pipeline path). Outdoor risk at Glenwood Elementary school is approximately 1.0 x 10^{-6} per year (one chance in one million per year).

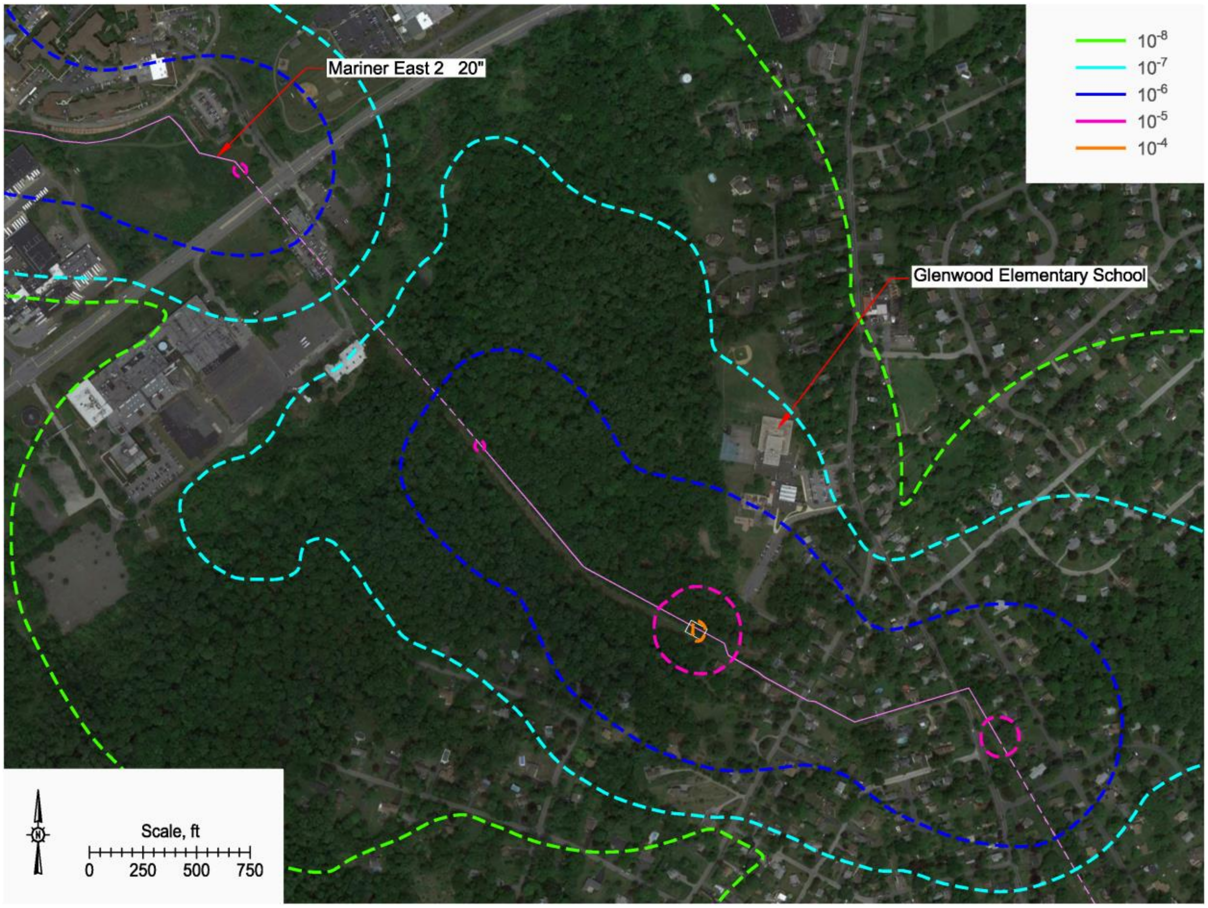

Figure 5-2
Risk Contours for the *Indoor* Public Due to the Mariner East 2 Pipeline Transporting Propane
Glenwood Elementary School Area

Interpreting the Results – ME2, Glenwood Area, Indoor
In Figure 5-2, the fatality risk contours are ONLY applicable to persons who are indoors, and so are only truly representative where there are buildings. Indoor risk at Glenwood Elementary school is less than 1.0 x 10^{-6} per year (one chance in one million per year) assuming a person stays in that location 24 hours a day, 364 days per year. The risk contours extend further in forested areas due to the potential for damaging vapor cloud explosions.

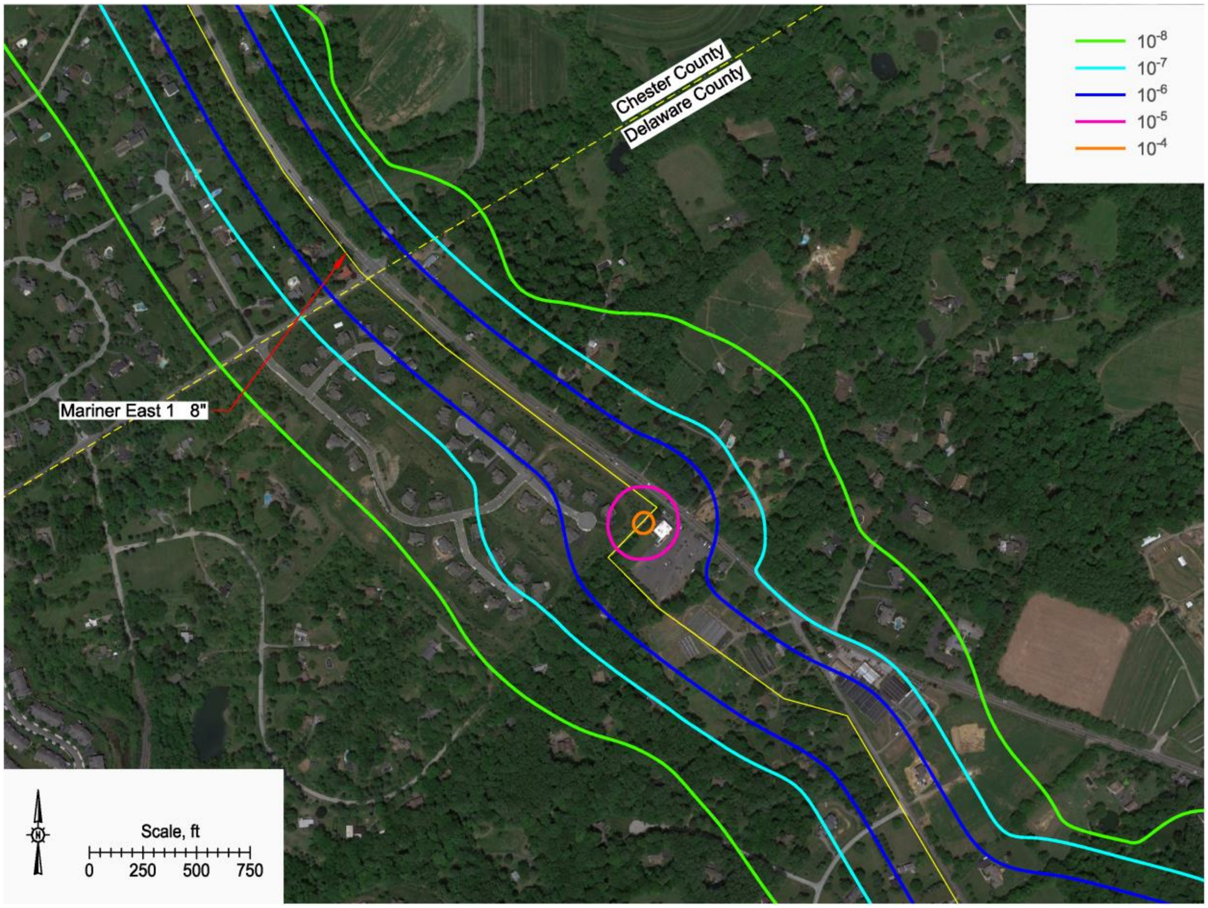

Figure 5-3
Risk Contours for the *Outdoor* Public Due to the Mariner East 1 Pipeline Transporting Propane Chester/Delaware Counties Line Area

Interpreting the Results – ME1, Counties Line Area, Outdoor
In Figure 5-3, this is the outdoor fatality risk that exists now in this area, because the ME1 pipeline is in place and operating. The area directly above the pipeline valve site (near the center of the picture) is predicted to have an individual risk level of about 1.0 x 10^{-4} per year, assuming continuous occupancy (the orange contour in the plot), with a slightly larger area of risk at a level of 1.0 x 10^{-5} per year (the magenta contour in the plot). Above the buried pipeline route, the risk is slightly greater 1.0 x 10^{-6} per year (the blue contours), and diminishes to less than 1.0 x 10^{-8} per year (the green contours) within about 800 feet.

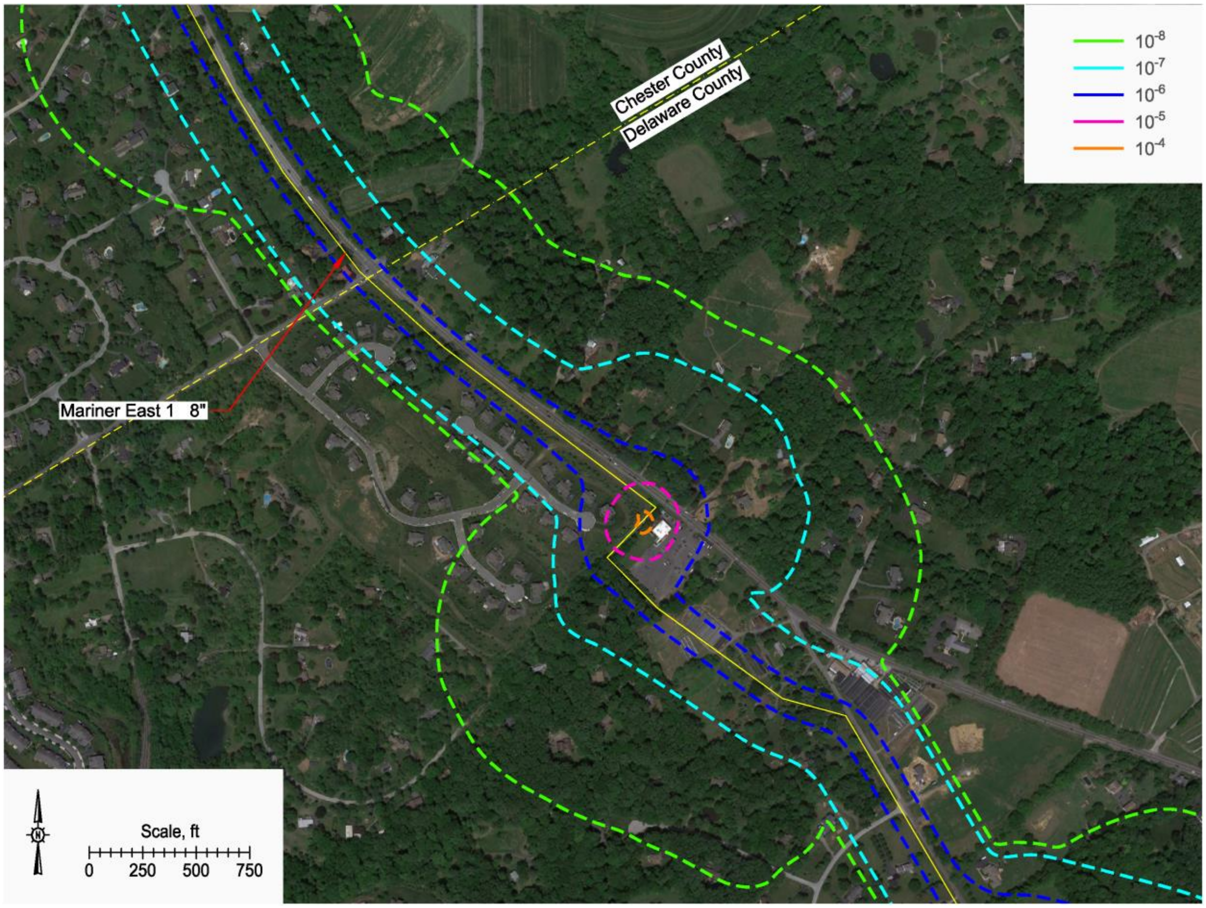

Figure 5-4
Risk Contours for the *Indoor* Public Due to the Mariner East 1 Pipeline Transporting Propane Chester/Delaware Counties Line Area

Interpreting the Results – ME1, Counties Line Area, Indoor
In Figure 5-4, this is the indoor fatality risk that exists now in this area, because the ME1 pipeline is in place and operating. The area directly above the pipeline valve site shows a higher level of risk, and is somewhere between 1.0 x 10^{-4} and 1.0 x 10^{-5} per year at Duffers Tavern (the restaurant/bar directly east of the pipeline valve site). Along the buried pipeline route, the indoor risk is less than that predicted for outdoors, except in specific locations where there are significant forested areas. However, the indoor risk is generally less than 1.0 x 10^{-6} per year (one chance in one million per year, the blue contours) at most indoor locations along the ME1 pipeline route.

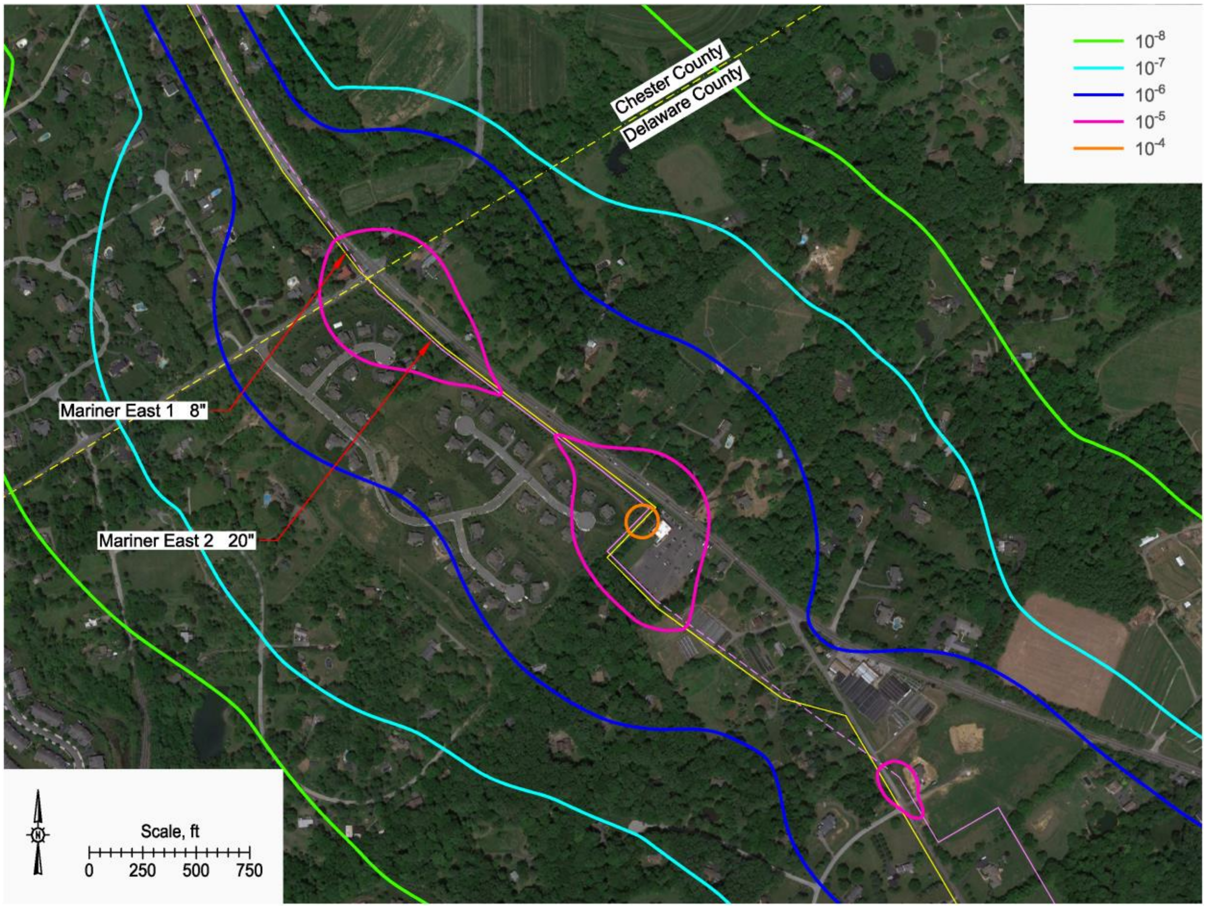

Figure 5-5
Risk Contours for the *Outdoor* Public Due to the Mariner East 1 and 2 Pipelines (Propane)
Chester/Delaware Counties Line Area

Interpreting the Results – ME1 + ME2, Counties Line Area, Outdoor
Figure 5-5, demonstrates the outdoor fatality risk that exists now in this area, plus the risk due to a release from the ME2 pipeline once it is in operation. Due to two pipelines operating, all areas above the pipeline experience a risk greater than 1.0 x 10^{-6} per year (one chance in one million per year, the blue contours). Elevated risk of 1.0 x 10^{-5} per year or greater (one chance in one hundred thousand per year) is found in broad areas around the pipeline valve site as well as areas around the HDD entry/exit points (the magenta contours). The HDD segments apply only to the ME2 pipeline and are shown as dashed lines along the pipeline route.

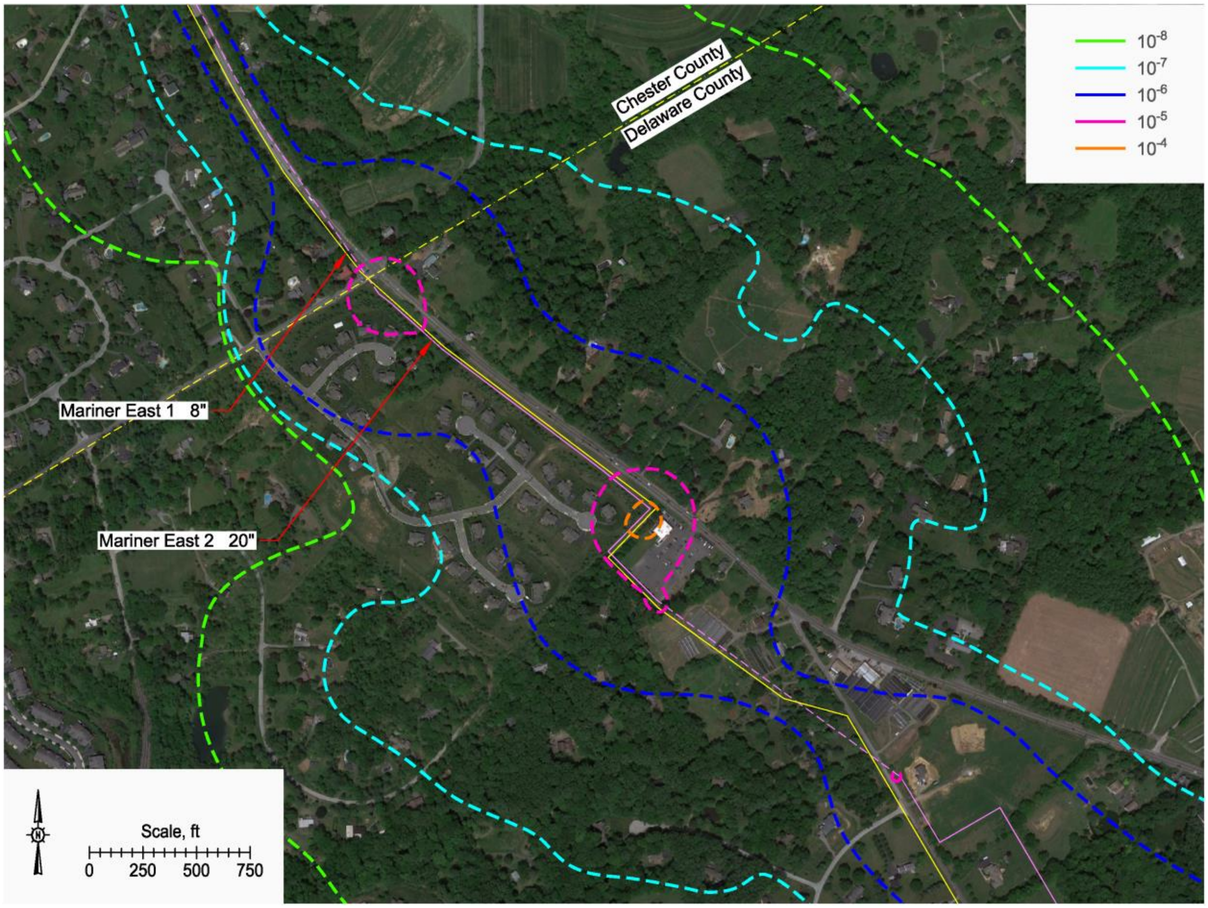

Figure 5-6
Risk Contours for the *Indoor* Public Due to the Mariner East 1 and 2 Pipelines (Propane) Chester/Delaware Counties Line Area

Interpreting the Results – ME1 + ME2, Counties Line Area, Indoor
Figure 5-6 shows that the pipeline valve site, when two pipelines are operating, imposes a fatality risk of 1.0 x 10^{-4} at Duffers Tavern (the restaurant/bar directly east of the pipeline valve site). Along the remainder of the pipeline route, the indoor risk shows pockets of 1.0 x 10^{-5} per year around the valve station and HDD entry/exit points. In specific locations where there are significant forested areas, the risk to indoors persons is often greater than outdoor, but in most cases the areas of greater risk are in the range of 1.0 x 10^{-7} to 1.0 x 10^{-8} per year.

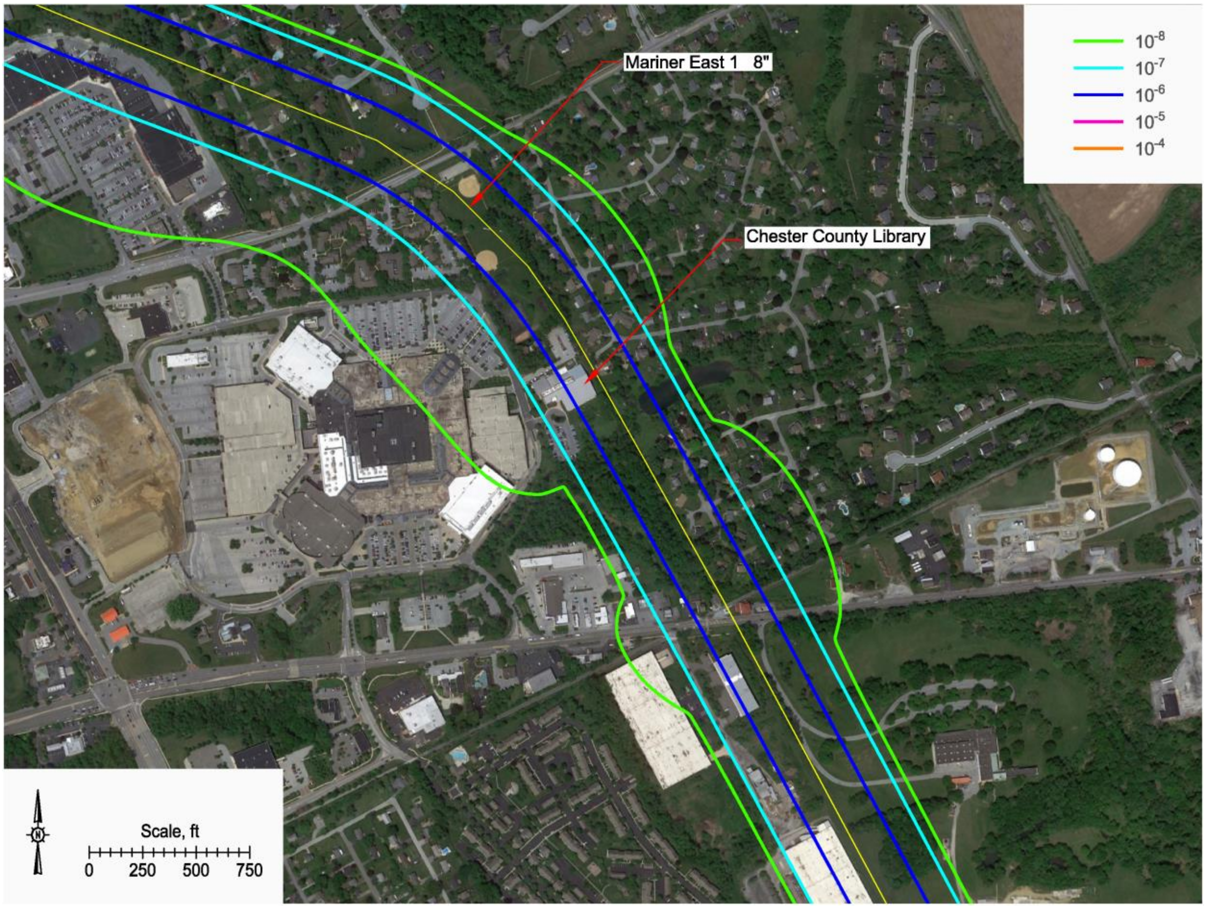

Figure 5-7
Risk Contours for the *Outdoor* Public Due to the Mariner East 1 Pipeline (Propane)
Chester County Library Area

Interpreting the Results – ME1, Chester County Library Area, Outdoor
The risk shown in Figure 5-7 is the outdoor fatality risk that exists now in this area, because the ME1 pipeline is in place and operating. Above the buried pipeline route, the risk is slightly greater 1.0 x 10^{-6} per year (the blue contours), and diminishes to less than 1.0 x 10^{-8} per year (the green contours) within about 600 feet. In some areas, this distance is greater due to higher density of potential ignition sources.

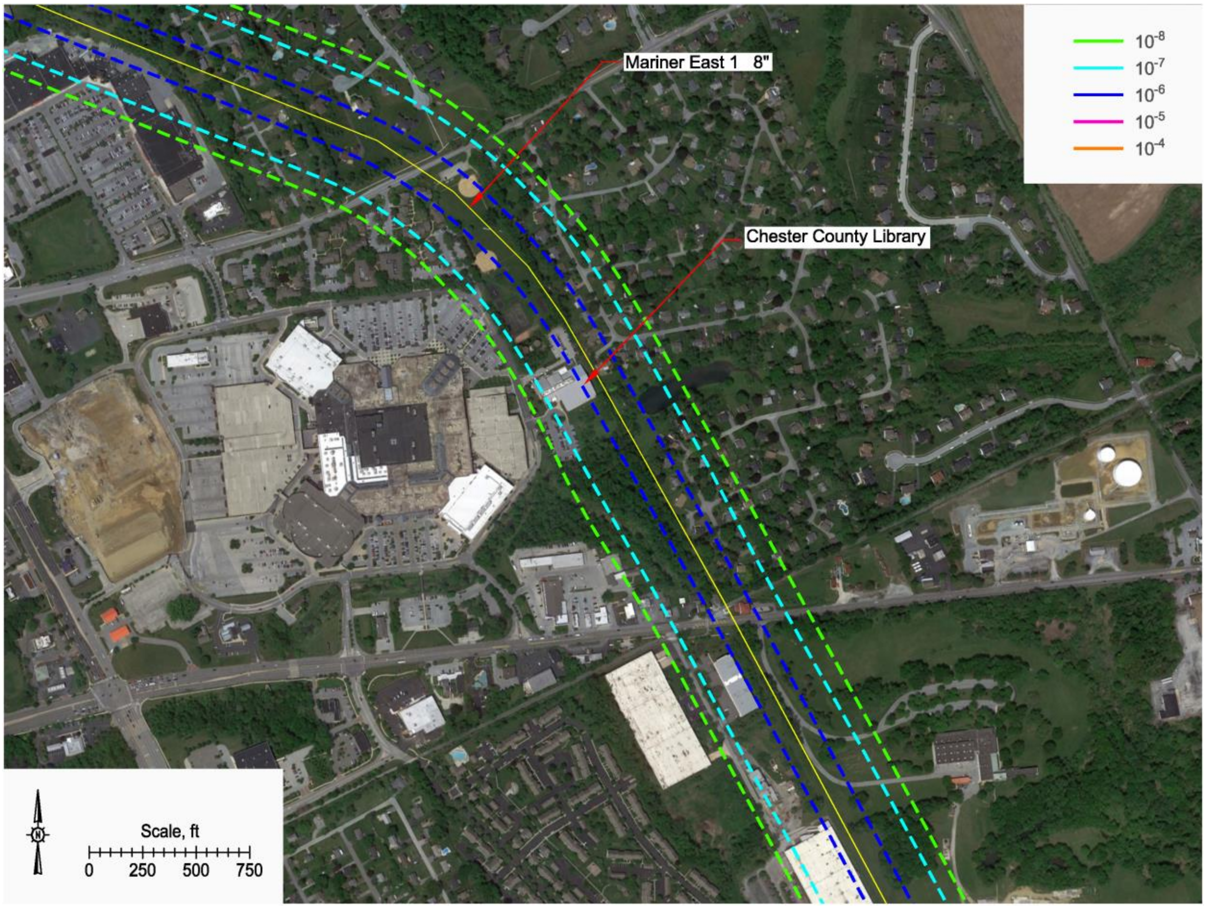

Figure 5-8
Risk Contours for the *Indoor* Public Due to the Mariner East 1 Pipeline (Propane)
Chester County Library Area

Interpreting the Results – ME1, Chester County Library Area, Indoor
The risk shown in Figure 5-8 is the indoor fatality risk that exists now in this area, because the ME1 pipeline is in place and operating. Above the buried pipeline route, the risk is slightly greater 1.0 x 10^{-6} per year (the blue contours), and diminishes to less than 1.0 x 10^{-8} per year (the green contours) within about 350 feet. The risk to persons inside the Chester County Library is approximately 1.0 x 10^{-6} per year (one chance in one million per year of fatality, assuming continuous occupancy).

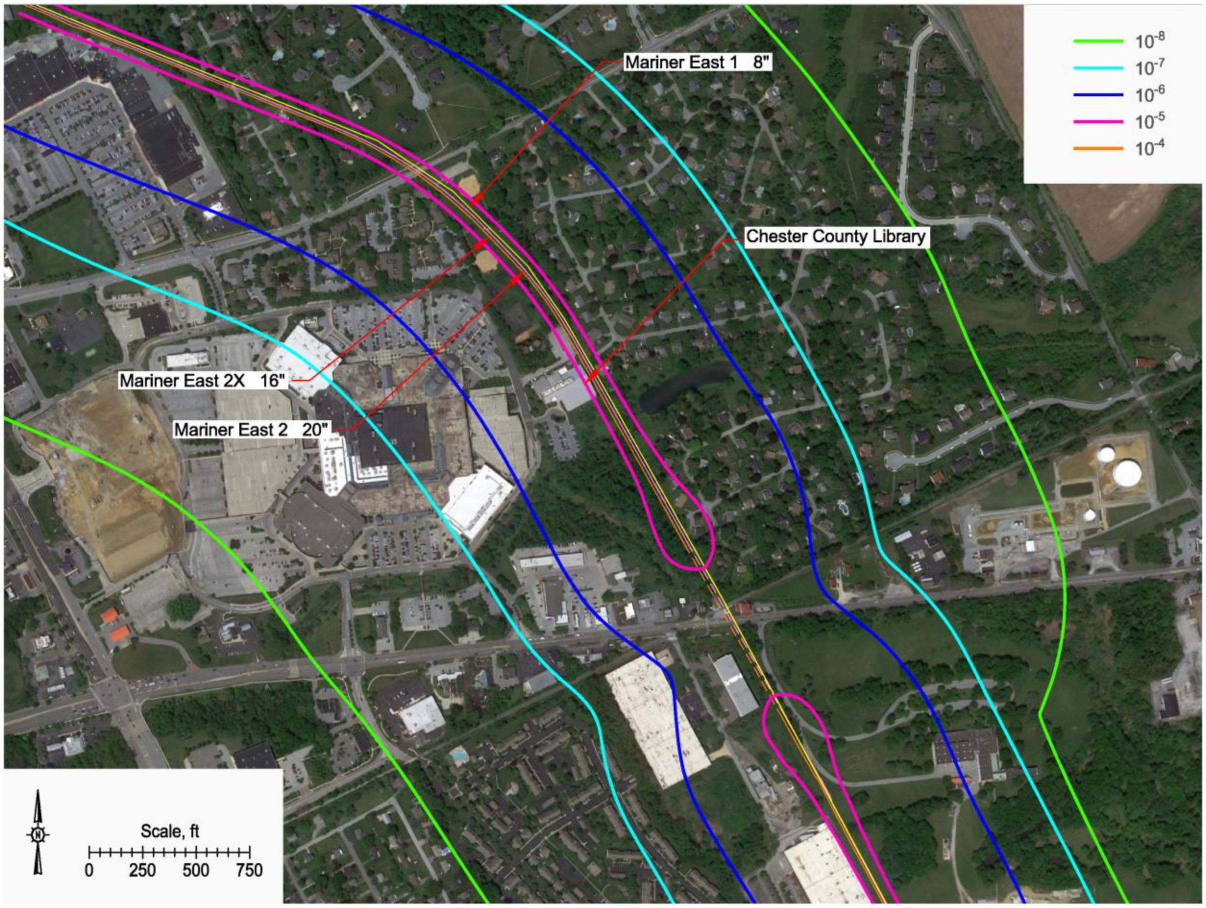

Figure 5-9
Risk Contours for the *Outdoor* Public Due to the Mariner East 1, 2, and 2X Pipelines
Chester County Library Area

Interpreting the Results – ME1 + ME2 + ME2X, Chester County Library Area, Outdoor
The risk shown in Figure 5-9 is the outdoor fatality risk that may exist in the future due to the existing ME1 pipeline, the ME2 pipeline, <u>and</u> the ME2X pipeline. Along the buried pipeline route, the risk is slightly greater 1.0 x 10^{-5} per year (the magenta contours), and diminishes to less than 1.0 x 10^{-8} per year (the green contours) within about 1,500 feet from the pipeline. There is slightly elevated risk at the HDD entry/exit points. There is slightly less risk above the pipeline route where the ME2 and ME2X pipelines are to be installed as HDD segments (the ME1 is still a conventional buried line in this segment).

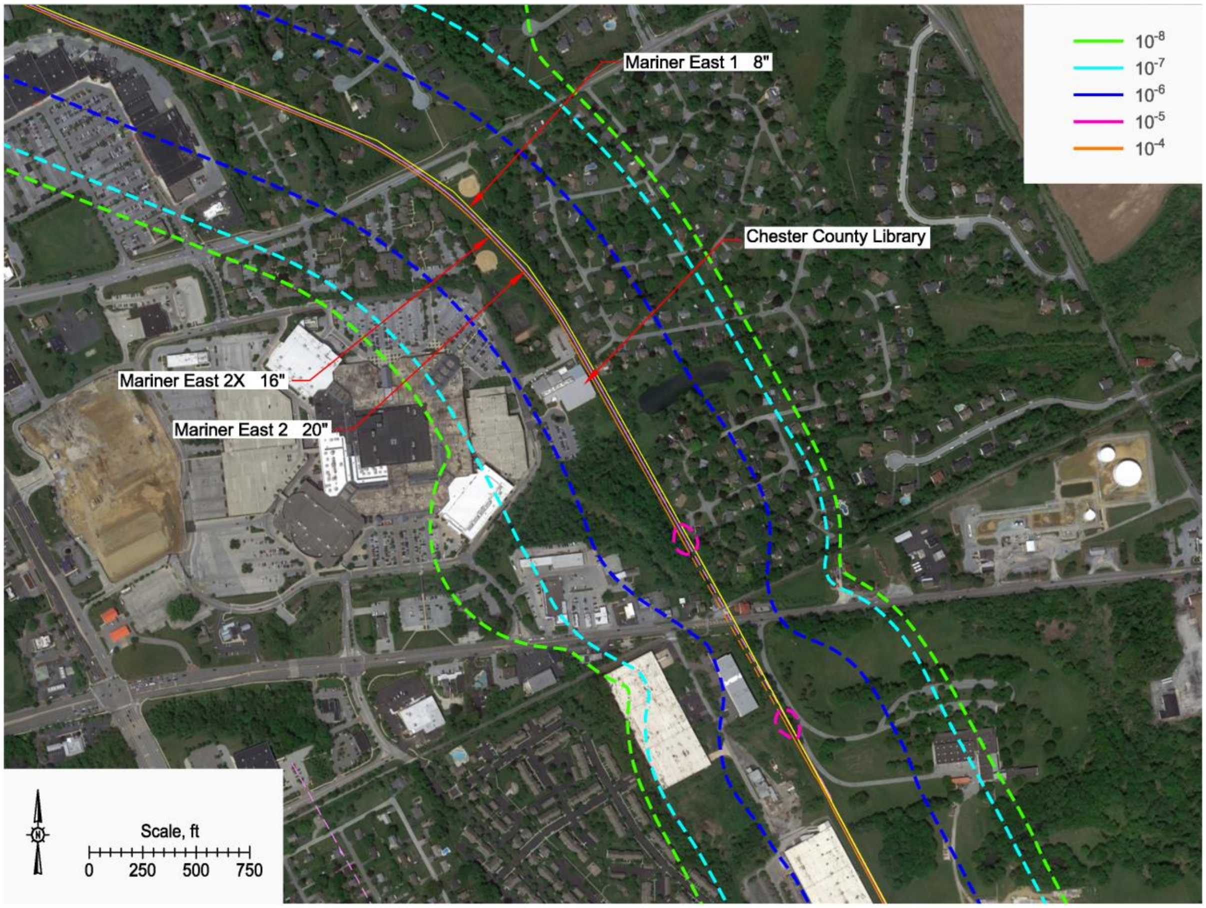

Figure 5-10
Risk Contours for the *Indoor* Public Due to the Mariner East 1, 2, and 2X Pipelines
Chester County Library Area

Interpreting the Results – ME1 + ME2 + ME2X, Chester County Library Area, Indoor
The risk shown in Figure 5-10 is the indoor fatality risk that may exist in the future due to the existing ME1 pipeline, the ME2 pipeline, <u>and</u> the ME2X pipeline. Along the buried pipeline route, the risk above 1.0 x 10^{-6} per year (the blue contours), but less than 1.0 x 10^{-5} per year, and diminishes to less than 1.0 x 10^{-8} per year (the green contours) within about 800 feet from the pipeline. There is slightly elevated risk at the HDD entry/exit points (1.0 x 10^{-5} per year, the magenta contours). The risk to persons inside the Chester County Library is greater than 1.0 x 10^{-6} per year (one chance in one million per year of fatality), but less than 1.0 x 10^{-5} per year assuming continuous occupancy.

5.3 Risk Acceptability (Tolerability) Criteria

A number of regulatory and research-based bodies have promulgated or suggested fatality risk tolerance levels for individual risk (location specific risk). While the risk tolerance levels are, in many cases, different, the objectives of all measures show consistent trends. For individual risk the following is assumed, although not stated in most regulations.

- The risk is defined as location specific individual risk.
- For the calculated individual risk value to be valid, a person must be at the stated location 365 days/year, and 24 hours/day.

Due to these issues, the risk value calculated is always higher than it would be if occupancy rates and times spent indoors and outdoors were to be factored in. This is one reason the risk methodology is called location specific individual risk (LSIR), since it is the risk to humans continuously present at a location.

With these caveats in mind, there are several definitions of acceptable individual risk values. Some of these are presented in Table 5-1. It should be noted that several of the agencies or code making bodies have used two risk criteria to define tolerability. Intolerable risk defines a level of risk where it and anything greater is deemed to be unacceptable. Negligible public risk defines the tolerable level of risk where any risk level lower than this value is acceptable.

5.4 Conservatism Built Into the Risk Analysis Study

As with any consequence or risk analysis study, assumptions and engineering approximations are made in order to calculate the risk associated with the pipeline. In general, assumptions are made that tend to overpredict the risk due to releases from the pipelines. Thus, Quest believes that the predictions of risk presented in this report are conservative – in other words, they show the risk to be higher than it really may be.

Table 5-1
Individual Risk Criteria

Country	Intolerable Public Risk	Negligible Public Risk	Notes
Abu Dhabi[18]	$1\ (10)^{-4}$	$1\ (10)^{-6}$	Abu Dhabi sets a "benchmark" for IR for the public at all installations is $1\ (10)^{-5}$. "Benchmark" is defined as "the overall IR level which project teams should aim for."
Canada[19]	$1\ (10)^{-4}$	$1\ (10)^{-6}$	No other land use within $1\ (10)^{-4}$ fatality/year contour
			Manufacturing facilities, warehouses and open spaces within $1\ (10)^{-5}$ contour
			Commercial uses, offices, and low density residential areas within $1\ (10)^{-6}$
			For risk lower than $1\ (10)^{-6}$, development is not restricted in any way
Flanders[20] (Belgium)	$1\ (10)^{-5}$	NA	At plant boundary: $1\ (10)^{-5}$ fatality/year is maximum tolerable
			At residential areas: $1\ (10)^{-6}$ fatality/year is maximum tolerable
			At sensitive locations: $1\ (10)^{-7}$ fatality/year is the max tolerable
Hong Kong[21]	$1\ (10)^{-5}$	NA	Hong Kong's only criteria is that off-site risk not be more than $1\ (10)^{-5}$ fatality/year.
Malaysia[22]	$1\ (10)^{-6}$	NA	For residential areas, schools, hospitals, and places of continuous occupancy: $1\ (10)^{-6}$ fatality/year
			For industrial developments: $1\ (10)^{-5}$ fatality/year
			Buffer zone minimum of 500 meters from hazardous facility or $1\ (10)^{-6}$ fatality/year risk contour, whichever is greater.
The Netherlands[23]	$1\ (10)^{-6}$	NA	For an overview of the criteria in English, see "Guidelines for Developing Quantitative Safety Risk Criteria", Appendix B. To quote from that book: "A new risk source may not be permitted if this would cause the risk to existing residential populations to exceed the $1\ (10)^{-6}$ fatality/year individual risk criteria for vulnerable populations, and new housing may not be permitted in an area if the risk from an existing industrial facility exceeds $1\ (10)^{-6}$ fatality/year."
New South Wales[24]	$5\ (10)^{-5}$	NA	Isocontours cannot be higher than the following, in each area:
			Sensitive Developments: $5\ (10)^{-7}$ fatality/year
			Residential Areas: $1\ (10)^{-6}$ fatality/year
			Commercial Developments: $5\ (10)^{-6}$ fatality/year
			Non-Industrial activity, or active open spaces: $1\ (10)^{-5}$ fatality/year
			Industrial Activity: $5\ (10)^{-5}$ fatality/year

[18] ADNOC (2000), Health, Safety and Environmental Management Guidelines, HSE Risk Management. Abu Dhabi National Oil Company (ADNOC Group), Version 1.0. March 2000.
[19] CSChE (2004), Risk Assessment – Recommended Practices for Municipalities and Industry. Canadian Society for Chemical Engineering, ISBN No. 0-920804-92-6, 2004.
[20] Flemish Government (2006), Risk Criteria Code of Good Practice for Risk Criteria for Human Risk of External Devices. Flemish Government Department of the Environment, Nature and Energy. Version 1, October 19, 2006.
[21] HKGPD (2008), Hong Kong Planning Standards and Guidelines. Hong Kong Planning Department
[22] CCPS (2009), Guidelines for Developing Quantitative Safety Risk Criteria. Center for Chemical Process Safety of the American Institute of Chemical Engineers. Published by John Wiley & Sons, Inc., Hoboken, New Jersey, 2009. (ISBN 978-0-470-26140-8)
[23] VROM (2004), Besluit Externe Veiligheid Inrichtingen (External Safety (Establishments) Decree), Staatscourant Sept. 23, 2004, nt. 183, 2004.
[24] HIPAP 10 (2011), Hazardous Industry Planning Advisory Paper No 10, Land Use Safety Planning. State of New South Wales Department of Planning, Sydney, NSW, Australia, January 2011. ISBN 978-1-74263-028-1.

Country	Intolerable Public Risk	Negligible Public Risk	Notes
Queensland[25]	$5 (10)^{-5}$	NA	Isocontours cannot be higher than the following, in each area: • Sensitive Developments: $5 (10)^{-7}$ fatality/year • Residential Areas: $1 (10)^{-6}$ fatality/year • Commercial Developments: $5 (10)^{-6}$ fatality/year • Non-Industrial activity, or active open spaces: $1 (10)^{-5}$ fatality/year • Industrial Activity: $5 (10)^{-5}$ fatality/year
Rio Grande do Sul, Brazil[26]	$1 (10)^{-5}$	$1 (10)^{-6}$	
São Paulo, Brazil[27]	$1 (10)^{-5}$	$1 (10)^{-6}$	Plant boundary: $1 (10)^{-5}$ fatality/year is maximum tolerable
			Plant boundary: $1 (10)^{-6}$ fatality/year is considered acceptable.
Singapore[28]	$5 (10)^{-5}$	NA	$5 (10)^{-5}$ fatality/year risk contour must be within plant boundary
			$5 (10)^{-6}$ fatality/year risk contour extends only into industrial developments
			$1 (10)^{-6}$ fatality/year risk contour extends only into commercial and industrial developments.
United Kingdom[29]	$1 (10)^{-4}$	$1 (10)^{-6}$	Land around a hazardous facility is broken into three zones: inner zone (IZ), middle zone (MZ), and outer zone (OZ). They are divided by iso-risk contours of "receiving or exceeding a dangerous dose" of $1 (10)^{-5}$/yr, $1 (10)^{-6}$/yr, and $3 (10)^{-7}$/yr. A dangerous dose is an amount of toxic substance, heat, or overpressure that has a 50% chance of killing an average person.
Victoria[30] "Interim"	$1 (10)^{-5}$	$1 (10)^{-6}$	Plant Boundary, max tolerable: $1 (10)^{-5}$ fatality/year
			Plant Boundary, negligible: $1 (10)^{-7}$ fatality/year
Western Australia[31]	$5 (10)^{-5}$	NA	Isocontours cannot be higher than the following, in each area:
			Sensitive Developments: $5 (10)^{-7}$ fatality/year
			Residential Areas: $1 (10)^{-6}$ fatality/year
			Commercial Developments: $5 (10)^{-6}$ fatality/year
			Non-Industrial activity, or active open spaces: $1 (10)^{-5}$ fatality/year
			Industrial Activity: $5 (10)^{-5}$ fatality/year
			Industrial Activity (Cumulative effect of multiple plants): $1 (10)^{-4}$ fatality/year

[25] Queensland Government (2008), Guidelines for Major Hazard Facilities, C - Systematic Risk Assessment, Queensland Government, Department of Employment and Industrial Relations. November 2008.
[26] FEPAM (2001), Industrial Risk Analysis Manual. Department of Environmental Control/Industrial Pollution Control Division, FEPAM No. 1, March 2001.
[27] CETESB (2011), Accidental Risk from Technical Origin. Method for Decision and Reference Terms. Environmental Company of the State of São Paulo, December 2011.
[28] NEA (2008), Guidelines for Quantitative Risk Assessment (QRA) Study. National Environment Agency. Pollution Control Department, Singapore, 2008.
[29] HSE (2008d), PADHI-HSE's Land Use Planning Methodology, 2008. http://www.hse.gov.uk/landuseplanning/padhi.pdf
[30] WorkSafe (2011), Guidance Note Requirements for Demonstration Advice to Operators of Major Hazard Facilities on Demonstrating an Ability to Operate the Facility Safely, WorkSafe Victoria. April 2011.
[31] WA-EPA (2000), Guidance for the Assessment of Environmental Factors (in accordance with the Environmental Protection Act 1986) – Guidance for Risk Assessment and Management: Off-site Individual Risk from Hazardous Industrial Plant. (No. 2) Environmental Protection Authority of Western Australia, July, 2000.

A few of the conservative assumptions (that lead to risk overprediction) are listed below. The contributions of these factors cannot be explicitly quantified. They are presented here to provide qualitative reasons why the actual risk would be expected to be lower than predicted.

- **Overprediction of Public Presence**: The risk calculations assume that people are present 24 hours a day, 365 days a year, at locations surrounding the pipelines. If any individual is at a given location for only a fraction of a year, the risk is less.
- **Ignoring Human Response Time**: For outdoor persons exposed to fire radiation from a jet fire, it was assumed that the duration of exposure was equal to thirty (30) seconds. This means that no protective or evasive action is taken by that individual for a full thirty seconds. If an individual moves away from the fire or finds shelter behind a solid object, their exposure to radiant energy will be reduced. Thus, the assumption of a 30-second exposure results in an overprediction of risk.
- **Ignoring Pipeline Response**: This analysis did not account for quick shutdown by Sunoco, nor isolation of the pipeline segments. While most of the consequences of the release scenarios will be realized within a few minutes of the release beginning, some larger events could be affected by a quick shutdown, and the duration of all events could be affected by shutdown and isolation activities.
- **Release Orientation**: Near horizontal releases were assumed to be oriented such that they are pointing in the direction the wind is blowing. This assumption allows the released material to travel the maximum distance before diluting below the lower flammable limit. Any other release direction (upwind, crosswind, etc.) would result in shortened impact zones. The net effect is an overprediction of risk.
- **Free Jets**: Release from buried pipe were assumed to create a crater that allowed for unobstructed release of material. This allows the HVLs to extend downwind further than they would if the release was partially obstructed, resulting in an overprediction of risk.

5.5 Comparison to Other Risks

Another way to evaluate the risk imposed by the pipeline on the public is by using fatality rates from other activities or accidental events. Table 5-2 lists several potential causes of death (primarily things that the general public may be exposed to) in the form of odds of death in a one-year period and approximate annual probability of fatality. Table 5-2 is based on statistics for 2015, the latest year for which these values are available. The likelihood or frequency of fatality values presented are based on the total U.S. population for 2015[32] (321,418,000), and so represent the risk of fatality for the general population of this country.

An examination of Table 5-2 reveals that there are many potential causes of death (including accidental falls, accidental drowning, and weather related deaths) that have a higher probability of fatality, when compared to the risk of fatality imposed by the Mariner East pipelines on the public.

[32] https://www.nsc.org/membership/member-resources/injury-facts

Table 5-2
Odds of Early Fatality Data from the National Safety Council's *Injury Facts, 2017 Edition*

Cause of Death	Annual Number of Deaths in U.S. Population†	Odds of Death in a One-Year Period (one chance in…)	Approximate Annual Probability of Fatality
Heart disease	614,348	519	1.93×10^{-3}
Cancer	591,699	539	1.84×10^{-3}
Stroke	133,103	2,396	4.17×10^{-4}
Influenza or pneumonia	55,227	5,774	1.73×10^{-4}
Accidental poisoning	47,478	6,770	1.48×10^{-4}
Motor vehicle accidents	37,757	8,513	1.17×10^{-4}
Falls	33,381	9,629	1.04×10^{-4}
Pedestrian (motor-vehicle accident)	6,258	50,952	1.96×10^{-5}
Accidental choking	5,051	63,635	1.57×10^{-5}
Accidental drowning	3,602	89,233	1.12×10^{-5}
Exposure to smoke, fire, or flames	2,646	121,473	8.23×10^{-6}
Complications of medical/surgical care	2,540	125,534	7.97×10^{-6}
Mechanical suffocation	1,863	172,527	5.80×10^{-6}
Exposure to forces of nature	1,377	231,559	4.32×10^{-6}
Electrocution	257	1,240,689	8.06×10^{-7}
Bitten or struck by dog or other mammals	119	2,679,471	3.73×10^{-7}
Lightning	27	11,904,370	8.40×10^{-8}

† Population is based on the total population of the U.S.A. in 2015

5.6 Risk Summary

The following information can be obtained after an inspection of the risk contours in Figures 5-1 through 5-10:

- The risk exceeds 1.0×10^{-4} per year (one chance in ten thousand per year) of being fatally affected by a pipeline release only in the immediate area around valve stations.
- The risk exceeds 1.0×10^{-5} per year (one chance in one-hundred thousand per year) at valve stations and at the HDD entry/exit points.
- The risk exceeds 1.0×10^{-5} per year along the pipelines' route when the ME1, ME2, and ME2X are co-located, but only for outdoor exposure.
- As a generalization, areas further than about 600 feet from the pipeline or pipelines are predicted to have an individual risk level less than 1.0×10^{-6} per year (one chance in one million per year).

Several other generalizations can be provided when reviewing the results of this analysis:

- The risk of fatality, as predicted by this analysis, falls to zero at a distance of about 2,100 feet from the ME2 or ME2X pipelines (less than one-half mile). This distance is shorter for the ME1 pipeline, about 1,100 feet (less than one-quarter of a mile).
- By comparison, the risk above the HDD sections is significantly lower than conventional-bury sections of the pipeline, but this does concentrate risk at the HDD entry and exit points.
- Due to the equipment present, and the aboveground placement of this equipment, the pipeline valve stations represent the highest risk locations, where the risk is approximately equal to being fatally involved in a motor vehicle accident.
- Along the pipeline route (away from valve stations and HDD entry/exit points), the risk is *about* 10% as likely as being fatally involved in a motor vehicle accident, where the ME1, ME2, and ME2X are co-located and all in operation. This risk is also about 150 times as likely as getting struck by lightning.