Overview of the Fossil Fuel Pipeline Explosion Evaluation

for the

International Isotopes, Inc.
FEP & DUF6 Deconversion Facility

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Why is a Pipeline Explosion Evaluation Necessary?

As described in NUREG-1520, the Integrated Safety Analysis must identify and evaluate all credible events that could result in facility-induced consequences (to workers, the public, or the environment) that exceed the performance requirements of 10 CFR 70.61 (NRC 2010)

Evaluation Goal

The goal of the Pipeline Explosion evaluation is to determine the **annual** probability that the rupture, release, and detonation from a nearby, underground, fossil fuel pipeline could generate a blast pressure wave greater than or equal to **one** psi at an IIFP process building

Why One PSI?

As described in Regulatory Guide 1.91, a blast pressure wave less than one psi would not cause significant damage to structures, systems, or components of concern (NRC 1978)

Which Buildings are Evaluated?

1) DUF6 Autoclave Building
2) DUF4 Process Building
3) FEP Process Building
4) FEP Oxide Storage Building
5) DUF4 Container Storage Building
6) Future DUF6 Autoclave Building
7) Future Oxide Process Building
8) Future Direct Oxide Building

What is the Risk-Based Performance Requirement?

Any accident with an annual probability less than 1E-5 is considered **highly unlikely** and therefore satisfies the risk-based performance requirements of NUREG-1520 (NRC 2010)

Pipeline Data

- [redacted]
- [redacted]

11" closest to site

- [redacted]
- Several pipeline owners /operators
- Pressure unknown for pipeline [redacted]
- Diameter unknown for pipelines [redacted]
  [redacted]

Main Steps of the Evaluation

A. Develop an explosion/mile/year metric based on published pipeline safety data

B. Calculate site-specific pipeline exposure distances as illustrated in Regulatory Guide 1.91 (NRC 1978)

C. Combine results of Step A and Step B to determine **annual probability**

Pipeline Safety Data

- Pipeline safety data is available from the Department of Transportation (DOT) Pipeline Hazardous Material Safety Administration (PHMSA) for natural gas (NG) and Hazardous Liquids (HL)
- Safety data documented via multiple PHMSA files:
    - NG Distribution, 1986 – 2004
    - NG Distribution, 2004 – 2009
    - NG Transmission 1986 – 2001
    - NG Transmission 2002 – 2009
    - HL 1986 – 2001
    - HL 2002 – 2008
    - Note: LPG data is included with HL data

NG Pipeline Safety Data

- PHMSA data files document Significant Incidents
- A Significant Incident involves at least one of these conditions:
    - Fatality, or injury that requires hospitalization
    - $50,000 or more damage measured in 1984 dollars
    - Highly volatile liquid releases of 5 barrels or more or other liquid releases of 50 barrels or more
    - Releases that cause unintentional fire or explosion

NG Pipeline Safety Data

- Explosions are not identified in old NG data files
- Explosions are identified in new NG data files
- Explosions/Significant Incident Rate from new data was applied to estimate Explosions for old data
- Selective filters applied to ensure irrelevant accidents are not counted (e.g. underwater pipeline accidents)
- Result: 51 NG pipeline explosions over 24 years

Hazardous Liquid Pipeline Safety Data

- LPG is considered a hazardous liquid (HL)
- Both HL databases explicitly identify Explosions
- Selective filters applied to ensure irrelevant accidents are not counted (e.g. offshore pipeline explosions)
- HL databases include 134 materials
- Explosion results counted for all HL pipelines except carbon dioxide, condensate, condensate – water, crude oil, diesel fuel, fuel oil, and kerosene
- Result: 21 LPG pipeline explosions over 23 years

NG Pipeline Explosion Metric

- National NG pipeline mileage (GT + GD) increased from 1.2 million miles to around 2.0 million miles from 1986 to year 2009
- To determine an average pipeline mileage over this time span, a linear growth rate was assumed
- There are roughly 90 miles of GD per mile of GT
- Average NG pipeline estimated at 1.43E+6 miles
- The NG explosion metric determined as:

51 explosions / 1.43E+6 miles / 24 years = 1.49E-6 exp/mi/yr

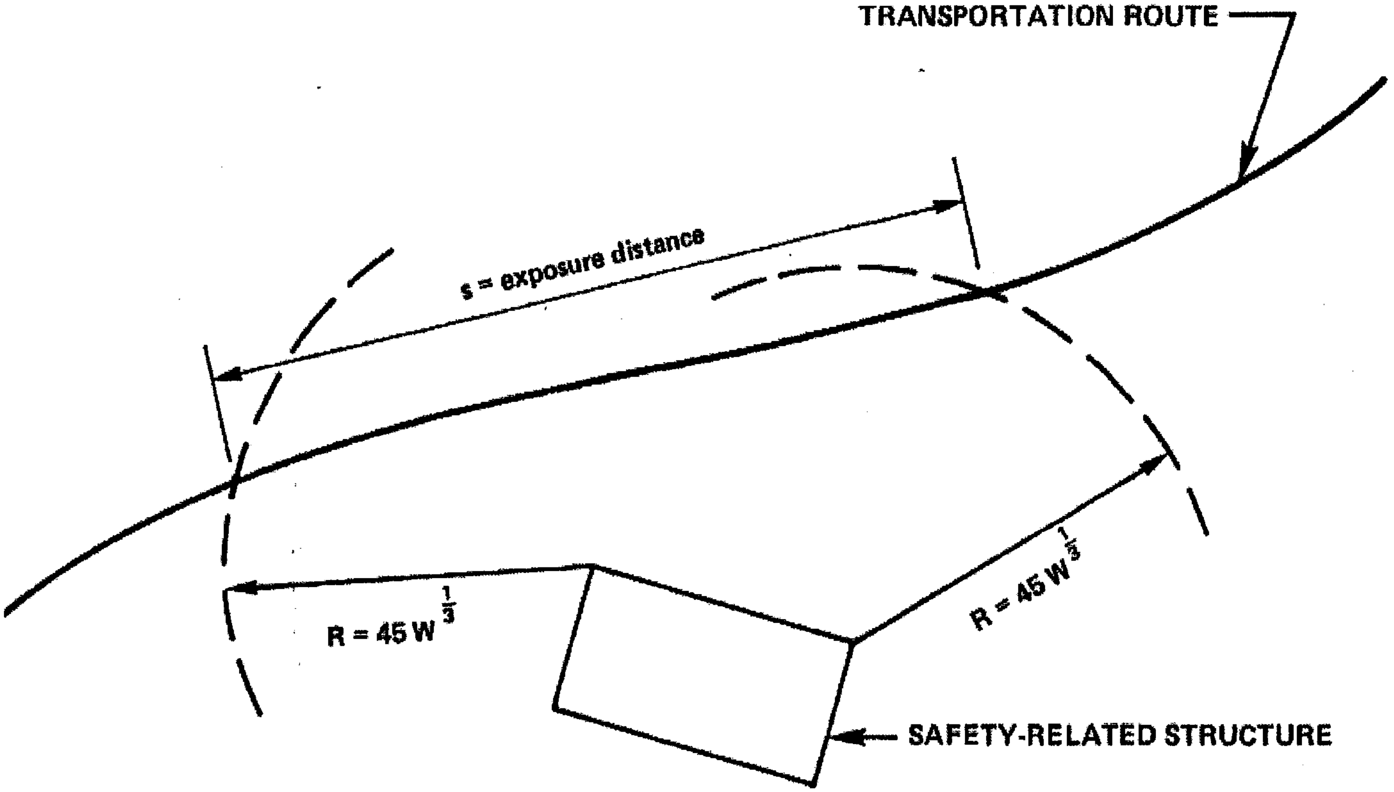
LPG Pipeline Mileage

- Unable to find national LPG pipeline mileage data from public source
- Submitted FOIA request to DOT PHMSA
- FOIA Data included only transmission pipeline mileage
- 2009 NG transmission pipelines : 21,354 miles
- 2009 LPG transmission pipelines: 23,064 miles
- LPG pipeline mileage 8% more than NG mileage

Pipeline Exposure Distance

- Exposure Distance is the span of pipeline with the potential to generate a one psi (or larger) blast pressure wave at a process building
- Regulatory Guide 1.91 provides a graphical illustration of exposure distance

Pipeline Exposure Distance



Source: Regulatory Guide 1.91 (NRC 1978)

Exposure Distance Variables

- Exposure Distance is a function of blast radius and pipeline proximity
- Blast radius is a function of fuel type, release rate, and atmospheric conditions (stability and wind speed)
- Release rate is a function of fuel type, pipeline size, and pipeline pressure

Release Rate

- Guillotine pipeline rupture assumed to occur
- Release attenuation due to soil cover is ignored
- Full bore release assumed from both ends of ruptured pipeline
- Initial release rate conservatively determined based on choked flow conditions
- Average release rate is determined as a fraction of the initial release rate based on an empirically determined decay factor (λ)

Choked Flow Conditions

$$Q_{in} = C_d \frac{\pi d^2}{4} p \frac{\varphi}{a_0}$$

where φ = flow factor = $\gamma \left(\frac{2}{\gamma + 1} \right)^{\frac{\gamma+1}{2(\gamma-1)}}$;

a_0 = sonic velocity of gas = $\sqrt{\frac{\gamma R T}{m}}$;

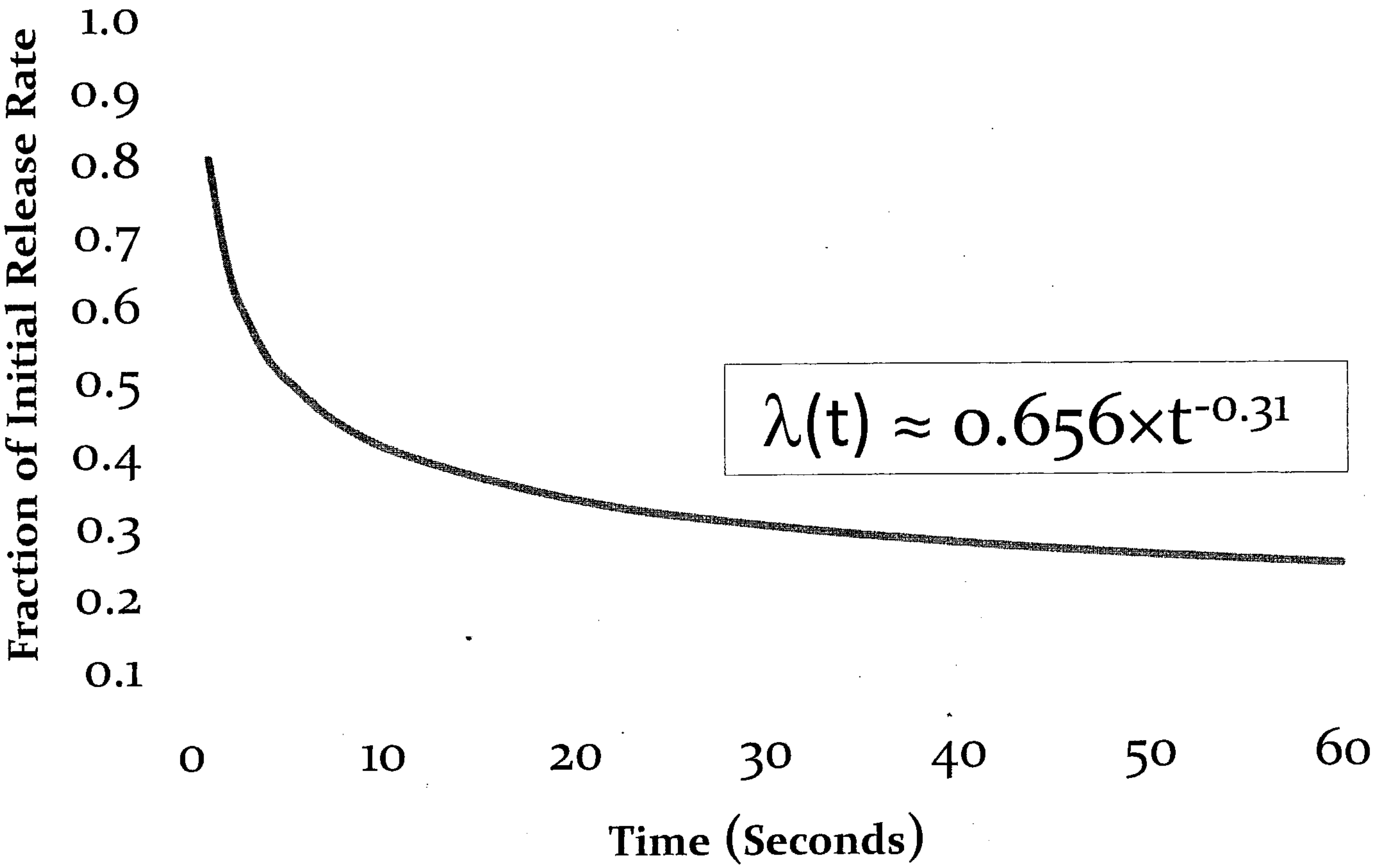
C_d = discharge coefficient ≅ 0.62;
γ = specific heat ratio of gas ≅ 1.306 for methane;
R = gas constant = 8,310 J/(kg mol)/K;
T = gas temperature ≅ 288 K or 15 C;
m = gas molecular weight ≅ 16 kg/mol for methane;
d = effective hole diameter ≅ line diameter; and
p = pressure differential ≅ line pressure.

Source: Gas Research Institute, 2000

Release Rate Decay Factor

- Empirical data from the Gas Research Institute (GRI) demonstrates a rapid initial decay in release rate due to pipeline depressurization
- Release rate decay is well characterized by a power series curvefit $\lambda(t) = W \times t^Z$
- To determine the one psi blast radius, the decay factor (λ) is based on the first five minutes after the release
- Integration of the power series curvefit gives $\lambda \approx 0.16$

Release Rate Decay



$$\lambda(t) \approx 0.656\times t^{-0.31}$$

Pipeline Release Rate

The equation below is applied to calculate the effective average release rate from a pipeline due to a guillotine type failure (GRI 2000)

$$Q_{eff} = 2\lambda Q_{in} = 2\lambda C_d \frac{\pi d^2}{4} p \frac{\varphi}{a_0}$$

Where λ is the decay factor and the coefficient 2 acknowledges the release of gas from both ends of the ruptured pipeline

Pipeline Release Rates

- Based on known or assumed pipeline data (size and pressure), an average release rate is determined for each pipeline
- [redacted]
- [redacted]

Application of ALOHA

- ALOHA software is applied to estimate the radius at which blast pressure drops below one psi
- Key ALOHA inputs include fuel type, average release rate, atmospheric stability, and wind speed
- ALOHA determines the release time that produces the maximum blast radius
- ALOHA algorithms limit release time to maximum of 60 minutes

Atmospheric Conditions

- Representative regional atmospheric stability and wind speed data obtained from the State of New Mexico
- Atmospheric data includes 9408 hourly records (more than a full year of data)
- Atmospheric data assembled into a canonical set of 43 combinations (based on 1 m/s wind speed increments)
- The frequency of occurrence for each set of conditions was then determined (*the reason for this will be discussed later*)

Atmospheric Frequency Data

				Stability Class				
			A	B	C	D	E	F

See slide 1/1

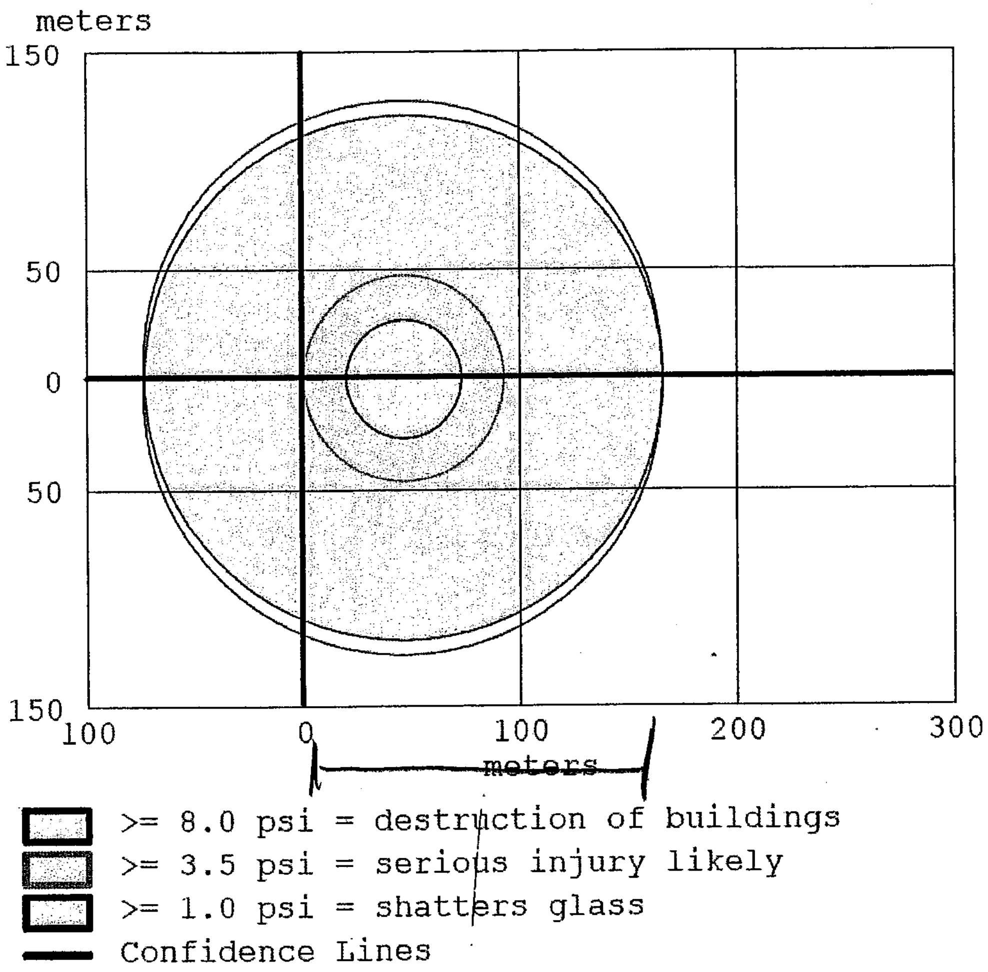
Application of ALOHA (cont)

- ALOHA disallows wind speeds less than 0.8 m/s
- For D0 and F0 conditions, the blast radius is assumed to be 25 percent larger than the blast radius for D1 and F1 conditions, respectively
- To reduce the volume of ALOHA simulations, a representative set of six NG release rates was selected for evaluation (5, 30, 85, 140, 195, and 250 kg/sec)

Application of ALOHA (cont)

- ALOHA output was then generated for each NG release rate and for all 43 atmospheric conditions
- Results were then gathered into a summary table, and power series curvefits were developed to characterize blast radius as a function of NG release rate
- ALOHA was applied separately for LPG releases
- Separate power series curvefits were developed to characterize blast radius as a function of LPG release rate

ALOHA Threat Zone Graphic



Pipeline Proximity

- For each pipeline, and each atmospheric condition, the calculations must determine the coordinates of the locations where the blast circle intersects the pipeline
- Therefore, a coordinate system was defined with the origin at the SW corner of the DUF6 Autoclave Building
- Pipeline locations represented with linear equations
- For each pipeline, the minimum distance to each process building is determined via linear geometry, and the nearest building corner is identified

Exposure Distance Calculations

For each pipeline, and for each set of atmospheric conditions, the radius of the one psi blast circle is determined based on the power series curvefit to the ALOHA results

Example: Consider Pipeline 14 (NG), for B Stability and a wind speed of 2 m/s. [redacted]. For B2 atmospheric conditions, the one psi blast radius is given as:

[redacted]

Exposure Distance Calculations

The [redacted] circle is mathematically located at the nearest building corner, and the coordinates of the points of intersection between the blast circle and pipeline [U and V] are analytically determined

The blast circle is then mathematically located at each of the adjacent building corners, and the coordinates of the points of intersection between the blast circle and pipeline are determined [W and X], [Y and Z]

Exposure Distance Calculations

- A total of six points of intersection are thus identified, designated as U, V, W, X, Y, and Z
- To determine exposure distance, the distance between each pair of coordinates is calculated, and the maximum result is selected
- There are six points, choose two, for 15 combinations
- For non-continuous pipelines, the distance results are adjusted as appropriate

Exposure Distance Calculations

- The selected exposure distance is then adjusted to account for the annual frequency at which the atmospheric conditions occur
- Example: For a given pipeline and a given set of atmospheric conditions, if the calculated exposure distance is 1055 feet, and the annual frequency of the atmospheric conditions is 0.4%, then the adjusted exposure distance would be (0.4%)(1055 ft) = 4.2 ft
- The total exposure distance for a single pipeline is then determined as the average of all 43 frequency adjusted exposure distances

Exposure Distance Calculations

Individual NG pipeline exposure distance results are then summed to determine the total span of NG pipeline with the potential to generate a one psi blast pressure wave at a nearby process building (DE_{NG}), and the annual probability is calculated as

$$P_{NG} = (1.49E\text{-}6 \text{ exp/mi/yr}) \times DE_{NG}$$

Exposure Distance Calculations

Similarly for LPG:

$P_{LPG} = (5.86E\text{-}7 \text{ exp/mi/yr}) \times DE_{LPG}$

Based on the data and methods applied herein, the total annual probability that the rupture, release, and detonation of a nearby, underground, fossil fuel pipeline would produce a one psi or larger blast pressure wave at an IIFP process building is:

$P_{TOT} = P_{NG} + P_{LPG} = 2.72E\text{-}07 + 1.12E\text{-}08$

$P_{TOT} = 2.84E\text{-}07$