Introduction to Pipeline Quantitative Risk Assessment

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Presented by
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Pipeline Incident, 2008 (V.A, U.S.A)

The 30” (53 yrs old) natural gas pipeline ruptured and ignited explosion destroyed everything with 560 ft of the rupture.

Cause of rupture: Internal and External corrosion

Damage: $5,416,000
Evacuations: 50 people evacuated
History of Pipeline

- 500 BC: First Hydrocarbon Pipeline (China)
- 1853: 25 km Natural Gas (Quebec)
- 1862: Oil (Ontario)
Pipeline Incidents in Canada

Reference: Transportation Safety Board of Canada
Canadian Pipeline Regulations

• AER Manual 005:
  Industry is responsible for understanding and complying with all pipeline-related regulatory requirements, including the development of safety loss management systems, effective integrity management programs, and suitable risk assessment / risk mitigation strategies.

• Canadian Energy Pipeline Association (CEPA):
  If a consequence is determined to be significant, Operating Companies should assess the risks associated with the hazards.

• BC Oil & Gas Commission
  If the applicant intends to design and site the LNG facility in accordance with a Quantitative Risk Assessment (QRA) as opposed to using the standard identified in the Regulation the applicant must submit the results of a preliminary QRA to the Commission as part of the LNG Facility Permit Application.
Why Quantitative Risk Assessment?

- Clear and defendable
- Not subjective and decision is based on mathematical risk evaluation.
- Accurate level of risk for land uses around pipeline.

Caution:
Misapplication or incomplete QRA
Pipeline QRA Methodology

**Failure Mode Analysis**
- Pipeline Design Parameters
- Hazard & Scenario Identification

**Consequences Analysis**
- Release rate and Dispersion
- Types of Fire
- Ignition
- Thermal radiation effects

**Frequency Analysis**
- Failure Mechanism
- Leaks vs. Rupture
- Event Tree Analysis

**Risk Assessment**
- Individual Risk
- Societal Risk

**Risk Reduction**

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Pipeline Failure Modes

<table>
<thead>
<tr>
<th>Failure Mode</th>
<th>Analysis</th>
<th>Consequences Analysis</th>
<th>Frequency Analysis</th>
<th>Risk Assessment</th>
<th>Risk Reduction</th>
</tr>
</thead>
<tbody>
<tr>
<td>External Interference</td>
<td>Failure Mode Analysis</td>
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<tr>
<td>External / Internal / Corrosion</td>
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<td>Material &amp; Construction Defect</td>
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<td>Ground Movement</td>
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<td>Geotechnical / Hydrological Forces</td>
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<tr>
<td>Incorrect Operations</td>
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<tr>
<td>Other</td>
<td></td>
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</tbody>
</table>
Alberta Pipelines Incident Causes

**Crude Oil**
- Weld: 19 (3.3%)
- Construction damage: 24 (4.5%)
- Overpressure: 8 (1.5%)
- Joint: 11 (2.0%)
- Earth movement: 15 (2.5%)
- Internal corrosion: 114 (21.2%)
- Valve/fitting: 80 (11.2%)
- Other: 84 (15.0%)
- Damage by others: 168 (31.7%)

**Natural Gas**
- Weld: 178 (3.2%)
- Construction damage: 170 (3.2%)
- Overpressure: 26 (4.8%)
- Joint: 9 (1.6%)
- Pipe: 99 (18.4%)
- Valve/fitting: 44 (8.3%)
- Other: 81 (15.6%)
- Damage by others: 834 (15.2%)
- Internal corrosion: 2,919 (52.2%)
- External corrosion: 640 (11.7%)

**Sour Gas**
- Weld: 7 (1.3%)
- Construction damage: 13 (2.4%)
- Overpressure: 5 (0.9%)
- Joint: 5 (0.9%)
- Earth movement: 6 (1.1%)
- Internal corrosion: 203 (49.6%)
- External corrosion: 42 (7.5%)
- Damage by others: 51 (9.8%)

Consequences Analysis

- Toxic Release
  - Toxic Dispersion
  - Fire
  - VCE
    - (Negligible Risk)

- Flammable Release
  - Release Rate
  - Ignition Probability
  - Dispersion
  - Release Rate
  - Ignition Probability

Risk Assessment

Failure Mode Analysis

Frequency Analysis

Risk Reduction
Leak & Rupture

• Leaks / Punctures
  – Alberta Pipeline Act defines a leak as ‘the escape of substance from a pipeline in a manner that does not immediately impair the operation of the pipeline’.

• Rupture / Line Break
  – a guillotine rupture.
  – an axial or nearly axial split
UKOPA Definition of Leak Sizes

UKOPA:

- Pin hole: equivalent hole diameter up to 6 mm;
- Small hole: hole diameter between 6 mm and 40 mm;
- Large hole: hole diameter greater than 40 mm but less than pipe diameter;
- Rupture: hole diameter equal to or greater than pipe diameter.
External Interference Failure Mode

- Example of critical defect lengths for UKOPA pipeline cases with 0.72 design factor

<table>
<thead>
<tr>
<th>Diameter (mm)</th>
<th>Wall thickness (mm)</th>
<th>Material grade</th>
<th>Critical defect length (mm)</th>
<th>Critical hole diameter limit rupture/leak (mm)</th>
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</thead>
<tbody>
<tr>
<td>168.3</td>
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<td>X42</td>
<td>28.97</td>
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<td>219.1</td>
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<td>X46</td>
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<td>406.4</td>
<td>7.9</td>
<td>X52</td>
<td>47.92</td>
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<td>914</td>
<td>9.5</td>
<td>X65</td>
<td>85.91</td>
<td>12.73</td>
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</table>
Buried Pipelines

• Modeling diffusion through the soil
• Crater Formation
  – Crater depth is a function of Pipe size and pressure, depth of soil, type of soil & moisture
  – Potential damage of adjacent line
  – Potential of escalation
  – Continuing fluid flow in the adjacent pipeline reduces the chance of damage
  – Radiative flame heating impact diminishes rapidly as distance increases
## Frequency Databases

<table>
<thead>
<tr>
<th>Database</th>
<th>Region</th>
<th>Fuel Type</th>
<th>Number of Incident</th>
<th>Frequency 10⁻³ per km.yr</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>EGIG</td>
<td>Europe</td>
<td>Gas</td>
<td>106 (2006 ~ 2010)</td>
<td>0.162</td>
<td>Since 1970</td>
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<td>CONCAWE</td>
<td>Europe</td>
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<td>DOT (PHMSA)</td>
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<td></td>
<td></td>
<td>• Large database</td>
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<td>APIA</td>
<td>Australia</td>
<td>Gas</td>
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<td>NEB</td>
<td>Canada</td>
<td>Gas &amp; Oil</td>
<td>21 (2005 ~ 2009)</td>
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<td>• Used for studies in Canada</td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>• Limited database</td>
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<td>World Bank</td>
<td>Russia &amp; FSU</td>
<td>Oil</td>
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<tr>
<td>UKOPA</td>
<td>UK</td>
<td>Gas</td>
<td>10 (2006 ~ 2010)</td>
<td>0.093</td>
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<tr>
<td>EUB (AER)</td>
<td>Alberta</td>
<td>Gas &amp; Oil (Incl. Sour)</td>
<td>&lt; 5 (NG)</td>
<td>0.8 (NG) \ 1.0 (Crude Oil)</td>
<td>• Used for studies in Canada</td>
</tr>
</tbody>
</table>
Aging & Frequencies

Built before 1953

Built after 1960

Reference: EGIG Report
Gas Pipeline Event Tree Analysis

Rupture
- Immediate Ignition (Y)
  - Fireball + Jet Fire
- Delayed Local Ignition (Y)
  - Jet Fire
- Delayed Remote Ignition (N)
  - Flash Fire + Jet Fire
  - No ignition
    - Toxic Dispersion (if applicable) (N)

Pipe Failure
- Immediate Ignition (Y)
  - Jet Fire
- Delayed Local Ignition (Y)
  - No ignition
    - Toxic Dispersion (if applicable) (N)

Puncture
- Immediate Ignition (Y)
  - Jet Fire
- Delayed Remote Ignition (N)
  - No ignition
    - Toxic Dispersion (if applicable) (N)

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Risk Assessment

Failure Mode Analysis
Consequences Analysis
Frequency Analysis
Risk Assessment
Risk Reduction

Tolerable if ALARP
Broadly acceptable

Risk Assessment

1E-3/year
1E-4/year
1E-6/year
1E-6/year

High / Unacceptable
Medium / Tolerable only if risk is reduced to ALARP
Low / Broadly Acceptable
Location Specific Individual Risk

Distance from Pipeline (m)

LSIR

Total
JF - Jet Fire
FB - Fireball
Flash Fires

1.0E-05
5.1E-06
1.0E-07

-3000 -2000 -1000 0 1000 2000 3000

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Risk Mitigation

• Wall Thickness
• Regular Surveillance
• Depth Cover
• Design Factor
• Protection Measures (e.g. concrete slab)
• Proof Testing of SIL rated Emergency Instruments
Valves’ Closing Time and Location
Thank you

If you’d like to find out more contact:
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