Migration From Older Risk Analysis Methods to Quantitative Models

PHMSA Committee Presentation

WKM

WWW.PIPELINERISK.NET


Bellingham, WA 1999


Appomattox, VA 2008


San Bruno, CA 2010


Kalamazoo River, MI 2010


Carlsbad, NM 2000


Mayflower, AR 2013

Kalamazoo River, 2010

$1,000,000,000 spent

10ft creek

PoF: 1/1000yr
CoF: $1B
Expected Loss: $1M/yr/10ft!

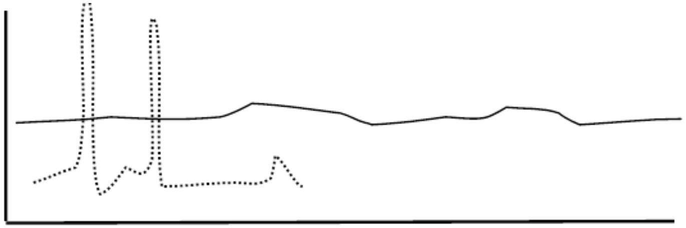
PL Risk

Objective:

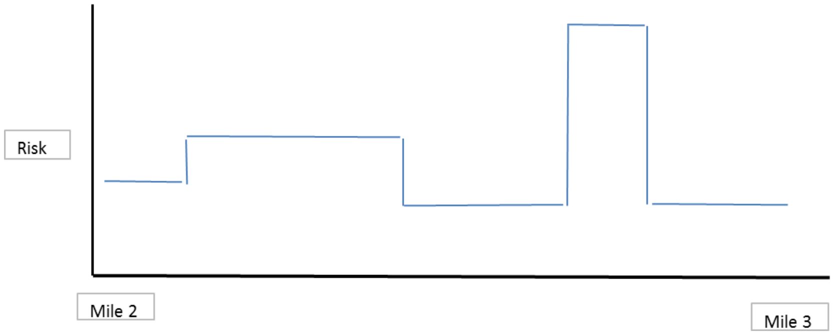
Demonstrate conversion of older, relative-risk models to modern quantitative methods

Agenda

- Regulatory Backdrop
- Tools vs Models
- PL RA Best Practice
- Migrating
- The Mechanics of Migrating
- Risk Mgmt Implications
- Essential Elements



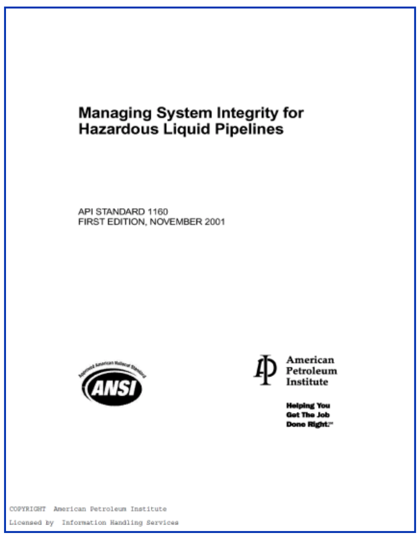
	Index/Score
depth cover	shallow = 8 pts
wrinkle bend	yes = 6 pts
coating condition	fair = 3 pts
soil	moderate = 4 pts

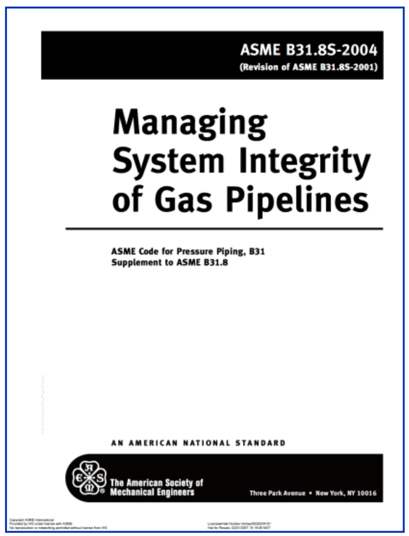


Regulatory Backdrop

Pertinent Regulatory/Standards

- 49 CFR Parts 192, 195
- Advisory Bulletin (Jan 2011)
- Public Presentations (June 2011)





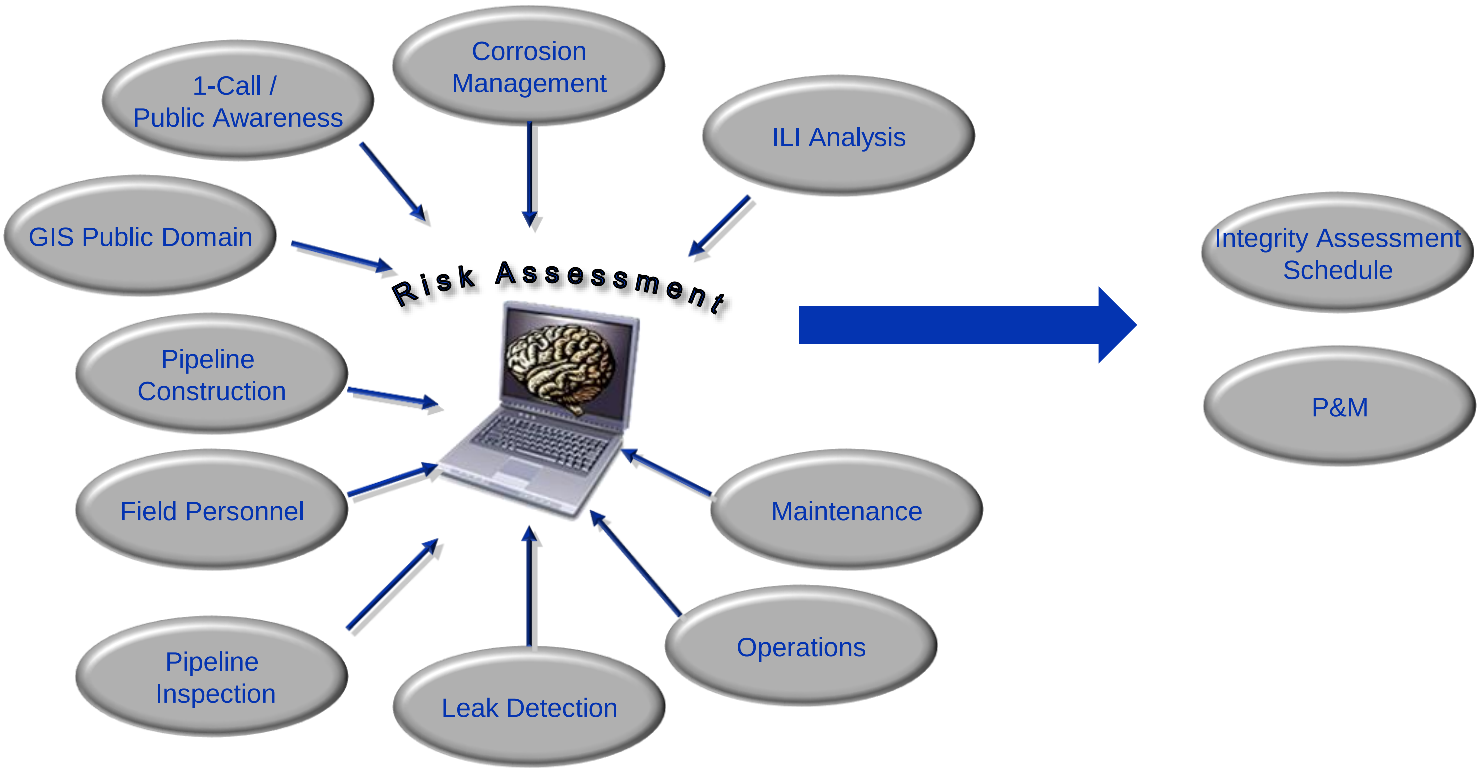
- ASME B31.8s
- API STANDARD 1160
  - Managing Pipeline System Integrity
- API Risk Based Inspection (RBI) RP's
- NACE DA RP's
- CSA Z662
  - Annex O
- ISO

Gas IM Rule Objectives

- Prioritize pipeline segments
- Evaluate benefits of mitigation
- Determine most effective mitigation
- Evaluate effect of inspection intervals
- Assess the use of alternative assessment
- Allocate resources more effectively

ASME B31.8S, Section 5

RA is the Centerpiece of IMP



IMP Objectives vs RA Techniques

Objectives

(a) prioritization of pipelines/segments for scheduling integrity assessments and mitigating action

(b) assessment of the benefits derived from mitigating action

(c) determination of the most effective mitigation measures for the identified threats

(d) assessment of the integrity impact from modified inspection intervals

(e) assessment of the use of or need for alternative inspection methodologies

(f) more effective resource allocation

Techniques

- ~~Subject Matter Experts~~
- ~~Relative Assessments~~
- ~~Scenario Assessments~~
- Probabilistic Assessments

Numbers Needed

- Failure rate estimates for each threat on each PL segment
- Mitigation effectiveness for each contemplated measure
- Time to Failure (TTF) estimates *(time-dep threats)*

ASME B31.8S Summary of Updates Needed

- The ASME B31.8s threat list confuses failure mechanisms and vulnerabilities.(~~*stable*~~); no ‘threat interaction’ issue for good RA
- The ASME B31.8s methodology discussion confuses risk models with characteristics of risk models. *(SME’s and probability are part of any good RA)*
- The stated objectives of risk assessment cannot be effectively accomplished using some of the risk assessment *techniques* that are currently acceptable according to ASME B31.8s.
- The use of weightings is problematic but appears to be mandated in inspection protocols based on ASME B31.8S language.

PHMSA Concerns

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Safety Administration

Inspections Identify Weaknesses in Risk Analysis

- Current challenge is for industry to develop
  - More rigorous quantitative risk analyses
  - More investigative approach
  - Engineering critical assessment
  - Robust approach for P&M measures
    - Technically sound risk-based criteria

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Safety Administration

Recent Events Illustrate Weaknesses in Risk Analysis

- Effective risk analysis might have prevented or mitigated recent high consequence accidents
- Weaknesses include inadequate:
  - Knowledge of pipeline risk characteristics
  - Processes to analyze interactive threats
  - Evaluation of way to reduce or mitigate consequences
  - Process to select P&M measures
    - Lack of objective, systematic approach

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Limitations of Simple Index Models

- Ineffective analysis of complex risk factor interactions
- Output not useful for identifying previously unrecognized threats/risks
- Not proven as adequate basis for evaluating P&M measures
- Poor capability to identify risk drivers
- Uncertainties (due to quantifying risk scores based on opinion) are not appropriately considered

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PHMSA Risk Assessment Concerns

- Weaknesses of Simple Relative Index Models
- Records (Availability and Quality of Data)
- Data Integration
- Interacting Threats
- Vintage/Legacy Pipe
- Connection to Real Decision-Making
- Uncertainties

Tools vs Models—Is it really a risk assessment?

PL RA Methodologies

ASME B31.8s
- Subject Matter Experts
- Relative Assessments
- Scenario Assessments
- Probabilistic Assessments

Qualitative
Quantitative
Semi-quantitative

Probabilistic
Mechanistic
Deterministic

QRA
PRA
Indexing
Scoring

	Index/Score
depth cover	shallow = 8 pts
wrinkle bend	yes = 6 pts
coating condition	fair = 3 pts
soil	moderate = 4 pts

PL Risk Modeling Confusion

Types of Models

- Absolute Results
- Relative Results

~~ASME B31.8s~~
~~•Subject Matter Experts~~
~~•Relative Assessments~~
~~•Scenario Assessments~~
~~•Probabilistic Assessments~~

Ingredients in All Models

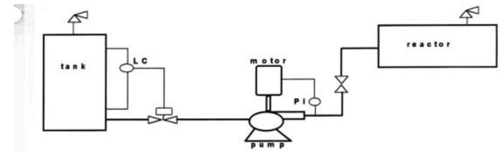
- Probabilistic methods
  - Scenarios, trees
  - Statistics
- SME (input and validation)

~~Qualitative~~
~~Quantitative~~
~~Semi-quantitative~~
~~Probabilistic~~

Hazard ID & Risk Analyses Tools NOT RA Methods

- Scenarios
- Event / fault trees
- Safety reviews / Checklists
- Matrix
- What-if analysis
- FMEA
- PHA, HAZOPS
- LOPA

High	5	6	7	8	9
	4	5	6	7	8
Med	3	4	5	6	7
	2	3	4	5	6
Low	1	2	3	4	5
	Low		Med		High



HAZOPS EXERCISE

Guideword	Cause	Consequence	Safeguards	Recommendation
No Flow				
More Flow				
Reverse Flow				
Less Flow				
Higher pressure				
Lower pressure				
Higher temperature				

Make and note any necessary assumptions (trip points, tank pressure, equipment failure modes, etc)

Use any method to designate lines and equipment (for recording purposes).

Use additional sheets of paper.

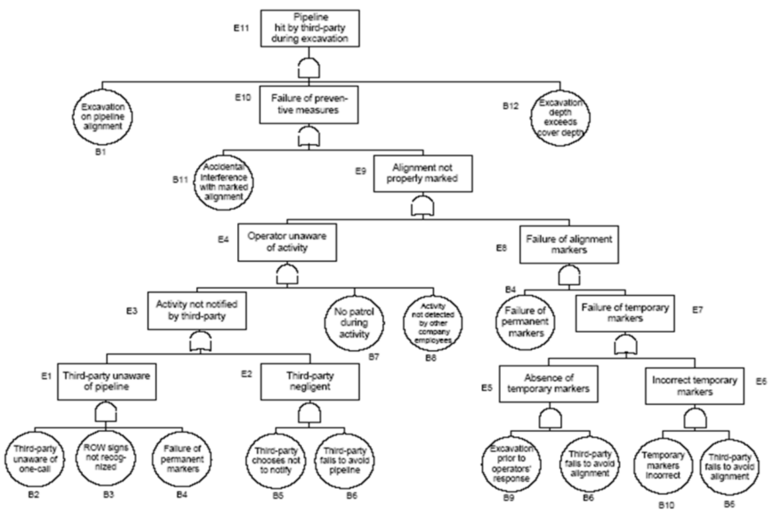
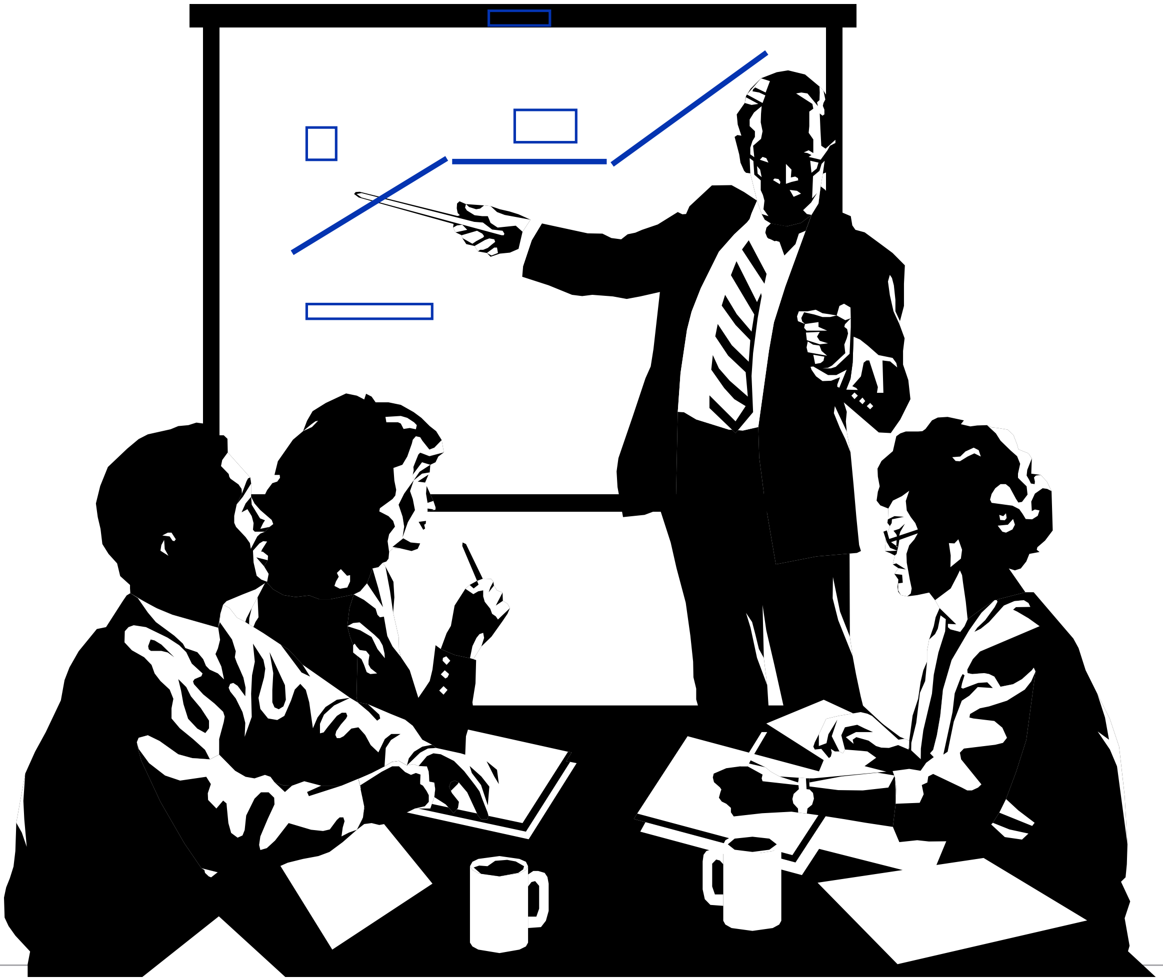


Figure 3.2 Fault tree for mechanical interference by a third party during excavation.

Passing the ‘Map Point’ Test



Is it a risk assessment?

Are location-specific results readily available?

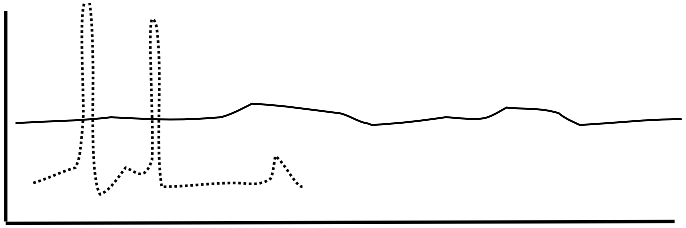
if not, how can decision-making be driven by RA?

Can a drill down be readily performed?

If not, how can diagnostics be conducted?

Can a profile be generated?

If not, how can risk mgmt. begin?



Risk Profiles

Is it a Technically-Strong Risk Assessment

Can it diagnose risk?

- Improves understanding
- Generates meaningful quantifications of risk
  - Verifiable (not scores)
  - Location-specific (not statistics-centric)
  - Profiles of risk elements
- Reflects real-world risk
  - Probabilistic considerations
  - Orders of magnitude
  - Balancing defenses vs strength
- Full info consumption
  - Mirrors SME thought processes
  - SME’s inputs
  - Uses inspection details

Details to follow . . .

Is it An Acceptable Pipeline Regulatory IMP RA Method?

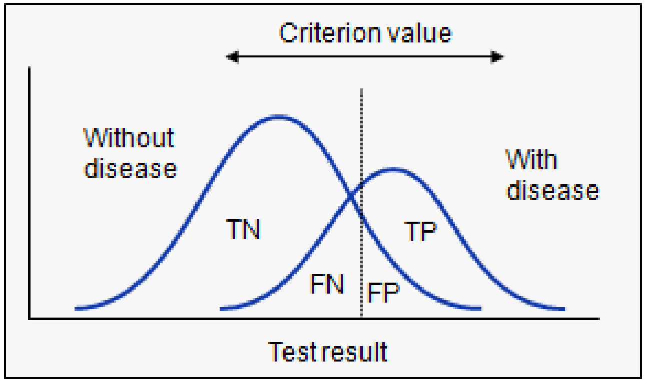
- Can it fully and correctly diagnose risk and directly support risk mgmt?
- Can it support US regulatory IMP
  - 'Letter of the law'
    - Data inclusion
    - Threats
    - Interactive threats
    - Valuations of mitigations
  - Spirit (objectives)
    - P&M = ALARP
    - Location-specific analyses
    - Drives decision-making (objectively)

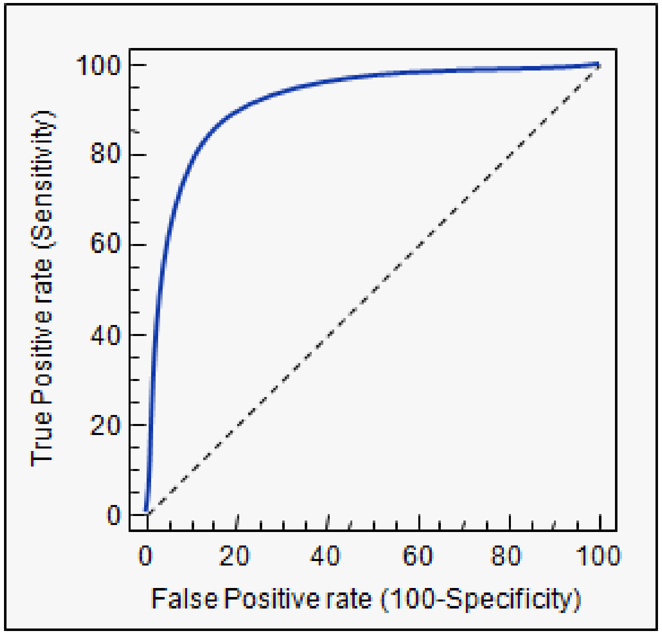
Is it a Good (Acceptable) Risk Assessment?

- All failure modes (‘threats’ type 1)
- All potential weaknesses (‘threats’ type 2)
- Verifiable estimates
- Full use of available info (incl min data sets)
- PoF distinct from CoF
- Transparent and robust PoF; f(exposure, mitigation, resistance)
- Declared conservatism
- Sufficient granularity
- Composite of CoF scenarios
- Profiles
- Proper aggregation

Receiver Operating Characteristic (ROC) Curve

statistical perspective	management perspective	public perspective
false positive	false alarm	crying wolf
false negative	missed alarm	wolf in sheep's clothing
true positive	actual alarm	wolf in plain sight
true negative	no alarm	no wolf





can you tolerate 20% FP in exchange for only missing one in one-hundred?

Pipeline Risk Assessment Best Practice

Risk = PoF x CoF

- Modelling CoF
  - Long history
  - Sophisticated models readily available
  - Models fully supported by advanced software
  - Mandated improvements NOT needed
  - Hazard zones and representative scenarios are key

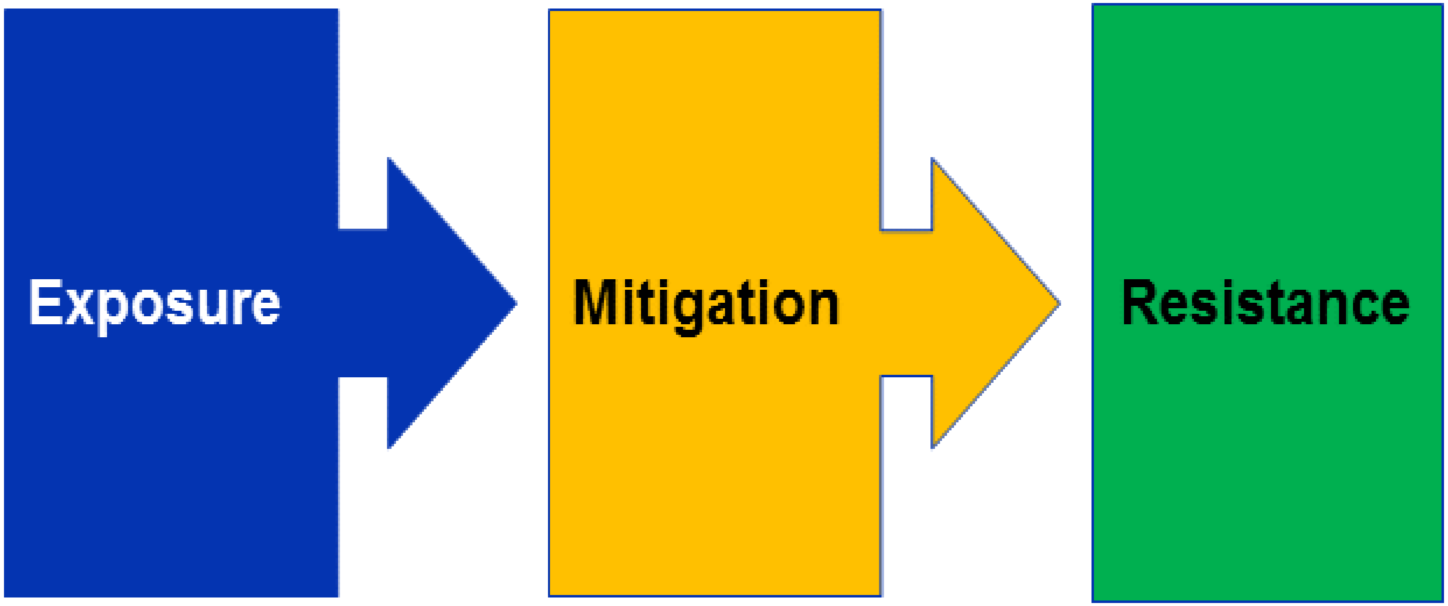
- Modelling PoF historically
  - Statistics-centric, or
  - Relative

- Modelling PoF today
  - Recent (beginning 17 yrs ago) developments have overcome both
    - Necessity for scoring/indexing
    - Reliance on statistics
  - Modernization might need to be mandated

Strong Assertion:

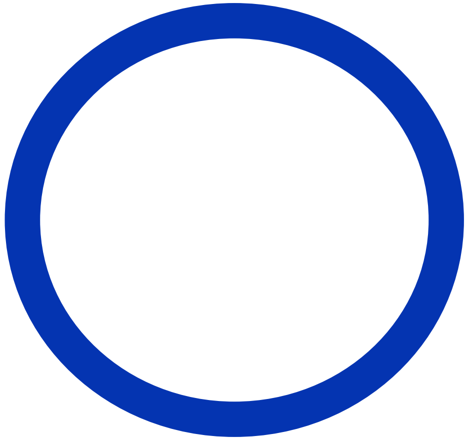
- **There is no defensible reason for using a relative risk assessment methodology to assess risk on any pipeline.**
- These older methods have significant disadvantages in all aspects:
  - Accuracy
  - Usability
  - Cost
    - Setup cost
    - Maintenance cost
  - Transparency/understandability
  - Utility
  - Training
  - Documentation creation
  - Objectivity
  - Verifiablity
  - Auditablility
  - Masking potential
  - Error rates

PoF: Key Aspects



In the beginning . . .

An engineered component is introduced into a constantly changing natural environment



Mother Nature and Murphy React

Excavators

Corrosion

Vehicles

Landslides

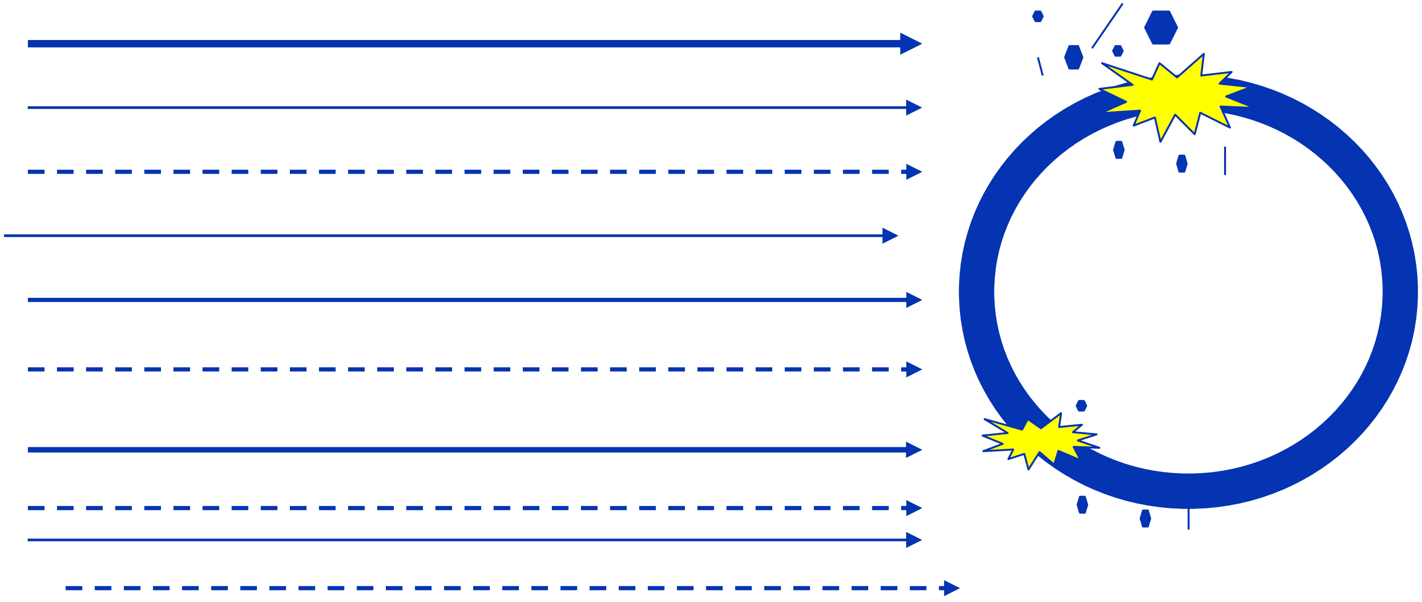
Cracking

Sabotage

Floods

Human Error

Etc



Mother Nature and Murphy React

Exposure =
Attacks

- Excavators
- Corrosion
- Vehicles
- Landslides
- Cracking
- Sabotage
- Floods
- Human Error
- Etc

Resistance =
Strength of
Component

Man Reacts, Part 1

Exposure =
Attacks

Excavators
Corrosion
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Landslides
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Floods
Human Error
Etc

Resistance =
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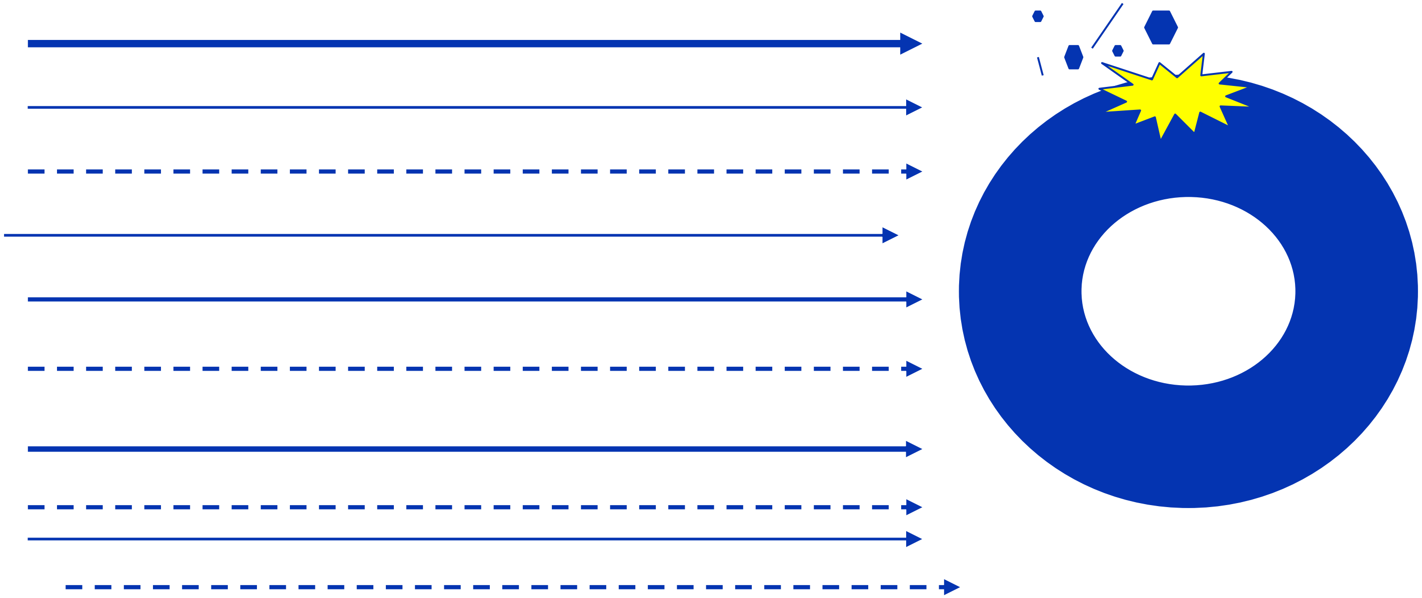


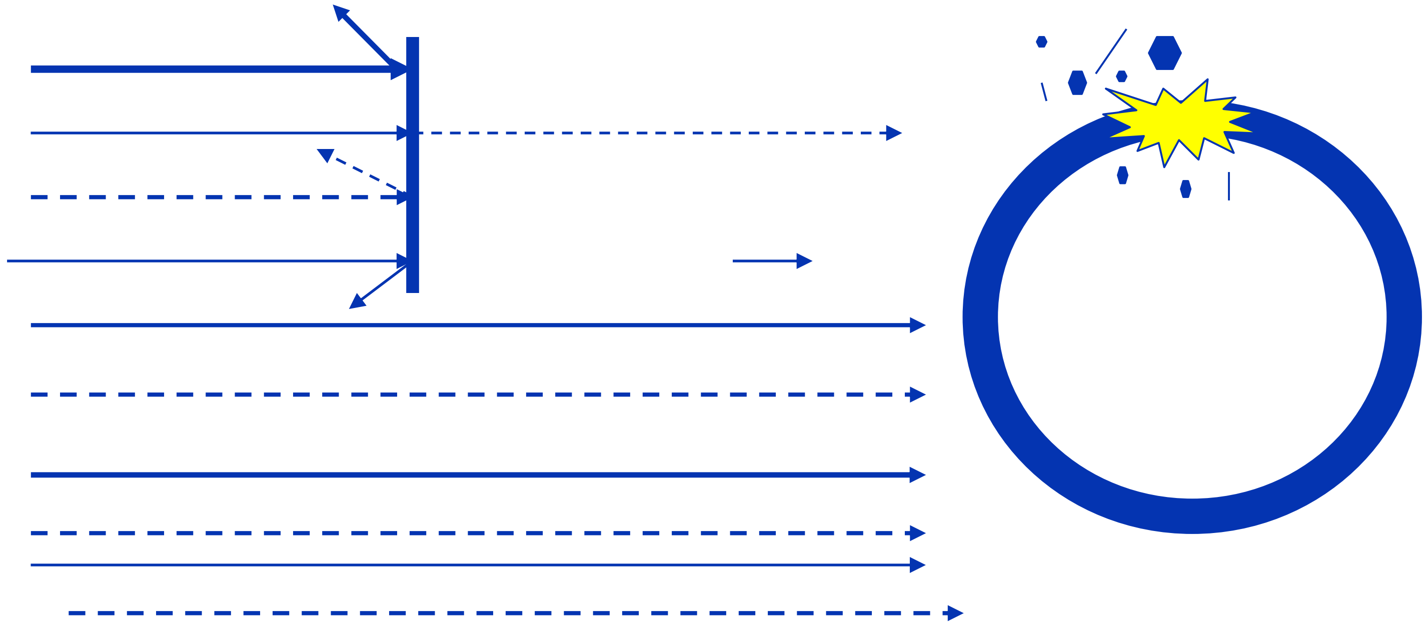
Man Reacts, Part 2

Exposure =
Attacks

Mitigation =
Barriers/Defenses

Resistance =
Strength of
Component

- Excavators
- Corrosion
- Vehicles
- Landslides
- Cracking
- Sabotage
- Floods
- Human Error
- Etc



Man Reacts, Part 2 (cont)

Exposure = Attacks

Mitigation = Barriers/Defenses

Resistance = Strength of Component

- Excavators
- Corrosion
- Vehicles
- Landslides
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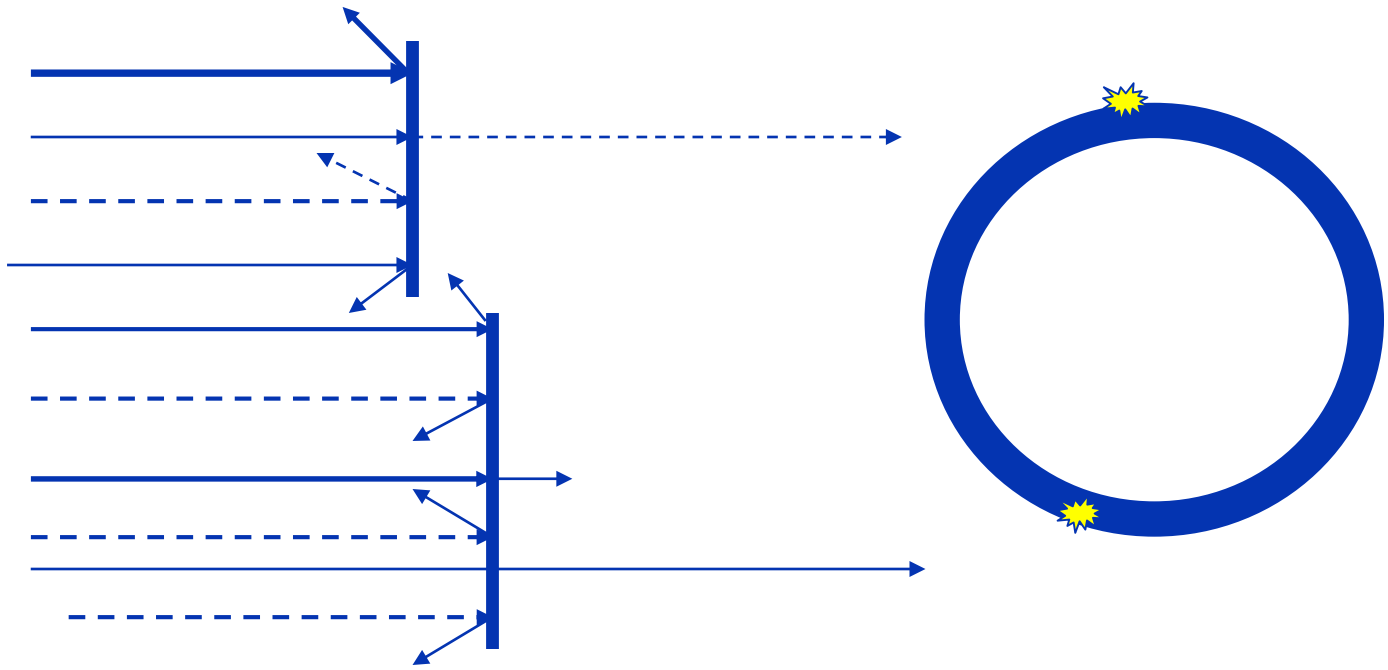

Understanding PoF—Nothing is Perfect

Exposure = Attacks

Mitigation = Barriers/Defenses

Resistance = Strength of Component

- Excavators
- Corrosion
- Vehicles
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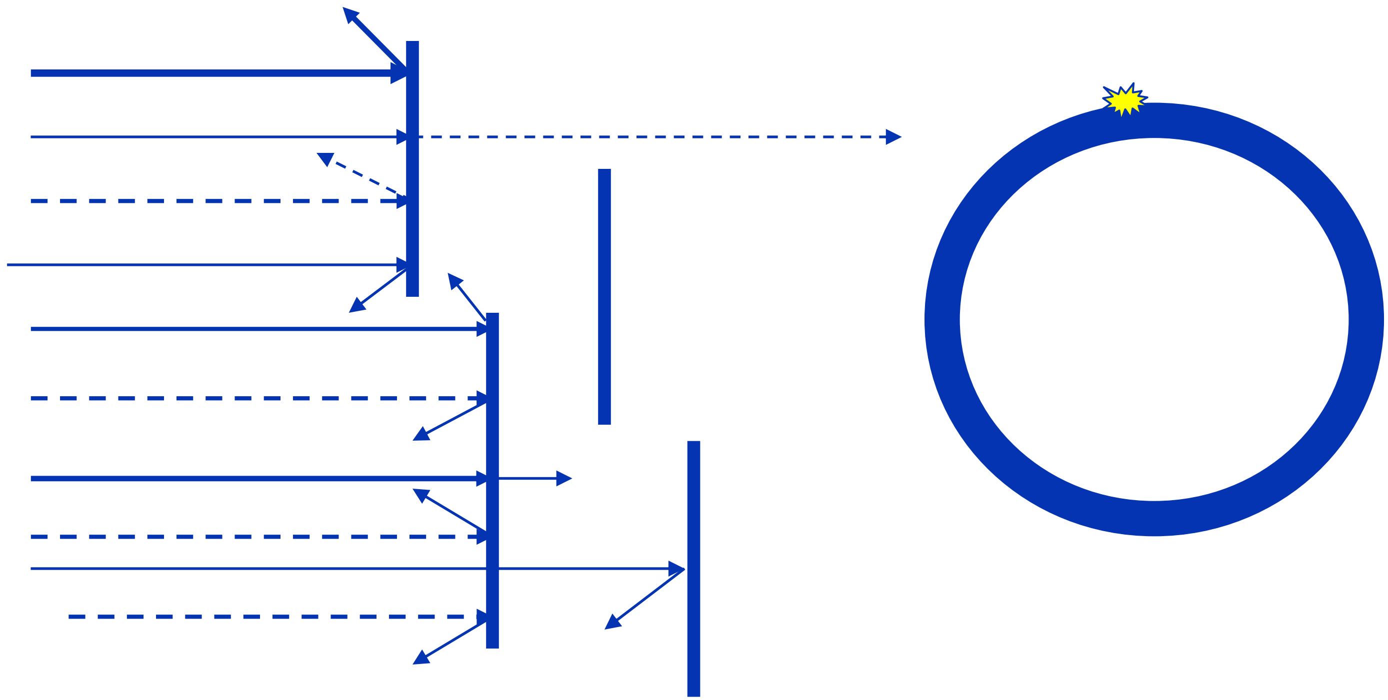
- Etc



Understanding PoF

Exposure =
Attacks

Mitigation =
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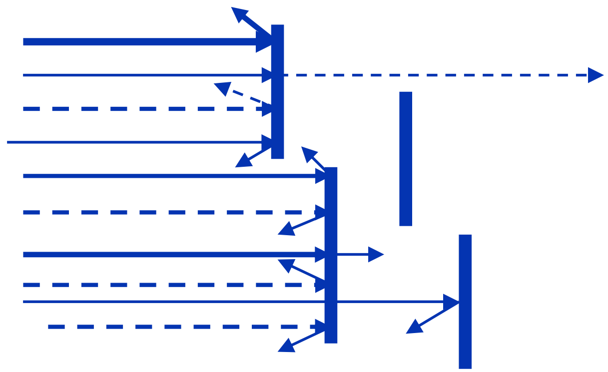
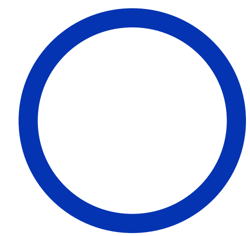
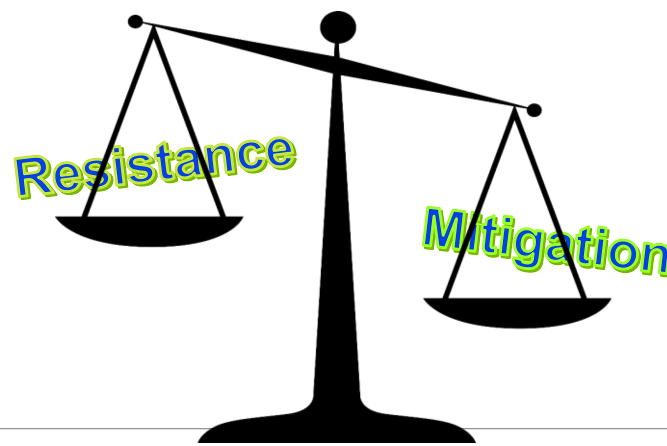






Information Use--Exposure, Mitigation, or Resistance?

pipe wall thickness
air patrol frequency
soil resistivity
coating type
CP P-S voltage reading
date of pipe manufacture
stress level
operating procedures
nearby traffic type and volume
nearby AC power lines (2)
ILI date and type
pressure test psig

maintenance pigging
surge relief valve
casing pipe
flowrate
depth cover
training
SMYS
one-call system type
SCADA
pipe wall lamination
wrinkle bend

Estimating Exposure

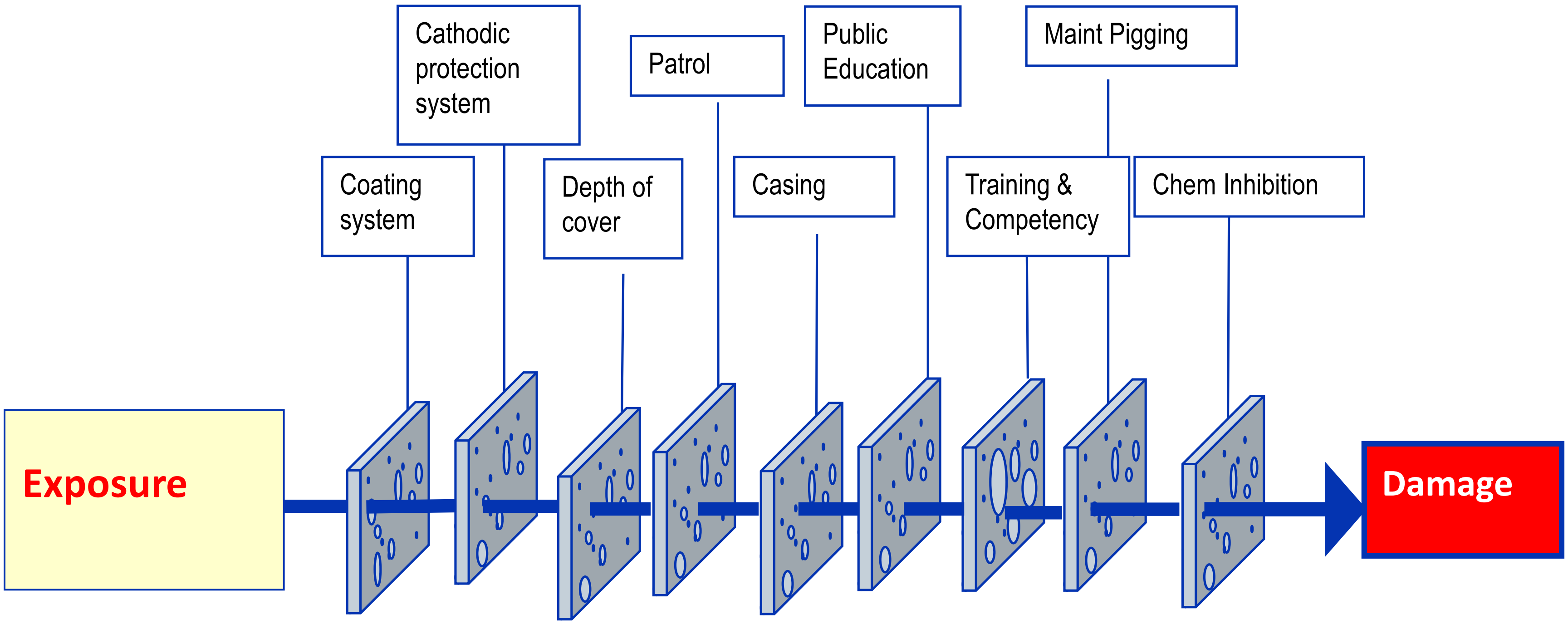
Events per mile-year (km-yr) for time independent mechanism

- third party
- incorrect operations
- weather & land movements
- sabotage

MPY (mm/yr) for degradation mechanisms

- Corrosion (Ext, Int)
- Cracking (EAC / fatigue)

Estimating Mitigation Effectiveness



Estimating Resistance

Component wall thickness as surrogate for ‘stress carrying capacity’

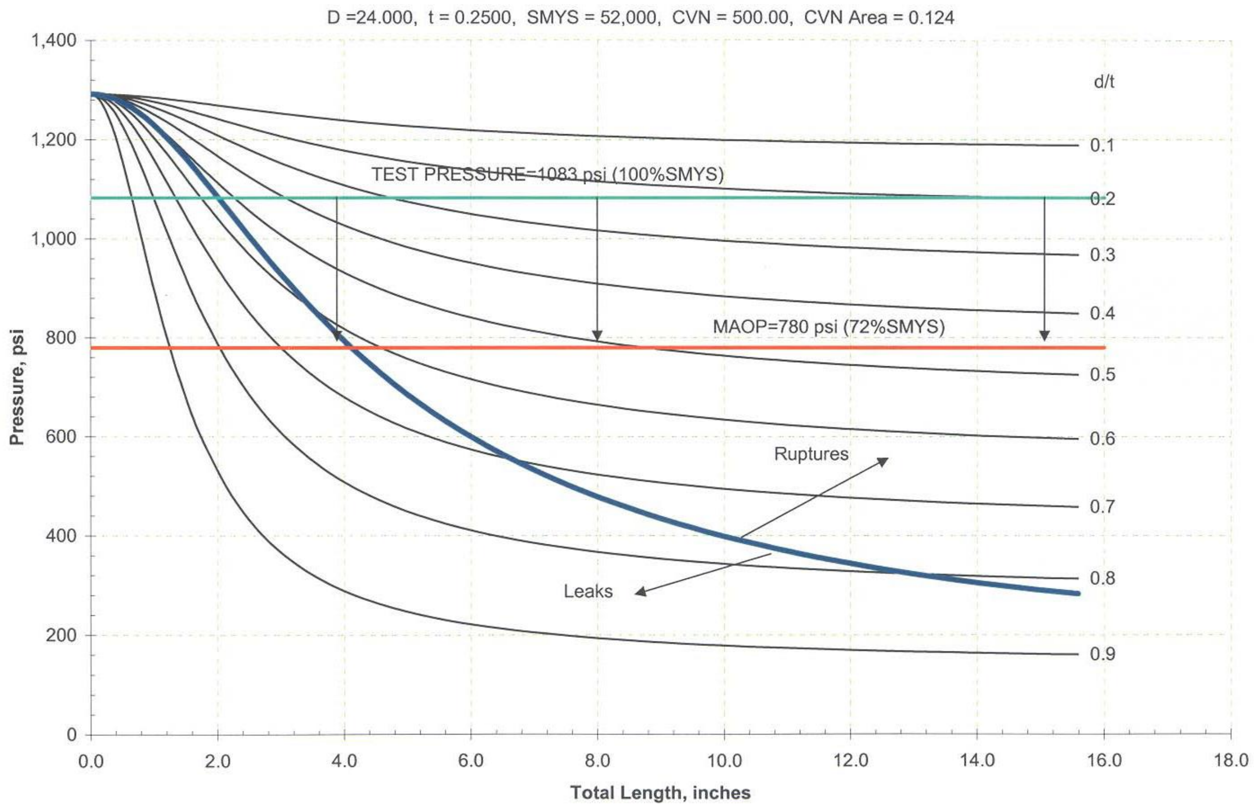
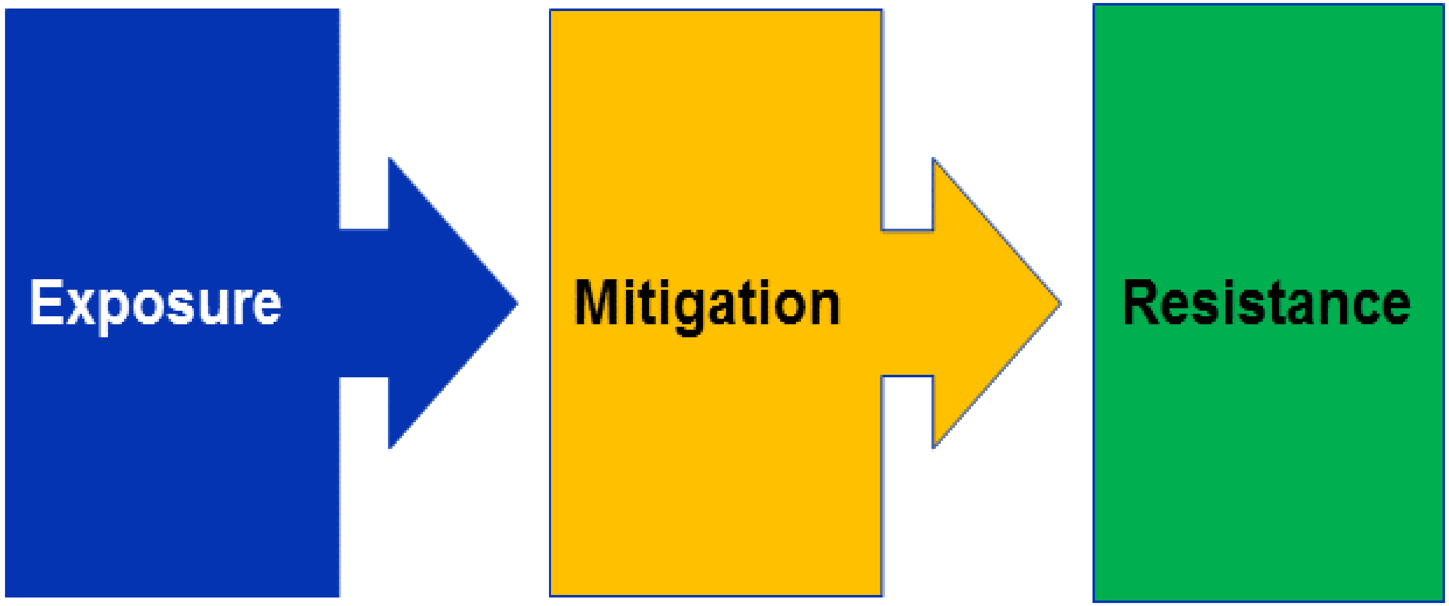


Figure 4. Example Used to Calculate Times to Failure for a High-Stress Pipeline

PoF: Critical Aspects



Probability of Damage or Failure—Simple Concept

- Probability of Damage (PoD)
- Probability of Failure (PoF)

Exposure
Mitigation
PoD
Resistance
PoF

Incidents/year x fraction blocked = PoD (damages/year)

Incidents/year x fraction blocked x fraction damage only = PoF (failures/year)

Probability of Damage or Failure—Simple Math

- Probability of Damage (PoD) = exposure x (1 - mitigation)

- Probability of Failure (PoF) = PoD x (1- resistance)

  {PoF = exposure x (1 - mitigation) x (1 - resistance)}

- PoF (time-dependent) = 1 / TTF

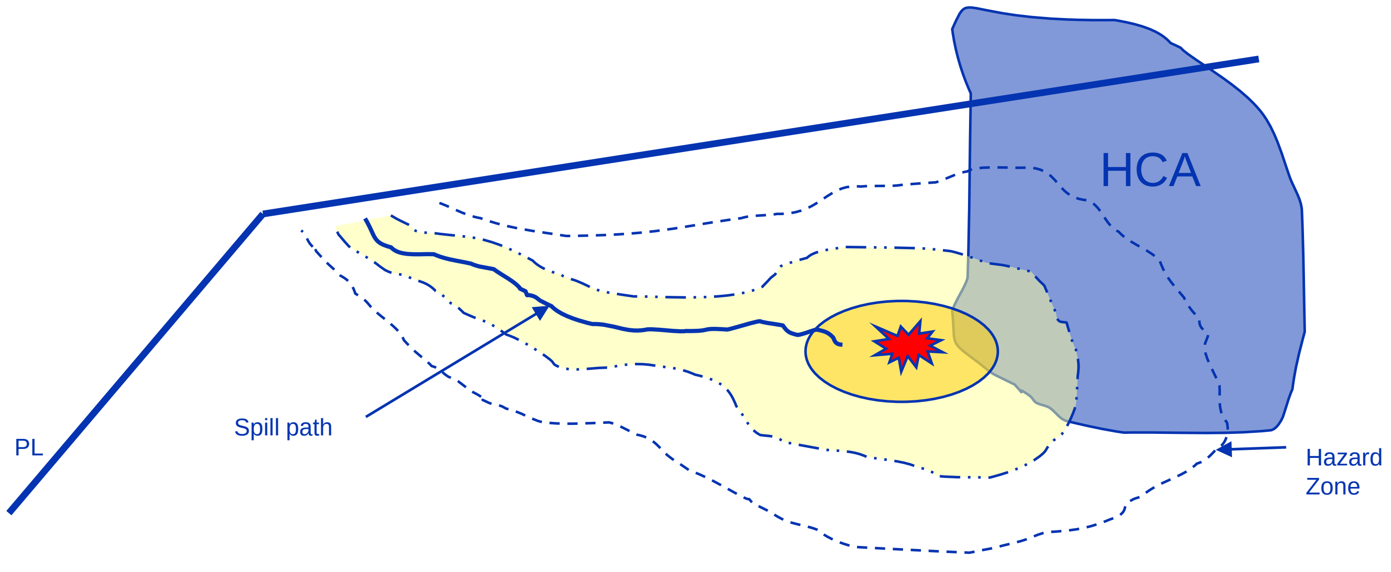
  = exposure * (1 – mitigation) / resistance *(example only)*

Consistent with Proven Design Methodologies

- Similar to: Limit State Design, Load and Resistance Factor Design, Structural Reliability Analyses
  - Focus on engineering principles rather than incident history
  - Accommodates either point estimates or probability distributions as inputs (Level 1 vs Level 2,3,4 methods)
  - Accommodates various definitions of ‘failure’ (choice of limit state)
  - Provides platform for various levels of rigor in evaluation (e.g., remaining strength calculations)
  - Offers more efficient solutions compared to previous, more-prescriptive methods (e.g., use of fixed safety factors)
- However . . . Key differences
  - Must de-couple mitigation from exposure
    - “Mitigated Exposure” greatly diminishes usefulness of RA in RM
    - Resistance is already de-coupled
  - De-emphasizes details of underlying probability theory

Consequence of Failure

- Understanding is well grounded after decades of research
- Must identify and acknowledge the full range of possible consequence scenario **hazard zones**
- Must consider 'most probable' and 'worst case' scenarios



Myths: Data Availability vs Modeling Rigor

Myth:

- Some RA models are better able to accommodate low data availability

Reality:

- Strong data + strong model = accurate results
- Weak data + strong model = uncertain results
- Weak data + weak model = meaningless results

Myth: QRA / PRA Requirements

Myth:

- QRA requires vast amounts of incident histories

Reality:

- QRA ‘requires’ <u>no</u> more data than other techniques
- <u>All</u> assessments work better with better information

- Footnotes:
  - Some classical QRA does over-emphasize history
  - Excessive reliance on history is an error in any methodology

Migrating

PL RA Methodologies—Migrate from What to What?

ASME B31.8s
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Qualitative
Quantitative
Semi-quantitative

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Migrate from What to What?

Index/Scoring Relative
"SME"
"Scenario"
Classical QRA

From
- Any non-model
- Model that is not IMP-suited

To
IMP Suited RA model
can meet all current and
future requirements of US
regulatory IMP

What’s Wrong with Statistics-Centric Modeling?

- Can’t separate exposure, mitigation, resistance
- Location-specific characteristics difficult to include
- Location-specific RA not supported
- Lack of Pertinent Data
- What is comparative population?
  - Unique set of characteristics vs statistically significant counts
  - Multi-factorial issues
- Extrapolations
  - From individuals to population—strong
  - From population to individual--Weak
- Bayesian?

Indexing--?

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- Vintage/Legacy Pipe
- Connection to Real Decision-Making
- Uncertainties

The Mechanics of Migrating

Requested Focus Issues

If it is possible, it would be help for us when composing the guidance document is you can work the following concepts in your presentation as appropriate.

1. How to migrate a relative or semi-quantitative model to a quantitative/probabilistic model
2. What to keep from a semi-probabilistic model and what needs to be improved to be useful in the probabilistic model
3. How to use data to identify and evaluate improvement opportunities in a semi-quantitative risk model before migrating to a probabilistic model
4. How to evaluate data quality and how to utilize quality information into a semi-quantitative and probabilistic risk model

.

Semi-quantitative = indexing, scoring, relative RA

1. How to migrate a relative or semi-quantitative model to a quantitative/probabilistic model

- Six step process
  1. Build translation tool
     - Hard data extract (eg, wall, SMYS, diam, depth, etc)
     - Judgement data extract
       - Units = Events/mile-yr, mpy, inches, %, instances/ft2
     - Assign uncertainty or PXX
  2. Run tool to translate all data from scores to verifiable values
  3. Supplement scores with additional data as required
  4. Conduct RA with converted data
  5. Perform QA/QC
     - Summaries
     - Distributions
     - Stats
     - Calibrations
  6. Adjust translation tool as needed (calibrations, validations)

	Index/Score	New	Measurement/Estimate
depth cover	shallow = 8 pts	mitigation	15%
wrinkle bend	yes = 6 pts	resistance	-0.07" pipe wall
coating condition	fair = 3 pts	mitigation	0.01 gaps/ft2
soil	moderate = 4 pts	exposure	4 mpy

Upgrading Old Scoring/Indexing RA's

- Exposure (events per year)
- Mitigation (% of avoided events)
- Resistance (% damage events that do not result in failure)

	Index/Score	New	Measurement/Estimate
depth cover	shallow = 8 pts	mitigation	15%
wrinkle bend	yes = 6 pts	resistance	-0.07" pipe wall
coating condition	fair = 3 pts	mitigation	0.01 gaps/ft2
soil	moderate = 4 pts	exposure	4 mpy

2. What to keep from a semi-probabilistic model and what needs to be improved to be useful in the probabilistic model

- Keep location-specific data that has been (or can be) verified
  - ‘Hard’ data
  - SME evaluations
- Keep info that is less adulterated by scoring
- Extract exposure, mitigation, resistance when confounded, if possible
- Improve all unverifiable information—convert to verifiable, if possible

3. How to use data to identify and evaluate improvement opportunities in a semi-quantitative risk model before migrating to a probabilistic model

- Data should be driving RA results, so improvement ops for <u>system</u> MIGHT be related to the RA results
  - Rank order listings
    - By risk
    - By PoF
      - By threat
    - By CoF
- Improvement ops for <u>model</u> are related to
  - Counts of data types—
    - how many attack types?
    - How many mitigations?
    - How many resistance factors?
  - Types of defaults being used and where they are used
  - Ability to covert to quantities: ie, depth = ‘medium’ = 28”
  - If opinion-based, degree to which SME’s were facilitated

4. How to evaluate data quality and how to utilize quality information into a semi-quantitative and probabilistic risk model

- Types of uncertainty
  - Don’t know—ie, not measured (epistemic)
  - ‘natural’ variability—ie, where in the distribution (aleatoric)
- Modeling Possibilities to account for ‘quality’
  - Confidence intervals
  - PXX (point estimates)
- Utilization (ie, re-use collected data of decent quality)
  - Use a simple translation tool
    - Hard data extract (eg, wall, SMYS, diam, depth, etc)
    - Judgement data extract
      - Units = Events/mile-yr, mpy, inches, %, instances/ft2
  - Assign uncertainty or PXX to every input

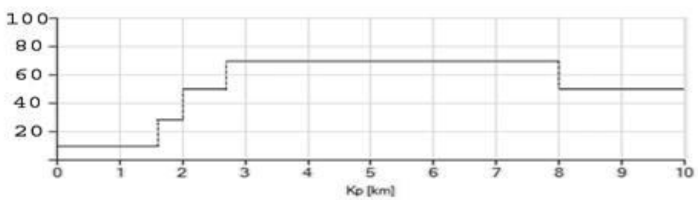
CoF

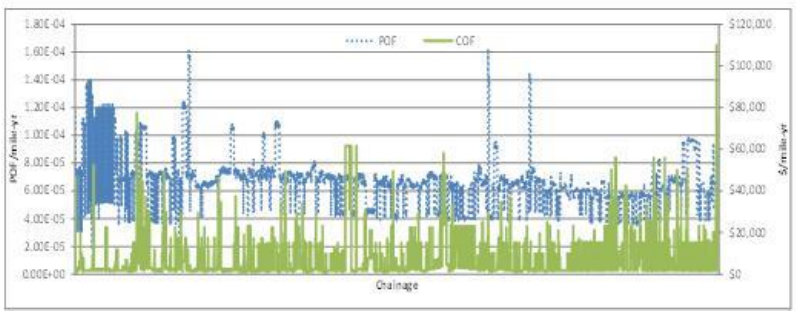
- Very strong tools commonly available
- Ensure that:
  - Quantitative methodology
    - Generation of hazard zone
    - ID receptors
    - ID damage states
    - Probability of various scenarios
  - Representative set of scenarios

Frequency of potential CoF scenarios is often overlooked:

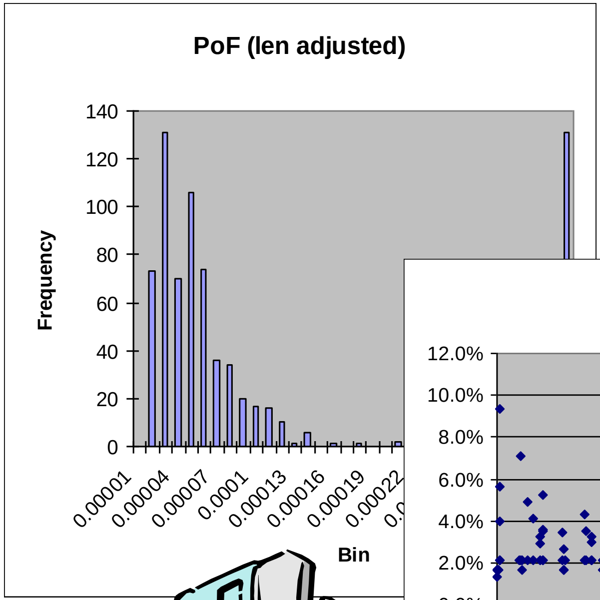
We need to know when ‘really bad’ is much more likely at location A than B, even though ‘really bad’ can happen at either.

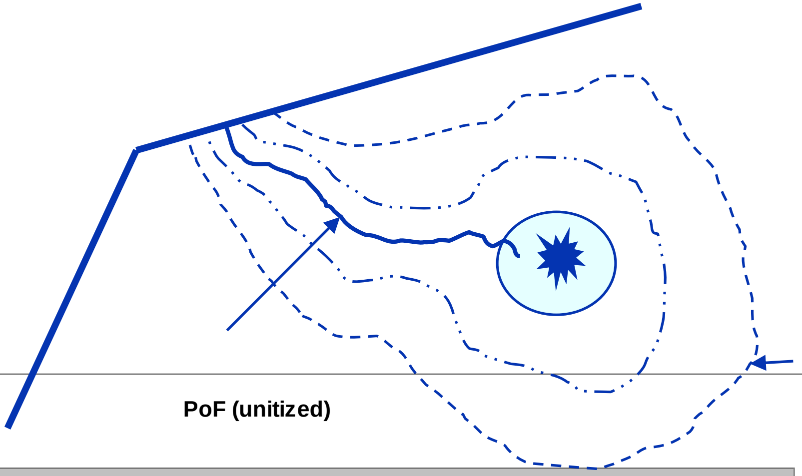
Risk Assessment Maturity

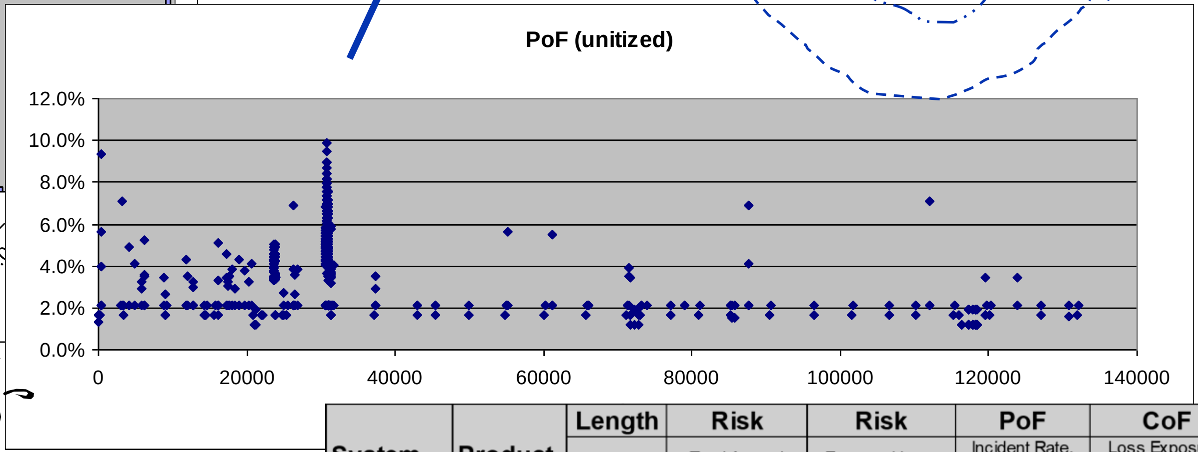


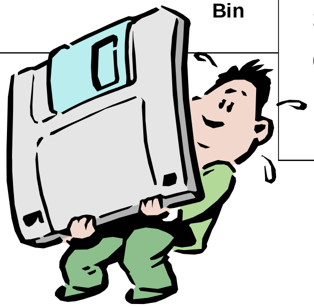


Modern Pipeline Risk Assessment









System	Product	Length miles	Risk Total Annual Exposure	Risk Expected Loss $/mi-yr	PoF Incident Rate, failures per mi-yr	CoF Loss Exposure, Probability-weighted $/failure
Elvira	gasoline	120	$ 142,080	$ 1,184	0.001	$ 1,184,000
Scaramonga	crude oil	408	$ 342,720	$ 840	0.0015	$ 560,000
Perseus	natural gas	23	$ 33,810	$ 1,470	0.007	$ 210,000

Modern RA Modeling Approach

- Supports ‘Letter & Spirit’ of IMP
- High resolution
- Measurements instead of scores
- Accurate/Appropriate mathematical relationships
- Full and Direct use of inspection results
- Ability to express results in absolute terms (verifiable)

Risk Management Implications

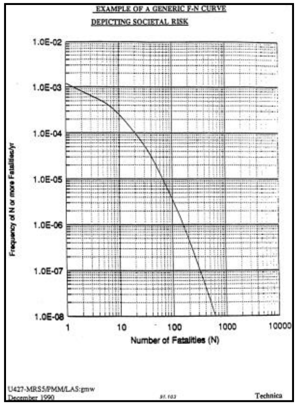
Managing Risks

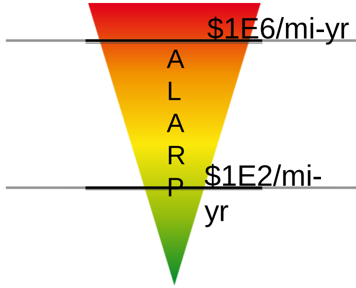
Situations in life often permit no delay; and when we cannot determine the action that is certainly the best, we must follow the action that is probably the best.

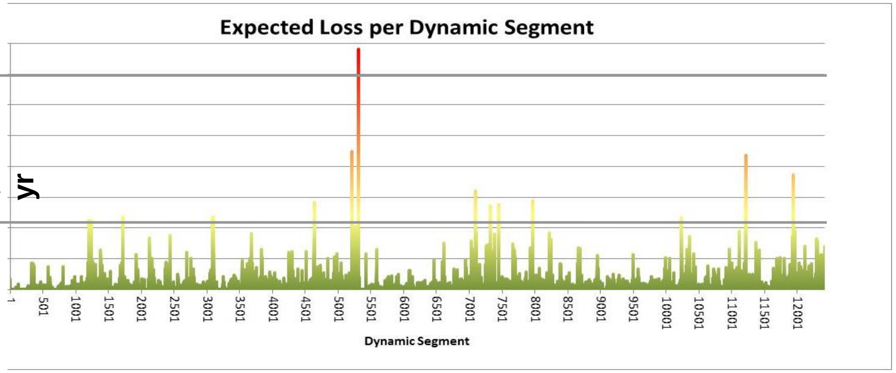
If the action selected is indeed not good, at least the reasons for selecting it are excellent.

Participating in Important Discussions

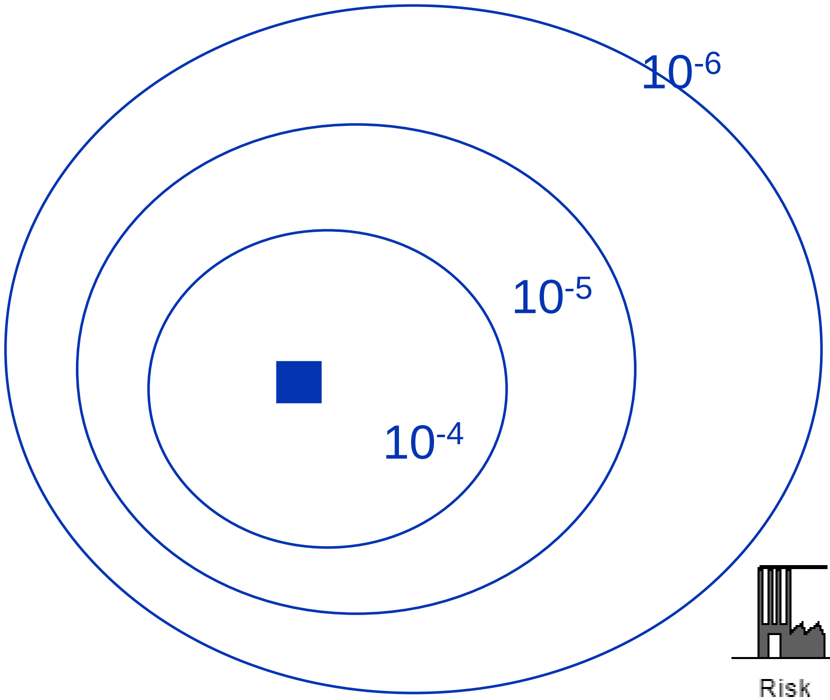
How safe is 'safe enough'?

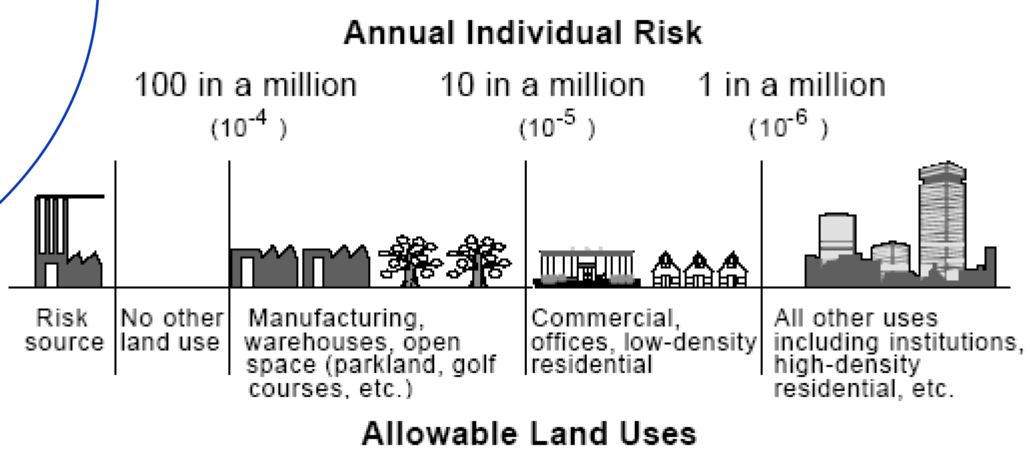






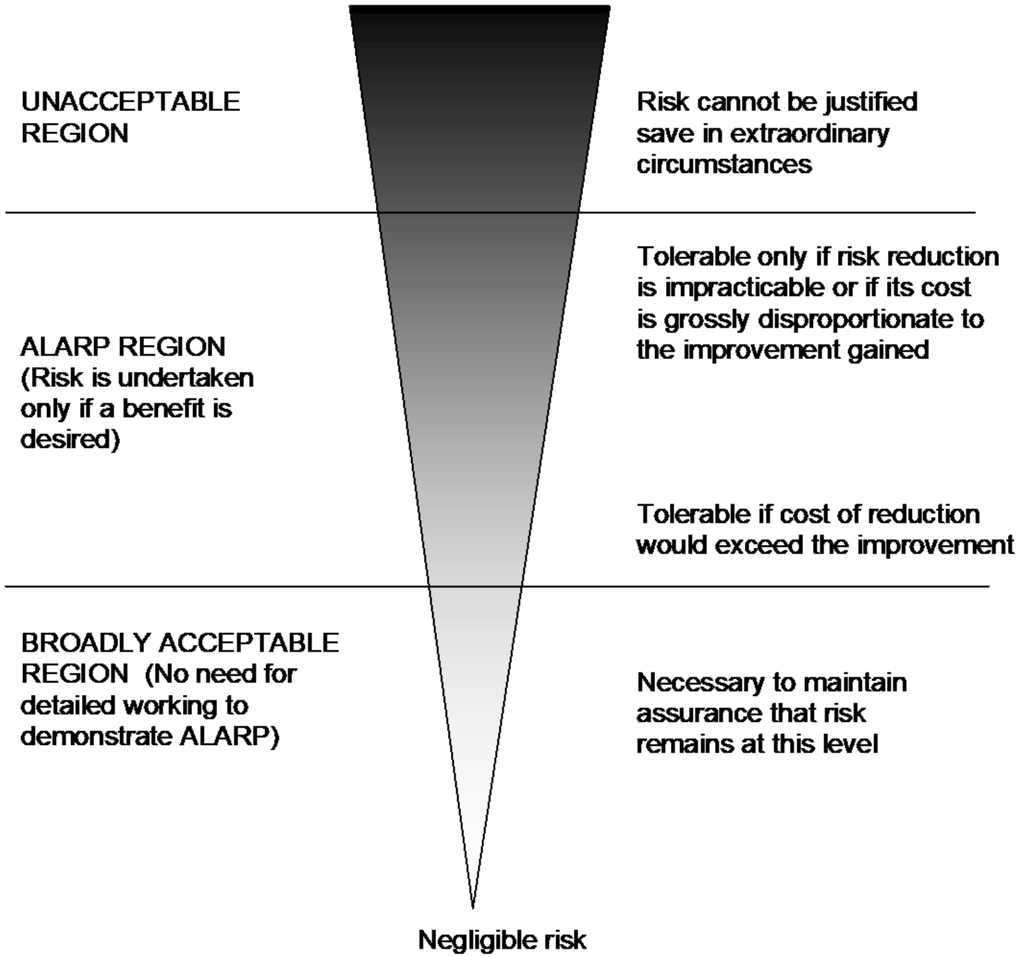
Canadian Risk-Based Land Uses



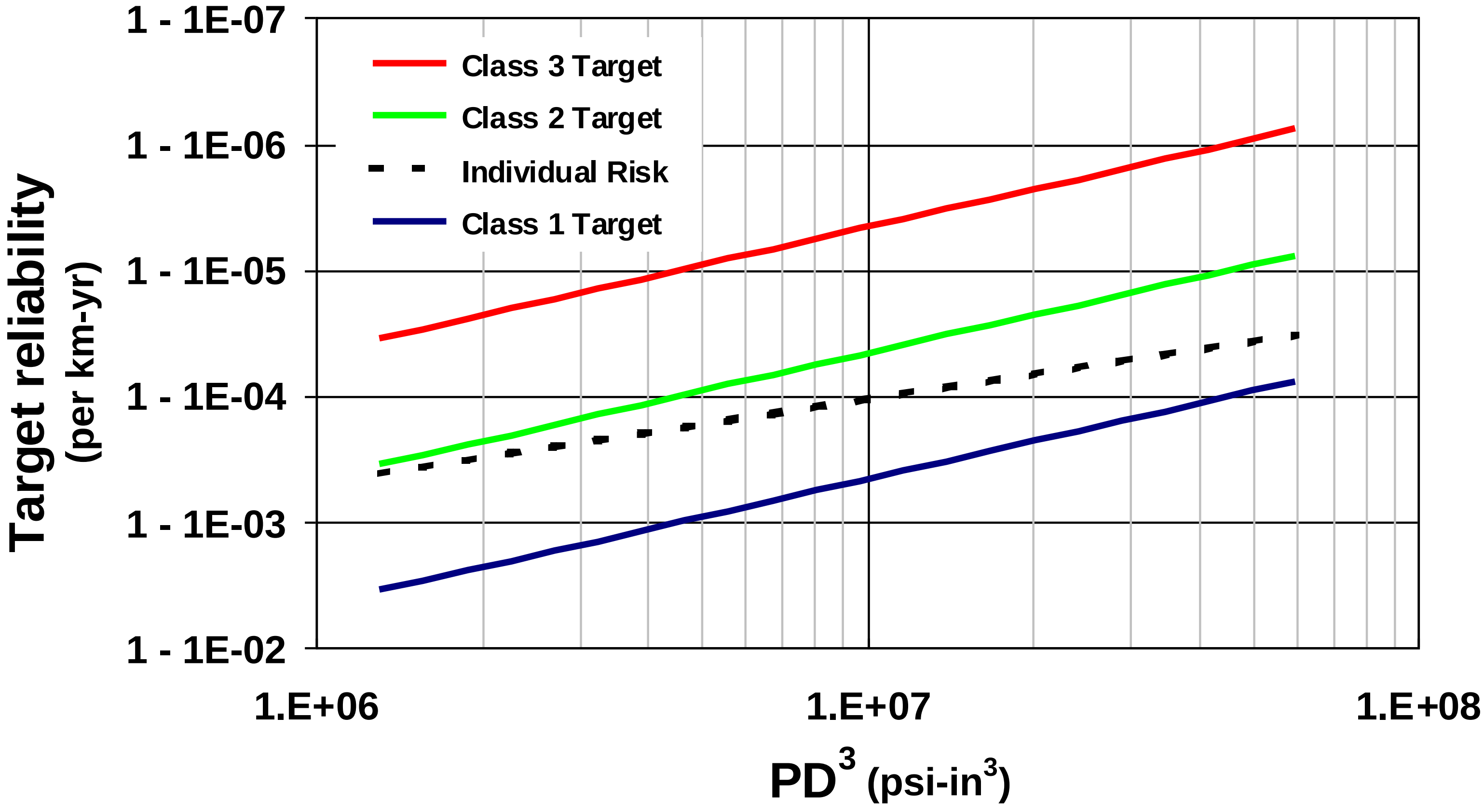


CSChE Risk Assessment – Recommended Practices, MIACC risk acceptability

Acceptable Risk



Reliability Targets

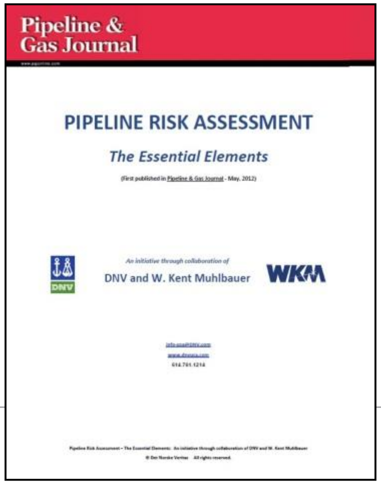


Essential Elements

Essential Elements

- The Essential Elements are meant to
  - Be common sense ingredients that make risk assessment meaningful, objective, and acceptable to all stakeholders
  - Be concise yet flexible, allowing tailored solutions to situation-specific concerns
  - Lead to *smarter risk assessment*
  - Avoid need for ‘one size fits all’ solutions
  - Response to stakeholder criticisms
  - Stepping stone towards RP

- The elements are meant to supplement, not replace, guidance, recommended practice, and regulations already in place
- The elements are a basis for risk assessment certifications
- www.pipelinerisk.net


Pipeline & Gas Journal

PIPELINE RISK ASSESSMENT

The Essential Elements

(First published in Pipeline & Gas Journal - May, 2012)

An initiative through collaboration of

DNV and W. Kent Muhlbauer

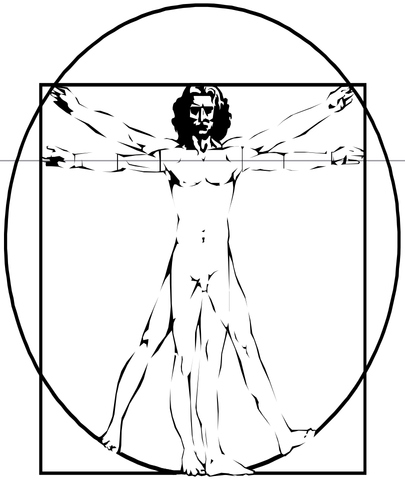
The Essential Elements

- Measurements in Verifiable Units
- Proper Probability of Failure Assessment
- Characterization of Potential Consequences
- Full Integration of Pipeline Knowledge
- Sufficient Granularity
- Bias Management
- Profiles of Pipeline Risk
- Proper Aggregation

Application of EE’s—benefits realized

- Efficient and transparent risk modeling
- Accurate, verifiable, and complete results
- Improved understanding of actual risk
- Risk-based input to guide integrity decision-making: *true risk management*
- **Optimized resource allocation leading to higher levels of public safety**
- Appropriate level of standardization facilitating smoother regulatory audits
  - Does not stifle creativity
  - Does not dictate all aspects of the process
  - Avoids need for (high-overhead) prescriptive documentation
- Expectations of regulators, the public, and operators fulfilled

Hawthorne Effect



"Anything that is studied, improves."

Anticipate enormously more useful information

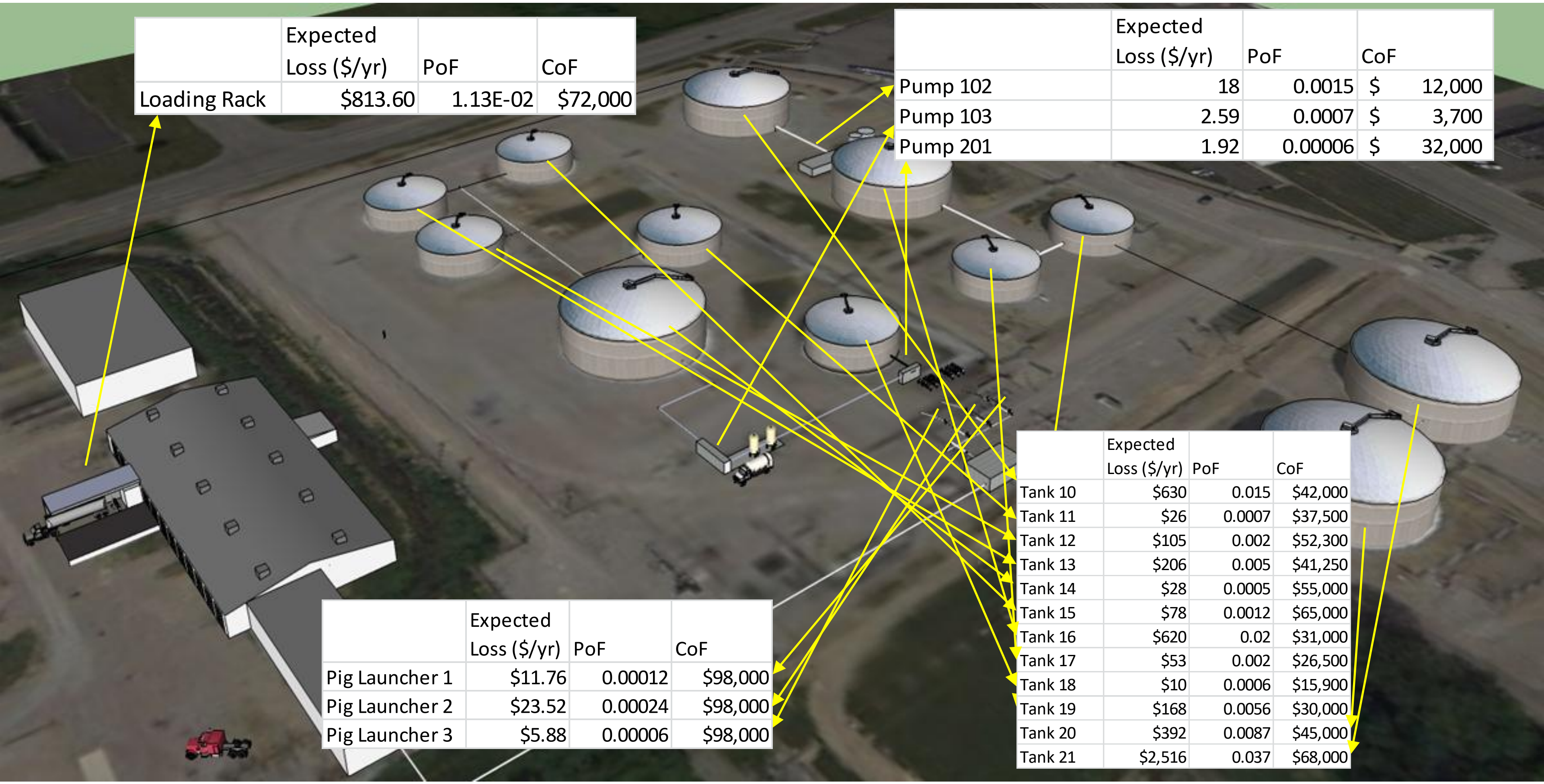
Appendix

‘Cook Book’ Not Needed

- Many difficulties would be associated with attempting to dictate and maintain a prescriptive approach to pipeline RA

Application to Facilities

- Equipment Specific Risk



	Expected Loss ($/yr)	PoF	CoF
Loading Rack	$813.60	1.13E-02	$72,000

	Expected Loss ($/yr)	PoF	CoF
Pump 102	18	0.0015	$ 12,000
Pump 103	2.59	0.0007	$ 3,700
Pump 201	1.92	0.00006	$ 32,000

	Expected Loss ($/yr)	PoF	CoF
Pig Launcher 1	$11.76	0.00012	$98,000
Pig Launcher 2	$23.52	0.00024	$98,000
Pig Launcher 3	$5.88	0.00006	$98,000

	Expected Loss ($/yr)	PoF	CoF
Tank 10	$630	0.015	$42,000
Tank 11	$26	0.0007	$37,500
Tank 12	$105	0.002	$52,300
Tank 13	$206	0.005	$41,250
Tank 14	$28	0.0005	$55,000
Tank 15	$78	0.0012	$65,000
Tank 16	$620	0.02	$31,000
Tank 17	$53	0.002	$26,500
Tank 18	$10	0.0006	$15,900
Tank 19	$168	0.0056	$30,000
Tank 20	$392	0.0087	$45,000
Tank 21	$2,516	0.037	$68,000

Facility Risks

Truck Loading

Expected Loss ($/yr)	$814
Total PoF	1.13E-02
Max CoF	$72,000

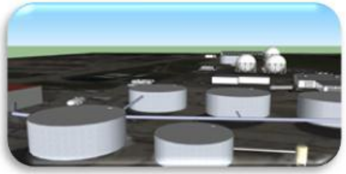
Pig Launchers

Expected Loss ($/yr)	$41
Total PoF	4.20E-04
Max CoF	$98,000

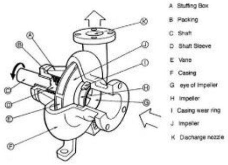
Pumps

Expected Loss ($/yr)	$23
Total PoF	2.26E-03
Max CoF	$32,000

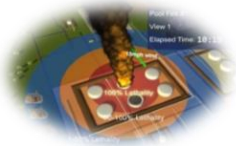
Tankage



Expected Loss ($/yr)	$4,831
Total PoF	9.46E-02
Max CoF	$68,000



Same models used in PLs



Total Facility

Expected Loss ($/yr)	$5,708
Total PoF	1.07E-01
Max CoF	$98,000

Additional Key Takeaways

- A definitive approach is now available
- Significant confusion and errors in terminology and current guidance documents
- Threat interaction requires no special treatment in a modern, complete RA
- Multiple models are not necessary
- Mandating a methodology is not needed—a short list of essential elements ensures acceptability
- RA model certification has begun

WWW.PIPELINERISK.NET