Pipeline Risk Assessment/Management

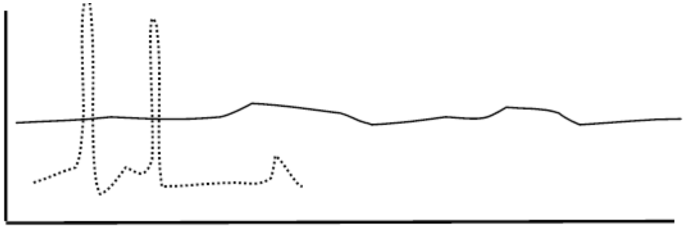
Mini-Workshop

Meeting

The Basics – PL Risk Management

Objective:

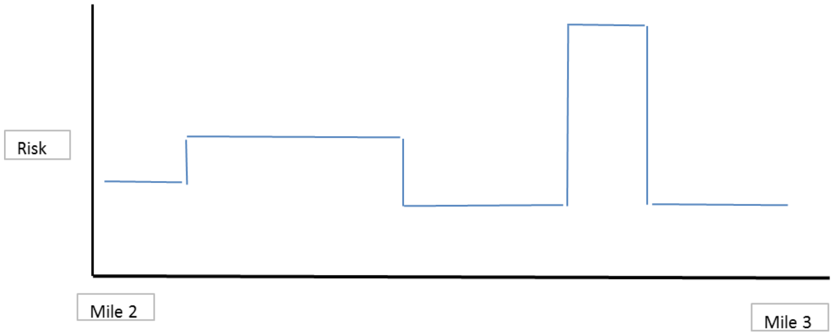
Understand the essential elements of an effective pipeline risk assessment and its role in risk management



Agenda

- Background
- Regulations/standards
- Risk Assessment
  - What to look for
  - Essential Elements
- Risk Mgmt Implications

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



Bellingham, WA 1999

Appomattox, VA 2008

San Bruno, CA 2010

Kalamazoo River, MI 2010

Carlsbad, NM 2000

Mayflower, AR 2013

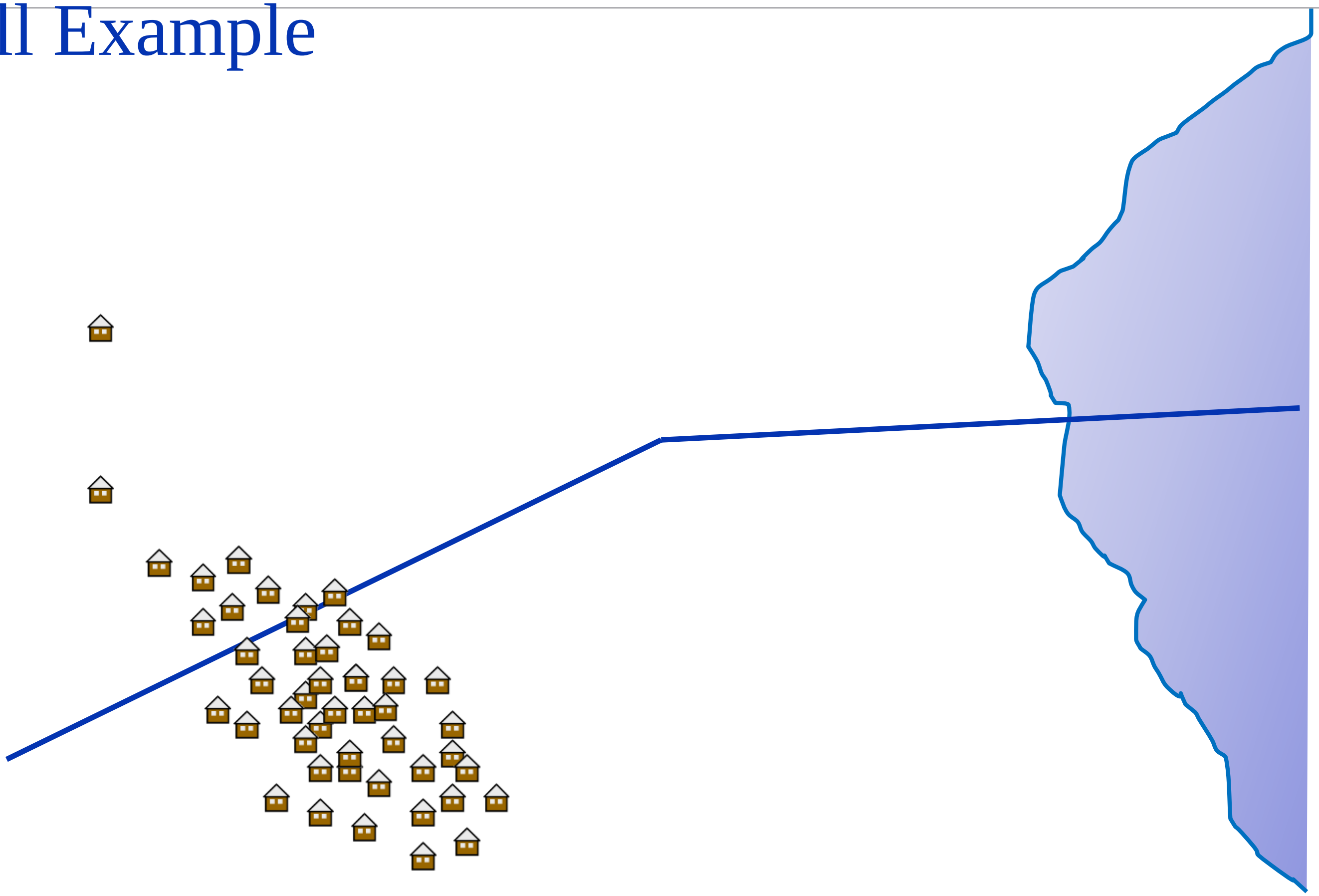
Kalamazoo River, 2010

$1,000,000,000 spent

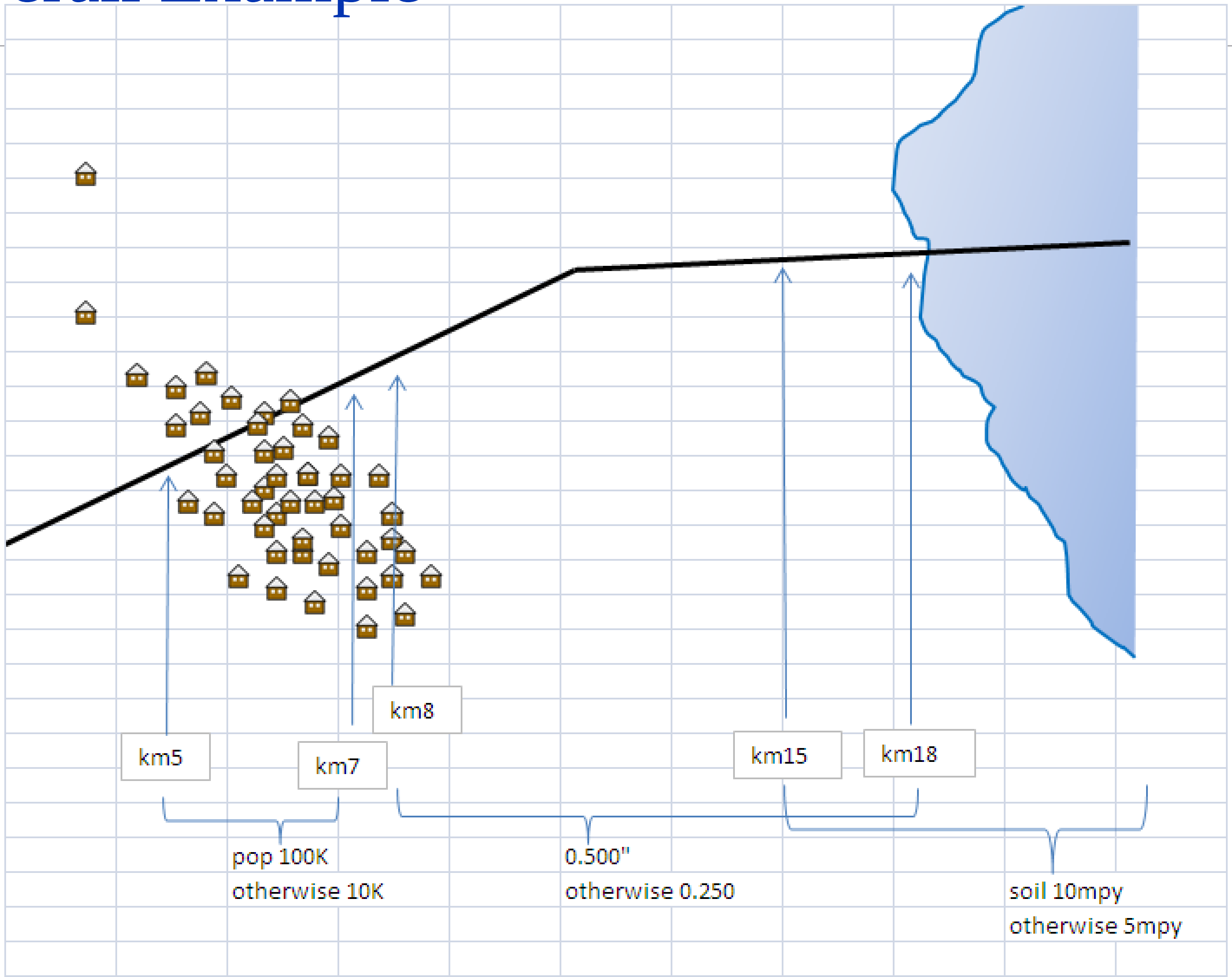
10ft creek

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

Overall Example



Overall Example



Overview Data Collection

beg	end	event	code	Units
0	8	pipe wall		inches
8	18	pipe wall		inches
18	20	pipe wall		inches
0	15	soil		mpy
15	20	soil		mpy
0	5	pop		$/event
5	7	pop		$/event
7	20	pop		$/event
0	20	coat/CP		% effective

How to segment?

Overview Risk Calcs

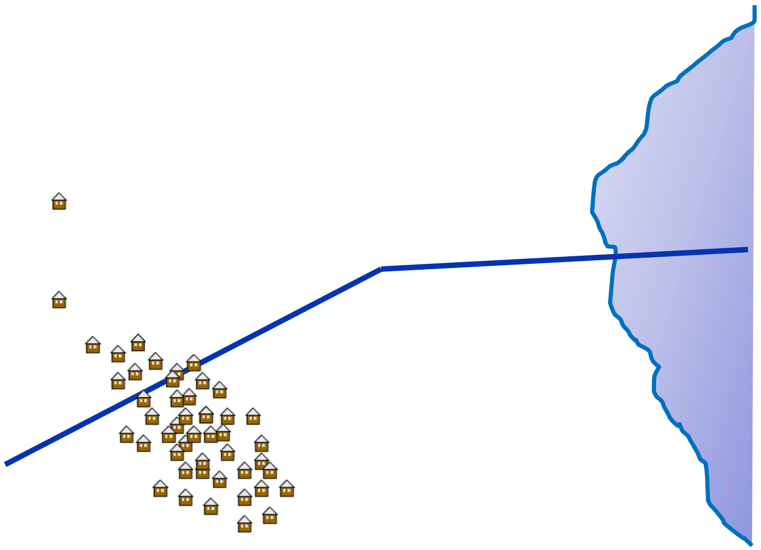
beg	end	pipe_wall	soil	pop	mpy mit	TTF, yrs	PoF, yr1	EL, $/yr
0	5	0.25	5	10000	0.5	500	0.002	$ 20
5	7	0.25	5	100000	0.5	500	0.002	$ 200
7	8	0.25	5	10000	0.5	500	0.002	$ 20
8	15	0.5	5	10000	0.5	1000	0.001	$ 10
15	18	0.5	10	10000	1	500	0.002	$ 20
18	20	0.25	10	10000	1	250	0.004	$ 40
							0.013	$ 310
				coat/CP	90%			

CoF = pop
TTF = pipe_wall / mpy mit
PoF = 1 / TTF
EL = PoF x CoF

Overall Example

1.3% PoF Corr Ext for 20 km
EL = $310 / year

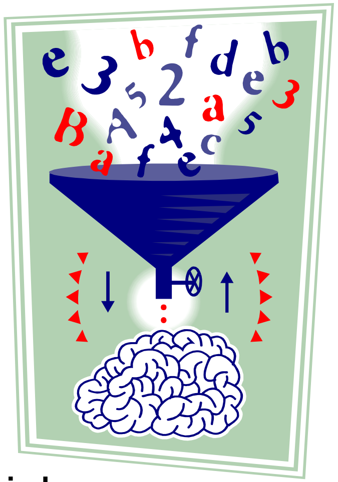
Demonstrations of
Centerlines
Efficient data collection
Data management
Dynamic segmentation
Risk estimates
Risk aggregation
High tech on a ‘scratch pad’



Background

Reality Check

- RM is not new; requires RA
- Risk-based decision-making is complex
  - Because the real world is complex, measuring risk is complex
    - 200+ variables & 200+ calculations for every inch of pipe
    - real factors, real considerations
  - RM is even more complex than RA

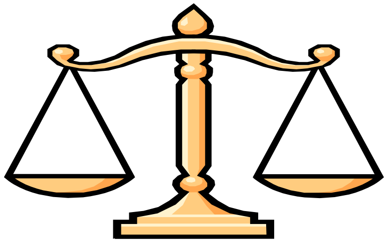


- Dealing with the complexity is worthwhile
  - increases understanding
  - shows full range of options; many opportunities to impact risk
  - cheaper than prescriptive 'solutions'
  - Improves decision-making

Reality Check, Part Two

If you put tomfoolery into a computer, nothing comes out of it but tomfoolery. But this tomfoolery, having passed through a very expensive machine, is somehow ennobled and no-one dares criticize it.

- Pierre Gallois

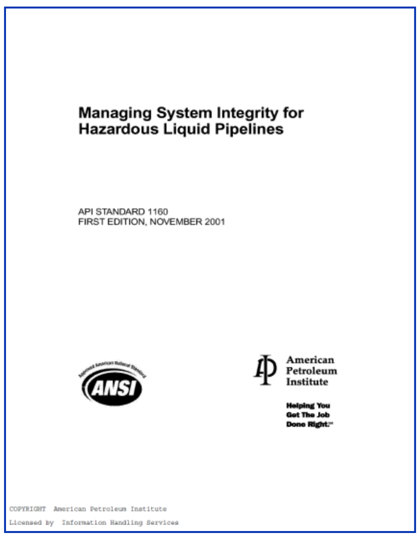


The Illusion of Knowledge

IMP RA Regulations & Standards

Pertinent Regulatory/Standards

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

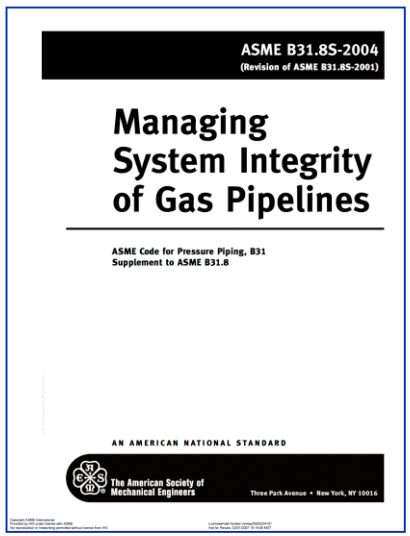

Managing System Integrity for Hazardous Liquid Pipelines

API STANDARD 1160
FIRST EDITION, NOVEMBER 2001

ANSI

American Petroleum Institute

Helping You Get The Job Done Right.


ASME B31.8S-2004
(Revision of ASME B31.8S-2001)

Managing System Integrity of Gas Pipelines

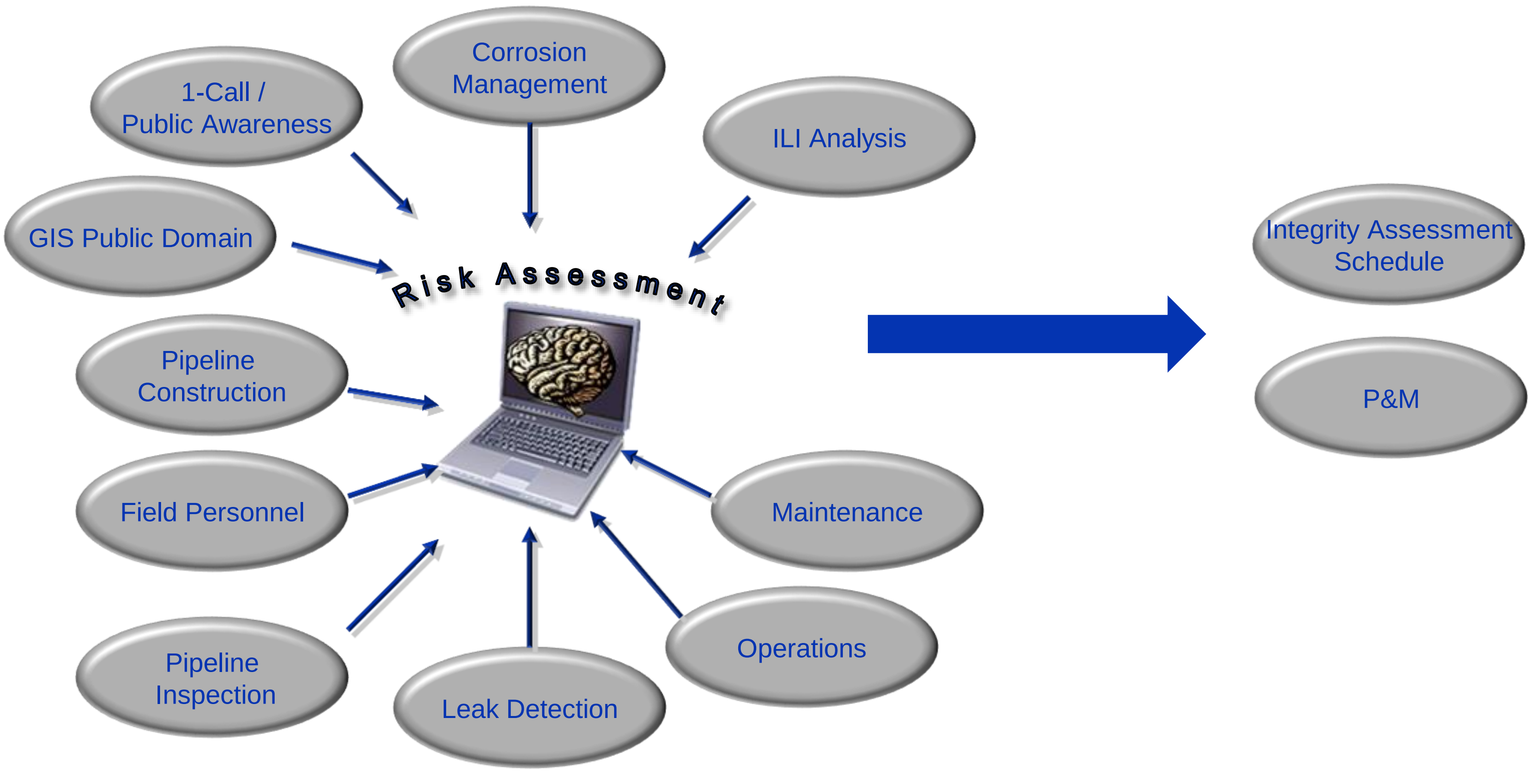
ASME Code for Pressure Piping, B31
Supplement to ASME B31.8

AN AMERICAN NATIONAL STANDARD

The American Society of Mechanical Engineers
Three Park Avenue • New York, NY 10016

- 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

RA is the Centerpiece of IMP



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

Gas IM Rule RA

- Account for relevant attributes
- Use conservative defaults for unknown data
- Identify significant risk-driving factors
- Sufficient segment discretization or resolution
- Predictive or “what-if” capability
- Updateable to reflect changes or new information
- Populating risk model is resource intensive
- Validate model, show to be plausible with respect to known history and significance of threats

ASME B31.8S, Section 5

B31.8S Threat Categories

- ASME B31.8 supplement considers 3 categories of threat:
  - *Time dependent* – may worsen over time; require periodic reassessment
  - ~~*Time stable* – does not worsen over time; one-time assessment is sufficient (unless conditions of operation change)~~
  - *Time independent* – occurs randomly; best addressed by prevention

Threat Categories: Time Dependent Threats

- External corrosion
- Internal corrosion
- Stress-corrosion cracking (SCC)

Threat Categories: Time Independent (Random) Threats

- Third-party/Mechanical damage
  - Immediate failure
  - Delayed failure (previously damaged)
  - Vandalism
- Incorrect operations
- Weather related
  - Cold weather
  - Lightning
  - Heavy rain, flood
  - Earth movement

Threat Categories:

~~Time Stable Threats~~ Resistance

- Manufacturing-related flaws in
  - Pipe body
  - Pipe seam
- Welding / Fabrication-caused flaws in
  - Girth welds
  - Fabrication welds
  - Wrinkled / buckled bend
  - Threads / couplings
- Defects present in equipment
  - Gaskets, O-rings
  - Control / relief devices
  - Seals, packing
  - Other equipment

ASME B31.8s

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

Confusion: tools vs models

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)*

PL RA Methodologies

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

Probabilistic
Mechanistic
Deterministic

Qualitative
Quantitative
Semi-quantitative

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

Measure in Verifiable Units

Absolute Risk Values

Frequency of consequence

- Temporally
- Spatially

•Incidents per mile-year

•fatalities per mile-year

•dollars per km-decade

conseq prob

<u>Ingredients</u>

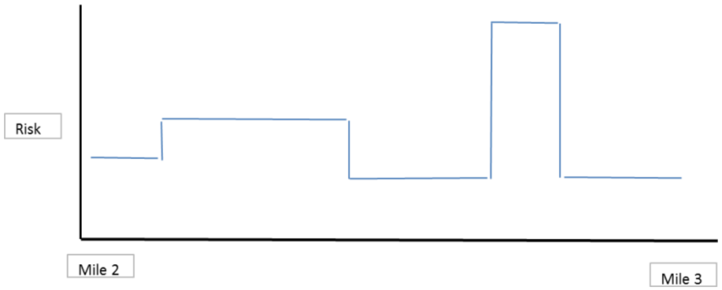
events/yr
events/mile-year
mpy corrosion
mpy cracking
TTF = pipe wall / mpy
% reduction in events/mi-yr
% reduction in mpy
% damage vs failure

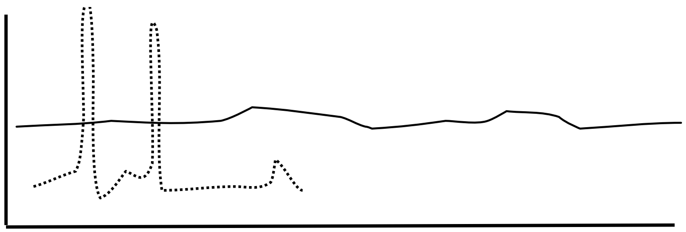
ASME B31.8S Summary of Updates Needed

- 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 ASME B31.8s threat list confuses failure mechanisms and vulnerabilities.
- The ASME B31.8s methodology discussion confuses risk models with characteristics of risk models or tools used in risk analyses.
- The use of weightings is always problematic, rarely appropriate, but appears to be mandated in inspection protocols based on ASME B31.8S language.

Inspecting a Risk Assessment

Easy to Spot (and Correct!) Methodology Weaknesses





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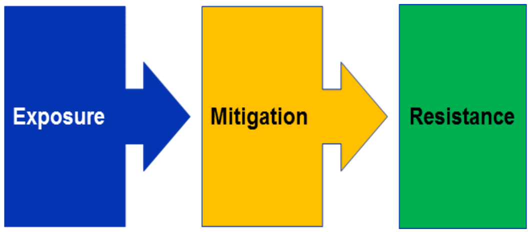


What does that mean?

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

Qualitative
Quantitative
Semi-quantitative

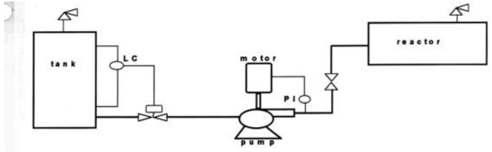
Probabilistic
Mechanistic
Deterministic

QRA
PRA
Indexing
Scoring

Hazard ID & Risk Analyses Tools

- 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.

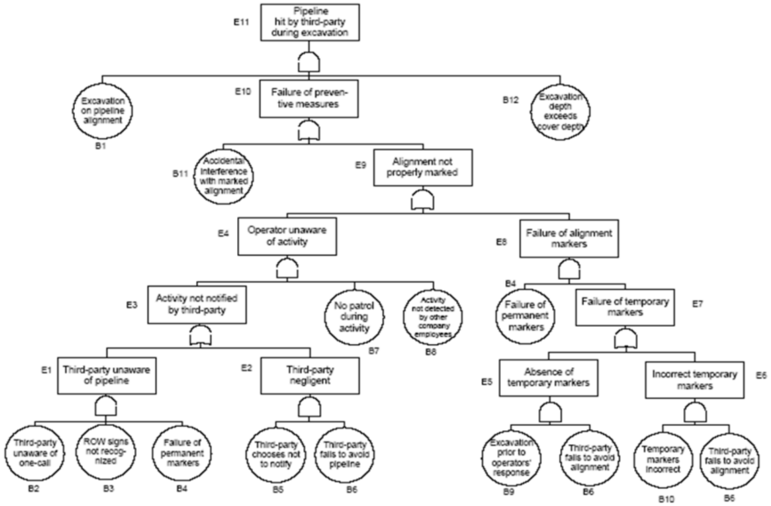
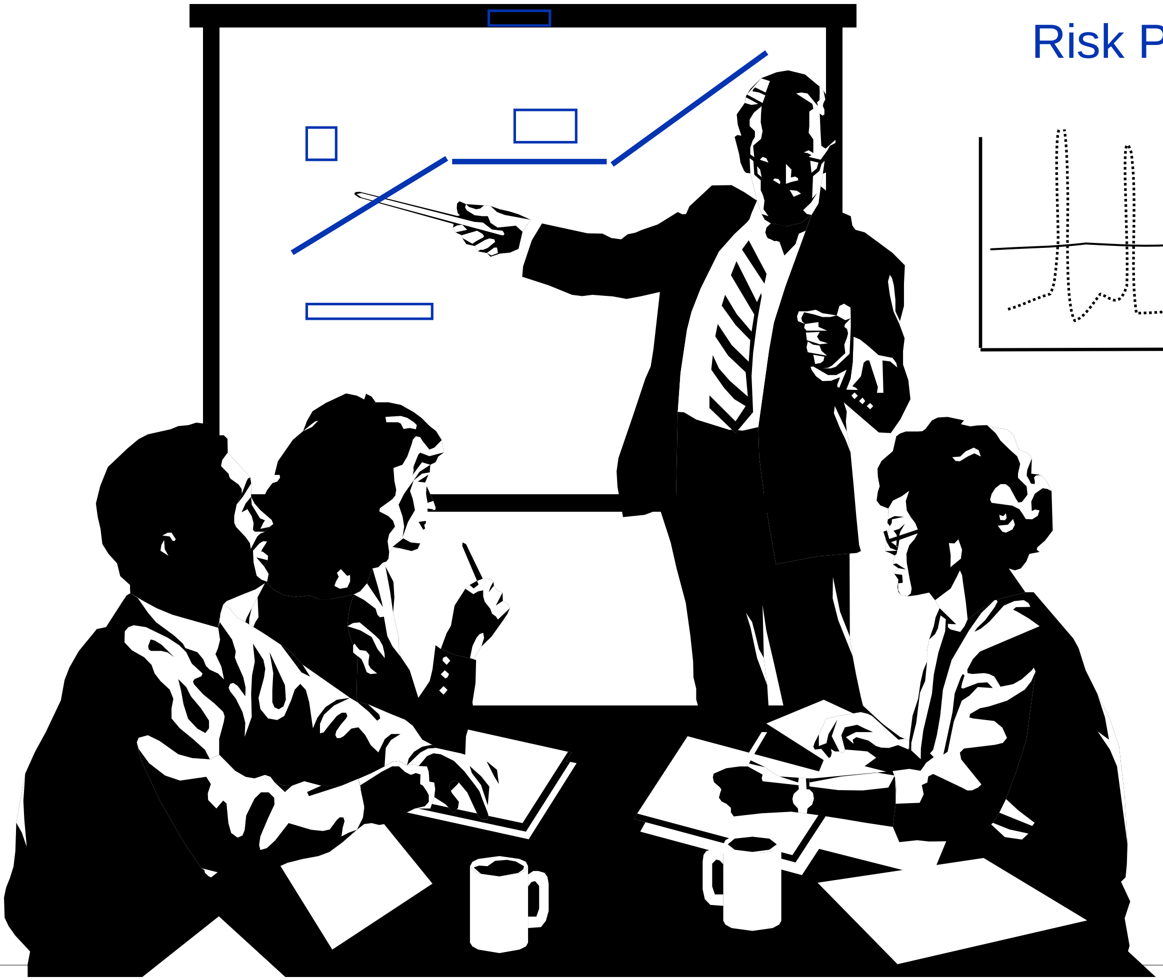


Figure 3.2 Fault tree for mechanical interference by a third party during excavation.

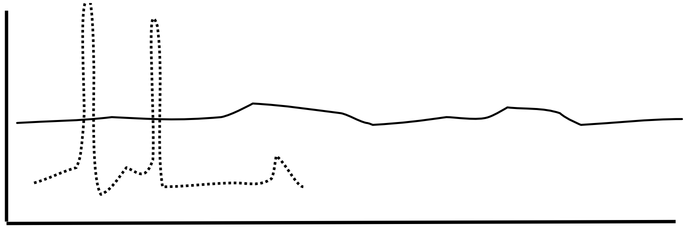
Judging a Risk Assessment

- “Technically justifiable . . .”
- “Logical, structured, and documented….”
- “Assurance of completeness…”
- “…incorporates sufficient resolution…”
- “Appropriate application of risk factors….”
- “Explicitly accounts for…” and combines PoF and CoF factors
- “Process to validate results…”
- P&M based on risk analyses

Passing the ‘Map Point’ Test

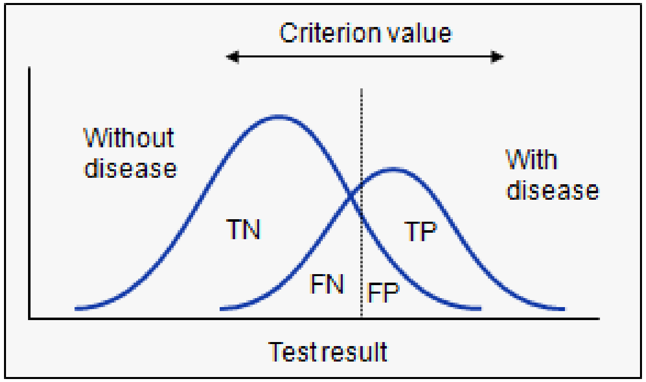


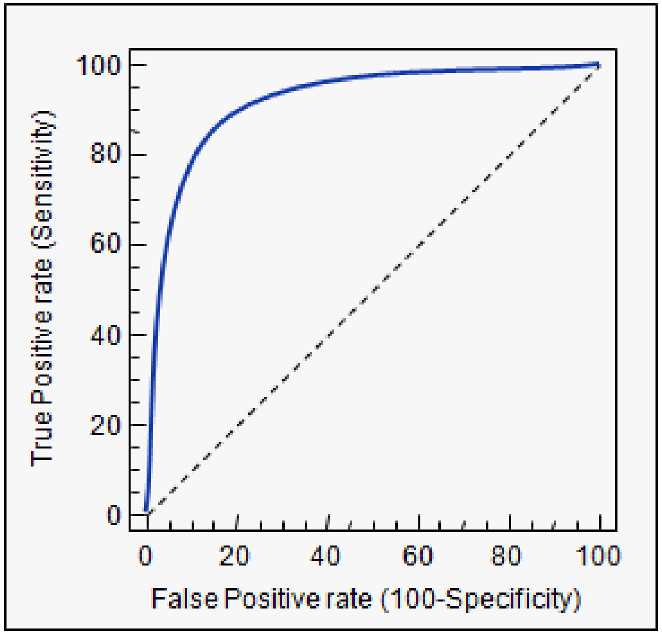
Risk Profiles



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?

PHMSA Concerns

U.S. Department of Transportation
Pipeline and Hazardous Materials
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

U.S. Department of Transportation
Pipeline and Hazardous Materials
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

U.S. Department of Transportation
Pipeline and Hazardous Materials
Safety Administration

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

U.S. Department of Transportation
Pipeline and Hazardous Materials
Safety Administration

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

Relative, Index, Scoring Models

- Intuitive
- Comprehensive
- Ease of setup and use
- Optimum for prioritization
- Mainstream
- Served us well in the past

Scoring Model Issues

- Artificial, inefficient layer
- Not designed for IMP
- Difficult to anchor
- Potential for masking
- Technical compromises
  - Weightings
  - Scale direction
  - Interactions of variables (dep vs indep)
- Validation (reg reqmt)
- New uses

Hearsay

Common Complaints:

"We've been waiting for two years to start generating results we can trust"

"We have a risk assessment, but we can't use the results for anything"

"We purchased a sophisticated off-the-shelf solution, but we're not really sure how it calculates risk"

"Our risk assessment methodology was developed internally ages ago, how do we know if it's still acceptable?"

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:

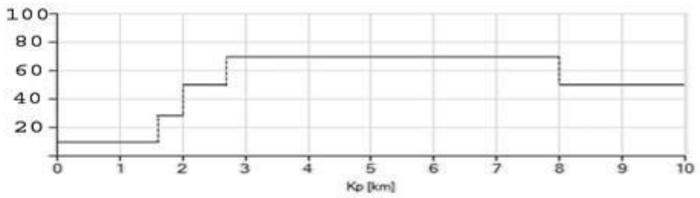
- QRA requires vast amounts of incident histories

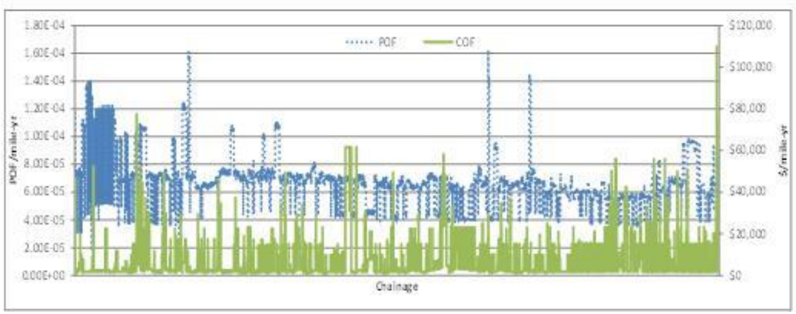
Reality:

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

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

Risk Assessment Maturity

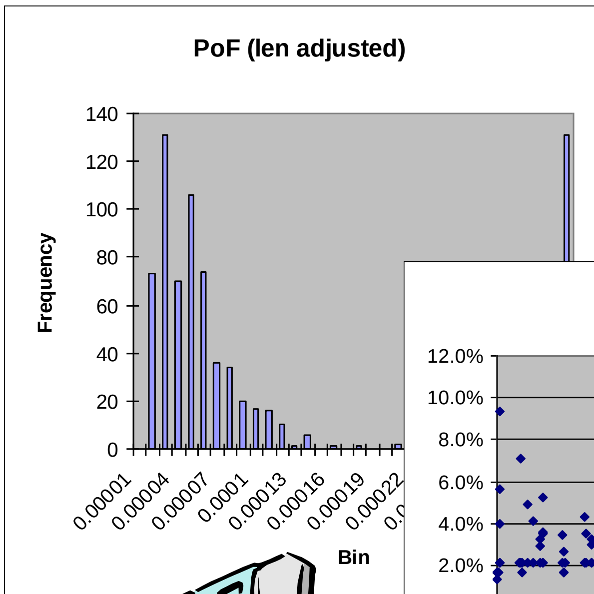


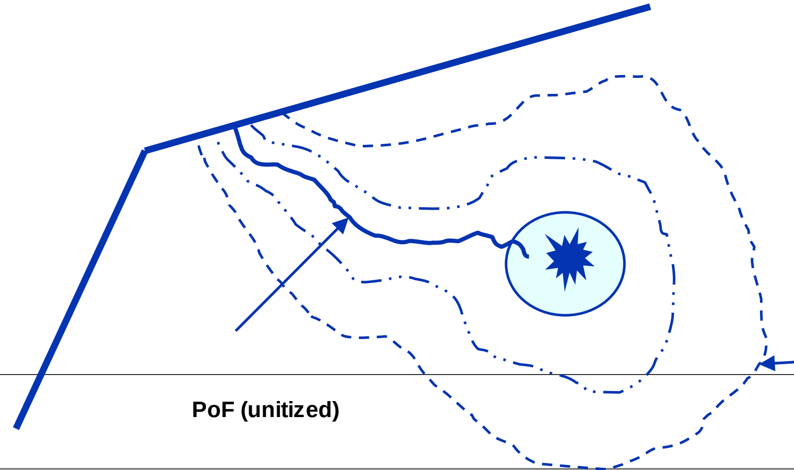


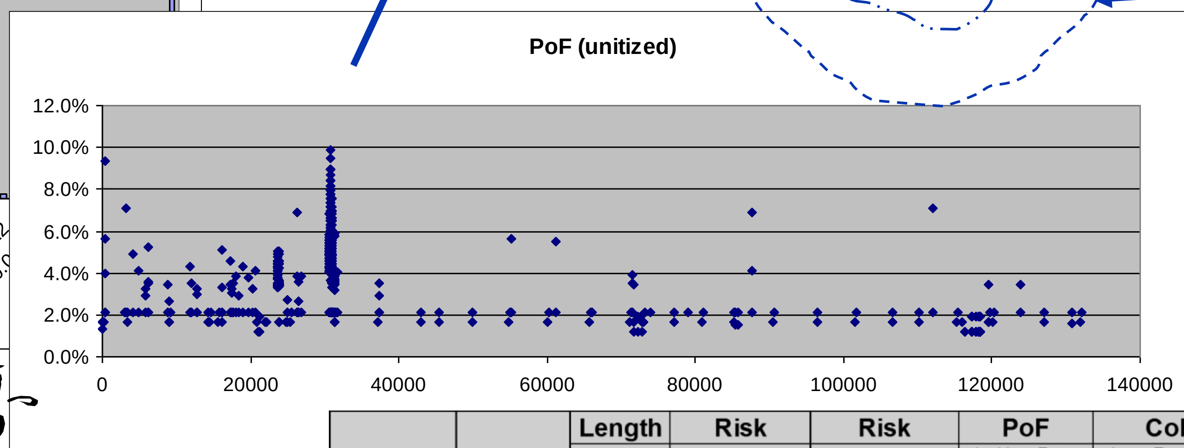
Modern RA Modeling Approach

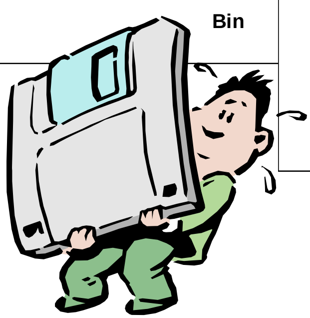
- High resolution
- Measurements instead of scores
- Accurate/Appropriate mathematical relationships
- Direct use of inspection results
- Ability to express results in absolute terms

Modern Pipeline Risk Assessment









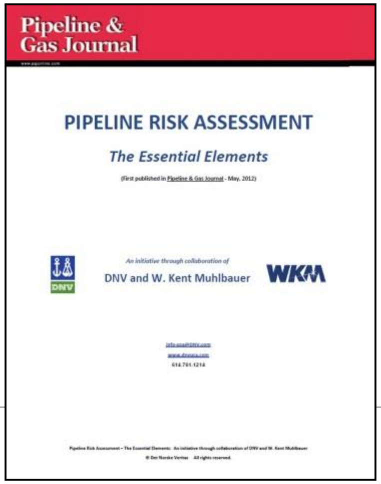
System	Product	Length miles	Risk Total Annual Exposure	Risk Expected Loss $/mi-yr	PoF Incident Rate, failures per mi-yr	CoF Loss Exposure, Probability-weighted $/failure
Elvira	gasoline	120	$ 142,080	$ 1,184	0.001	$ 1,184,000
Scaramonga	crude oil	408	$ 342,720	$ 840	0.0015	$ 560,000
Perseus	natural gas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

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

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 Risk

Proper Aggregation

Measure in Verifiable Units

- Must include a definition of “Failure”
- Must produce *verifiable* estimates of PoF and CoF in commonly used measurement units
- PoF must capture effects of length and time
- Must be free from intermediate schemes (scoring, point assignments, etc)

> “Measure in verifiable units” keeps the process transparent by expressing risk elements in understandable terms that can be calibrated to reality

Verifiable Risk Values

Measure in Verifiable Units

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

events/yr
events/mile-year
mpy corrosion
mpy cracking
TTF = pipe wall / mpy
% reduction in events/mi-yr
% reduction in mpy
% damage vs failure

Risk = Frequency of consequence
- Temporally
- Spatially

- Incidents per mile-year
- fatalities per mile-year
- dollars per km-decade

conseq prob

Why measurements instead of scores?

- Less subjective
- Anchored in ‘real world’ (incl orders magnitude, OR gates, etc)
- Defensible, verifiable over time
- Avoids need for ‘cook book’
- Avoids erosion of score definitions
- Allows calculation of costs and benefits
- Supports better decisions
- Auditable

Probability of Failure Grounded in Engineering Principles

1. Measure in Verifiable Units
2. **Probability of Failure Grounded in Engineering Principles**
3. Fully Characterize Consequence of Failure
4. Profile the Risk Reality
5. Integrate Pipeline Knowledge
6. Incorporate Sufficient Granularity
7. Control the Bias
8. Unmask Aggregation

- All plausible failure mechanisms must be included in the assessment of PoF
- Each failure mechanism must have the following elements independently measured:
  - Exposure
  - Mitigation
  - Resistance
- For each time dependent failure mechanism, a theoretical remaining life estimate must be produced

Proper PoF Characterization

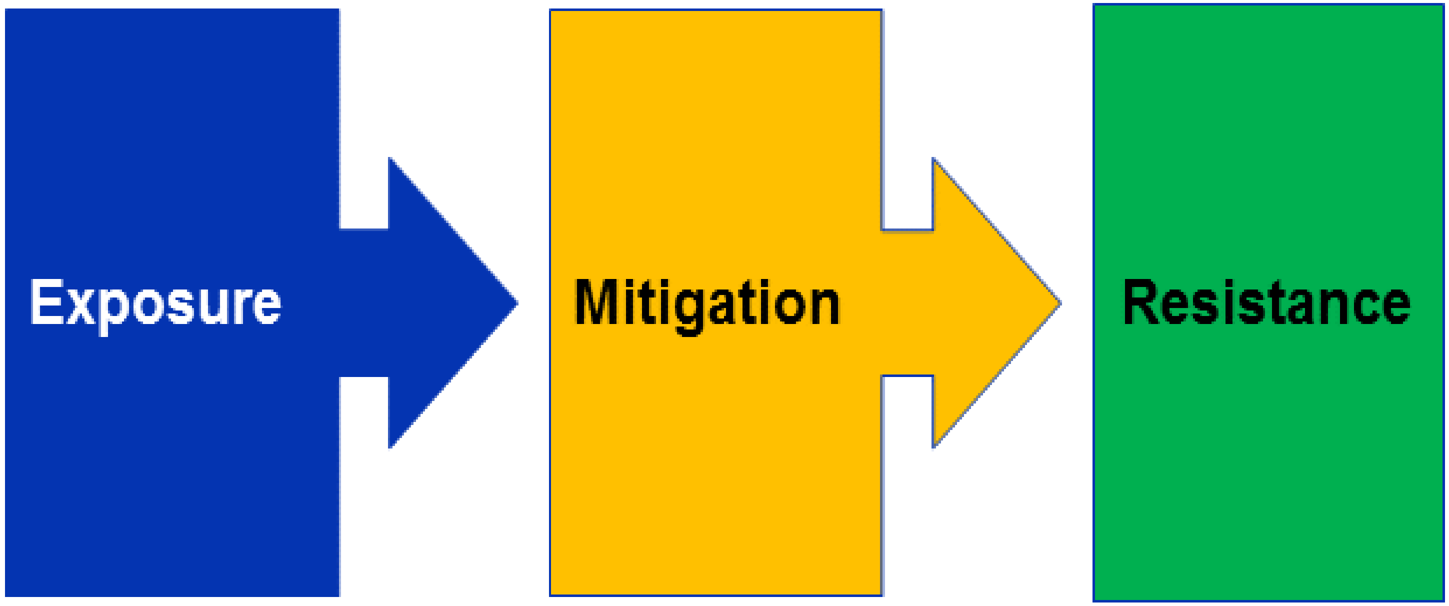
Probability of Failure Grounded in Engineering Principles

- Exposure: likelihood and aggressiveness of a failure mechanism reaching the pipe when no mitigation applied (ATTACK)
- Mitigation: prevents or reduces likelihood or intensity of the exposure reaching the pipe (DEFENSE)
- Resistance: ability to resist failure given presence of exposure (SURVIVABILITY)

Information Use--Exposure, Mitigation, or Resistance?

pipe wall thickness	*maintenance pigging*
air patrol frequency	*surge relief valve*
soil resistivity	*casing pipe*
coating type	*flowrate*
CP P-S voltage reading	*depth cover*
date of pipe manufacture	*training*
stress level	*SMYS*
operating procedures	*one-call system type*
nearby traffic type and volume	*SCADA*
nearby AC power lines (2)	*pipe wall lamination*
ILI date and type	*wrinkle bend*
pressure test psig	

PoF: Critical Aspects



Probability of Damage or Failure—Simple Math

Probability of Failure Grounded in Engineering Principles

- 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)*

Exposure
Mitigation } PoD
Resistance

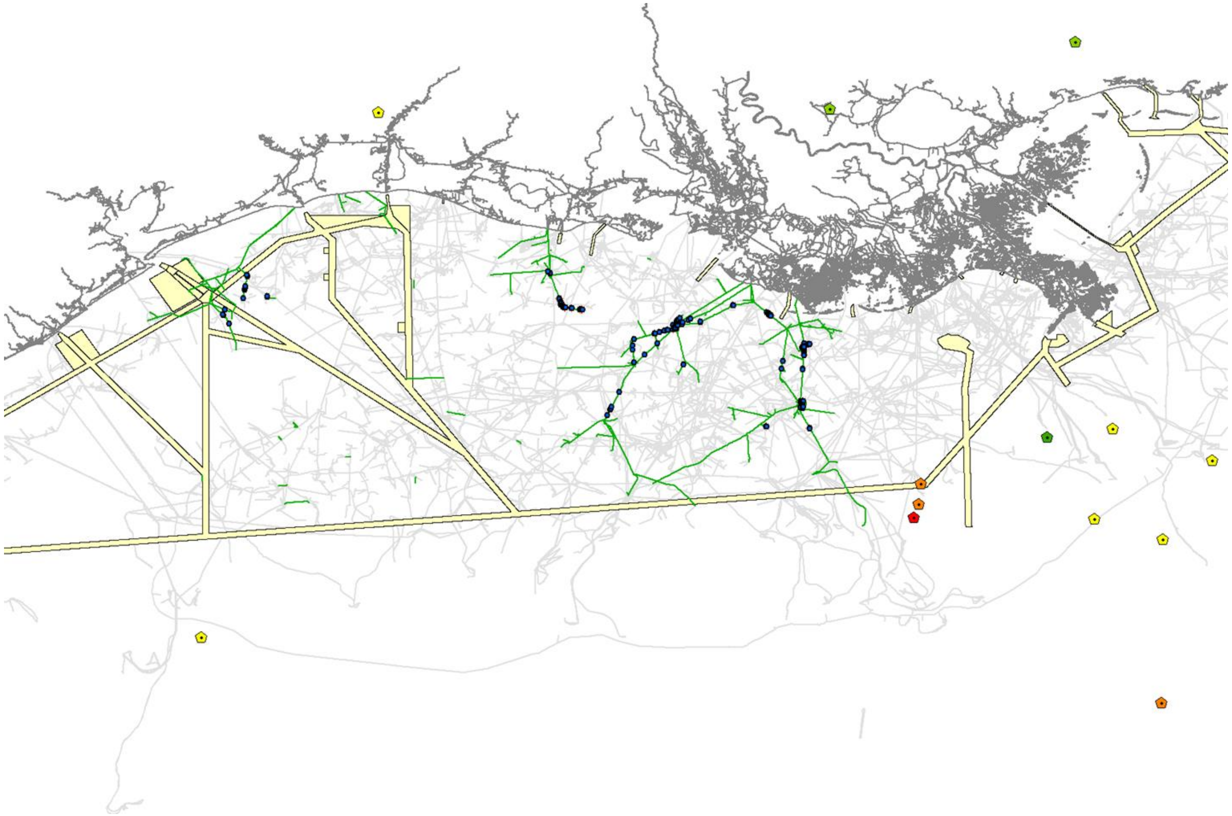
Exposure, Mitigation, Resistance } PoF

Estimating Threat Exposure

- Events per mile-year (km-yr) for time independent mechanism
  - third party
  - incorrect operations
  - weather & land movements
- MPY (mm/yr) for degradation mechanisms
  - Corrosion (Ext, Int)
  - Cracking (EAC / fatigue)

List the Exposures

Example: Exposures Offshore RA



Sample Exposure Estimates

- Vehicle impact; 1 mile along busy highway

  0.1 to 10 events/mile-year

- excavation; 530 ft heavy construction

  ~400 events/mile-year

- vehicle impact; 1 mile along RR

  ~0.01 events/mile-year

- power pole falling

  0.05 to 2 events/mile-year

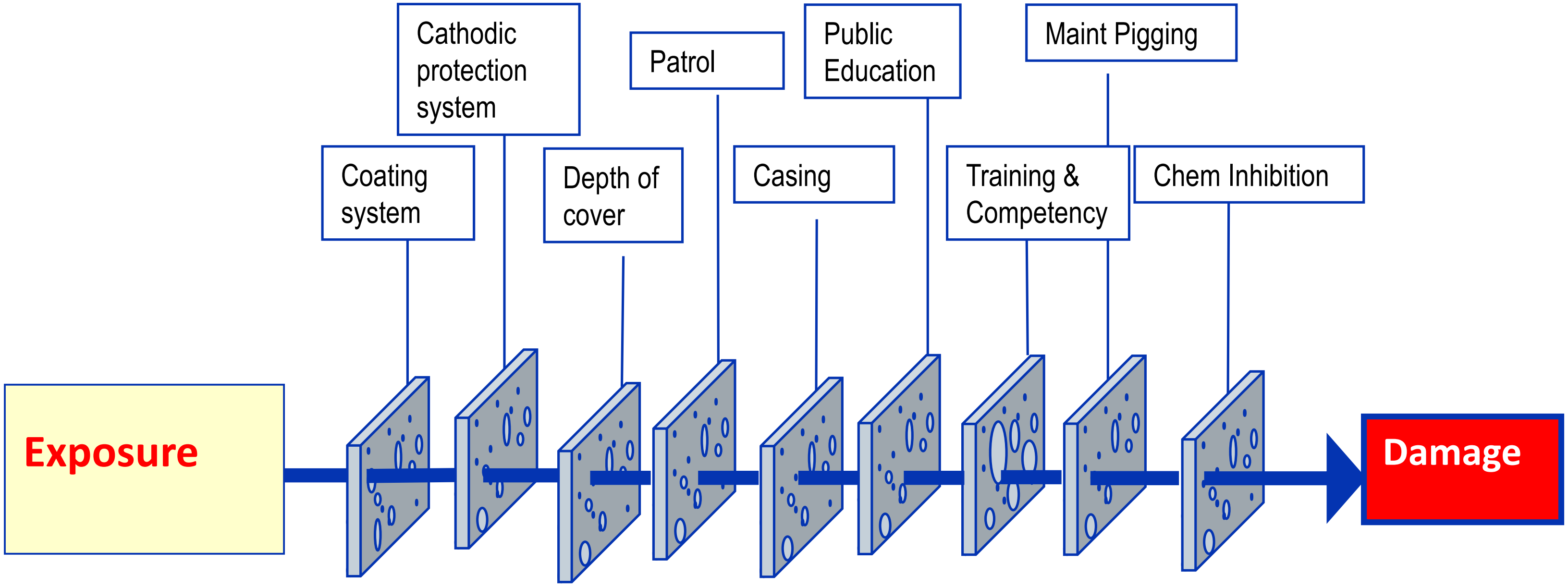
Rates: Failures, Exposures, Events, etc

Failures/yr	Years to Fail	Approximate Rule Thumb
1,000,000	0.000001	Continuous failures
100,000	0.00001	fails ~10 times per hour
10,000	0.0001	fails ~1 times per hour
1,000	0.001	fails ~3 times per day
100	0.01	fails ~2 times per week
10	0.1	fails ~1 times per month
1	1	fails ~1 times per year
0.1	10	fails ~1 per 10 years
0.01	100	fails ~1 per 100 years
0.001	1,000	fails ~1 per 1000 years
0.0001	10,000	fails ~1 per 10,000 years
0.00001	100,000	fails ~1 per 100,000 years
0.000001	1,000,000	One in a million chance of failure
0.0000000001	1,000,000,000	Effectively, it never fails

Advantages of Estimates as Measurements

- Estimates can often be validated over time
- Estimate values from several causes are directly additive. E.G. Falling objects, landslide, subsidence, etc, each with their own frequency of occurrence can be added together
- Estimates are in a form that consider segment-length effects and supports PoF estimates in absolute terms
- Avoids need to standardize qualitative measures such as "high", "medium", "low" avoids interpretation and erosion of definitions over time and when different assessors become involved.
- Can directly incorporate pertinent company and industry historical data.
- Forces SME to provide more considered values. It is more difficult to present a number such as 1 hit every 2 years

Estimating Mitigation Measure Effectiveness



Measuring Mitigation

Probability of Failure Grounded in Engineering Principles

Strong, single measure

Or

Accumulation of lesser measures

Mitigation % = 1 - (remaining threat)

Remaining threat = (remnant from mit1) AND (remnant from mit2) AND (remnant from mit3) …

Measuring Mitigation

Exposure	Mitigation	Reduction	freq damage	prob damage
events/mi-yr			events/mi-yr	Prob/mi-yr
10	90.0%	10	1	63.2%
10	99.0%	100	0.1	9.52%
10	99.9%	1000	0.01	1.00%

Mitigation % = 1-[(1-mit1) x (1-mit2) x (1-mit3)…]

In words:

Mitigation % = 1 - (remaining threat)

Remaining threat = (remnant from mit1) AND (remnant from mit2) AND (remnant from mit3) …

Measuring Mitigation

What is the overall mitigation effectiveness if:

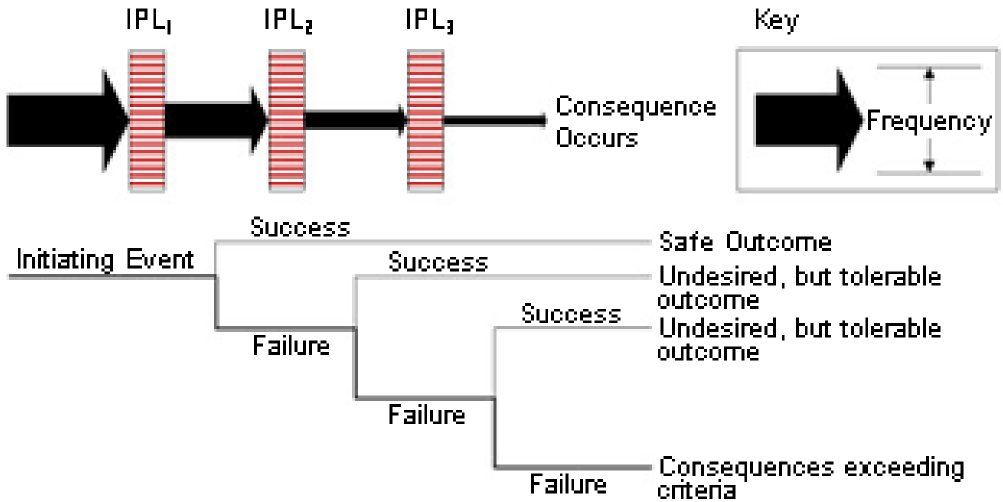
Depth cover	50%
One call	60%

Reported Mitigation Benefits

Mitigation	Impact on risk
Increase soil cover	56% reduction in mechanical damage when soil cover increased from 1.0 to 1.5 m
Deeper burial	25% reduction in impact failure frequency for burial at 1.5 m; 50% reduction for 2m; 99% for 3m
Increased wall thickness	90% reduction in impact frequency for >11.9-mm wall or >9.1-mm wall with 0.3 safety factor
Concrete slab	Same effect as pipe wall thickness increase
Concrete slab	Reduces risk of mechanical damage to “negligible”
Underground tape marker	60% reduction in mechanical damage
Additional signage	40% reduction in mechanical damage
Increased one-call awareness and response	50% reduction in mechanical damage
Increased ROW patrol	30% reduction in mechanical damage
Increased ROW patrol	30% heavy equipment-related damages; 20% ranch/farm activities; 10% homeowner activities
Improved ROW, signage, public education	5–15% reduction in third-party damages

Level of Protection Analysis

LOPA
ANSI/ISA-84.00.01-2004, IEC 61511 Mod



http://www.plg.com/svc_opRisk_LOPA.html

SIL selection requirements of the American National Standards Institute (ANSI)/Instrumentation, Systems, and Automation Society (ISA) standard 84.00.01 – 2004

Damage Vs Failure

Probability of Failure Grounded in Engineering Principles

- Probability of damage (PoD) = *f* (exposure, mitigation)
- Probability of failure (PoF) = *f* (PoD, resistance)

Exposure } PoD
Mitigation }
Resistance

PoD, Resistance } PoF

Resistance

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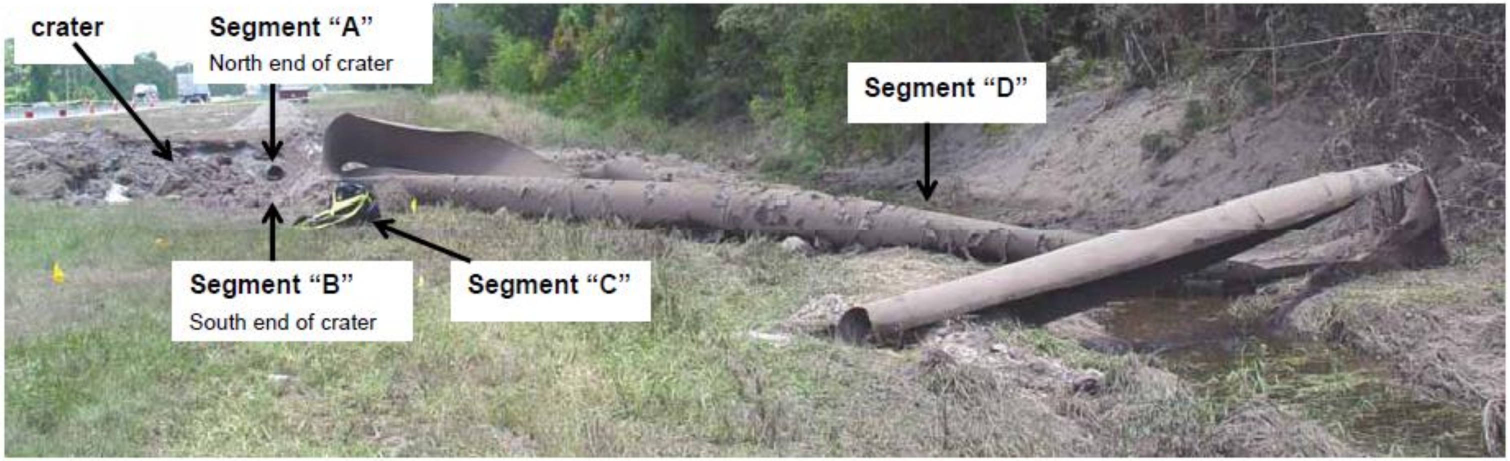


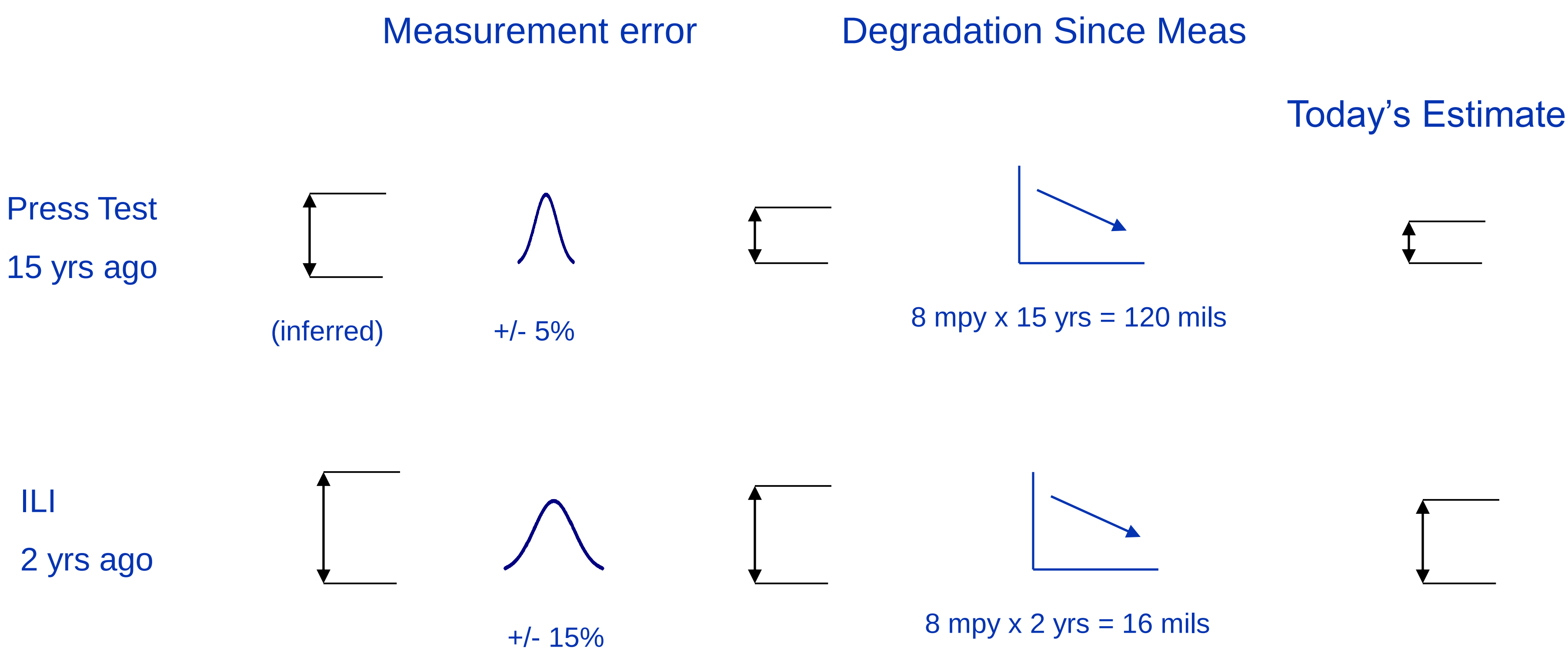
Figure 1. Photographs of the two fracture pipe segments and crater. Photograph on the upper page is looking north. Composite photograph at the lower portion of the page is looking west. The origin of the fracture was determined to be located in the area indicated by arrow "O". General direction of fracture propagation is indicated by white unmarked arrows.

Estimating Resistance

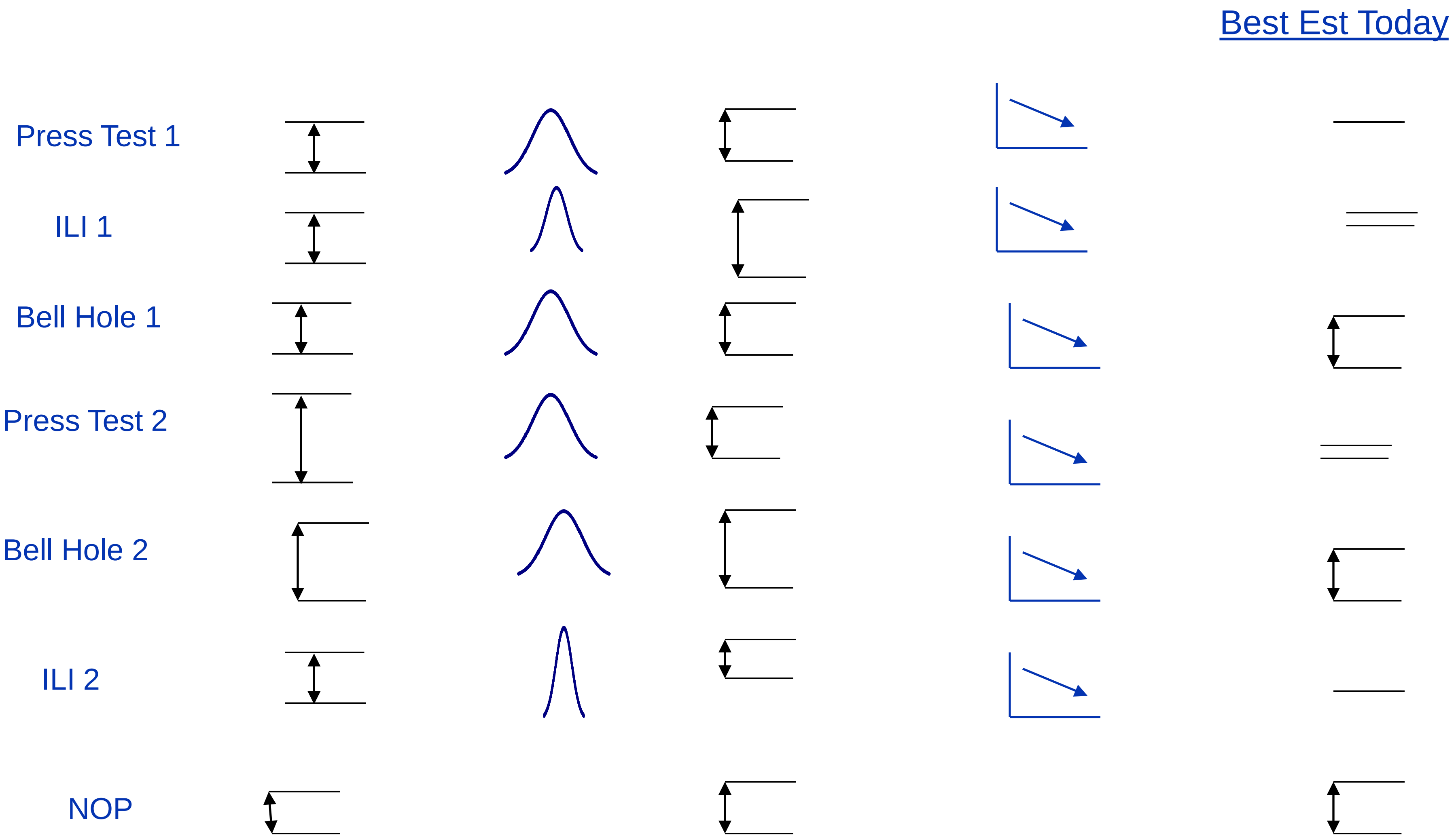
- Pipe spec (original)
- Historical issues
  - Low toughness
  - Hard spots
  - Seam type
  - Manufacturing
- Pipe spec (current)
  - ILI measurements
  - Calcs from pressure test
  - Visual inspections
  - Effect of estimated degradations
- Required pipe strength
  - Normal internal pressure
  - Normal external loadings

Probability of Failure Grounded in Engineering Principles

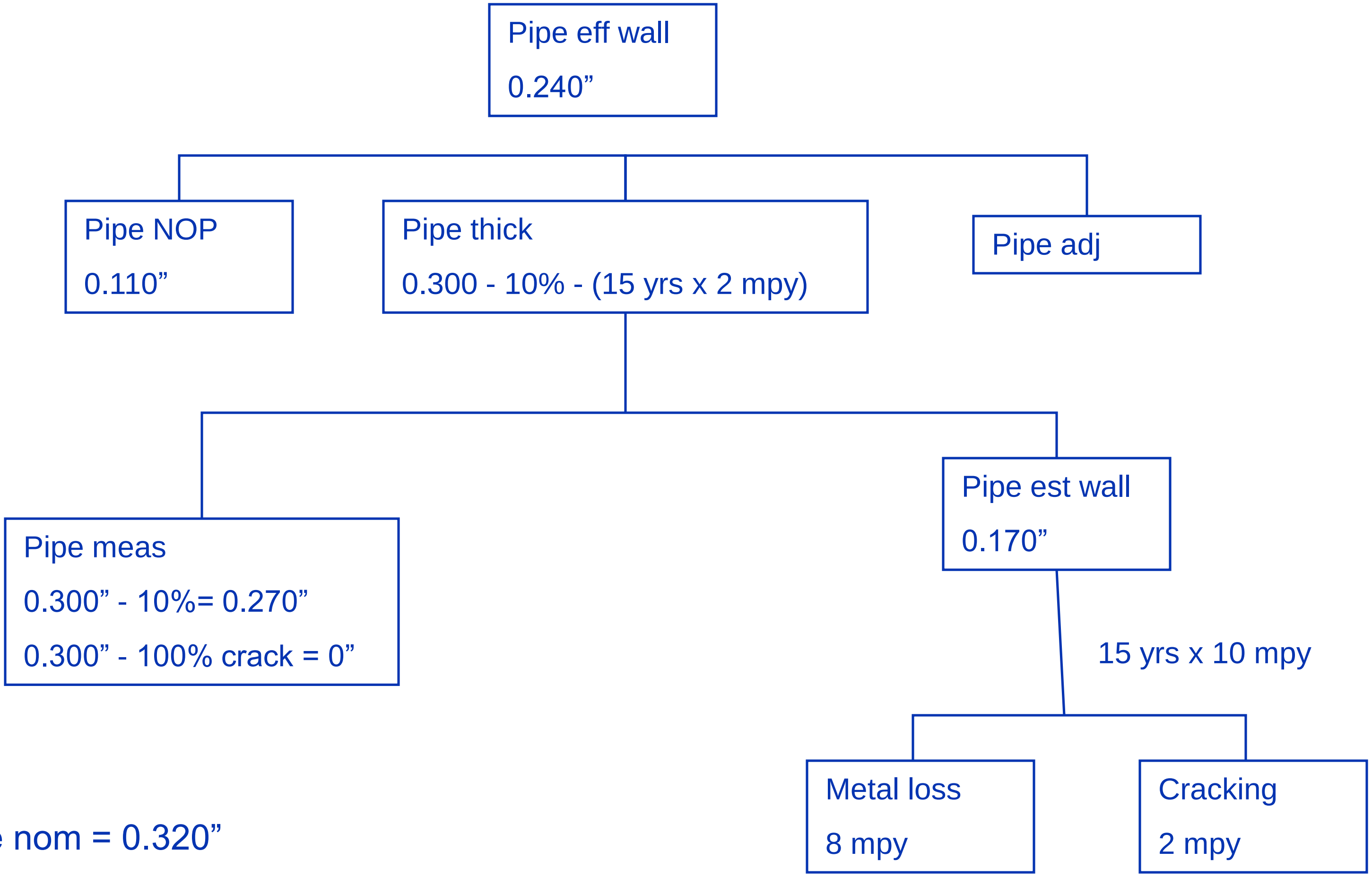
Best Estimate of Pipe Wall Today



Best Estimate of Pipe Wall Today



Pipe Wall Available



Pipe nom = 0.320”

Loads & Stresses

- Stress capacity
- Load capacity
- Effective wall thickness
- Fraction of damage events that do not result in failure

Full solution: …*formal reliability assessment to study the relation of tensile strain resistance distribution to tensile strain demand distribution*

Comprehensive

- Pipe specification;
- Last measured wall thickness;
- Age of last measured wall thickness;
- Wall thickness "measured" (implied) by last pressure test;
- Age of last pressure test;
- Detection capabilities of last inspection (ILI, etc), including data analyses and confirmatory digs;
- Maximum depth of a defect remaining after last inspection; age of last inspection
- Estimated metal loss mpy since last measurement;
- Estimated cracking mpy since last measurement;
- Maximum depth of a defect surviving at last pressure test and/or normal operating pressure (NOP) or last known pressure peak;
- Penalties for possible manufacturing/construction weaknesses

Why Exp-Mit-Res?

- Implicit, if not explicit, categorization because:
  - knowledge of all 3 is required for PoF
- Benefits of explicit categorization
  - without all 3, inability to diagnose
  - without diagnosis, inability to optimize P&M
- Eg, Corr in sand vs swamp

Upgrading Old RA's

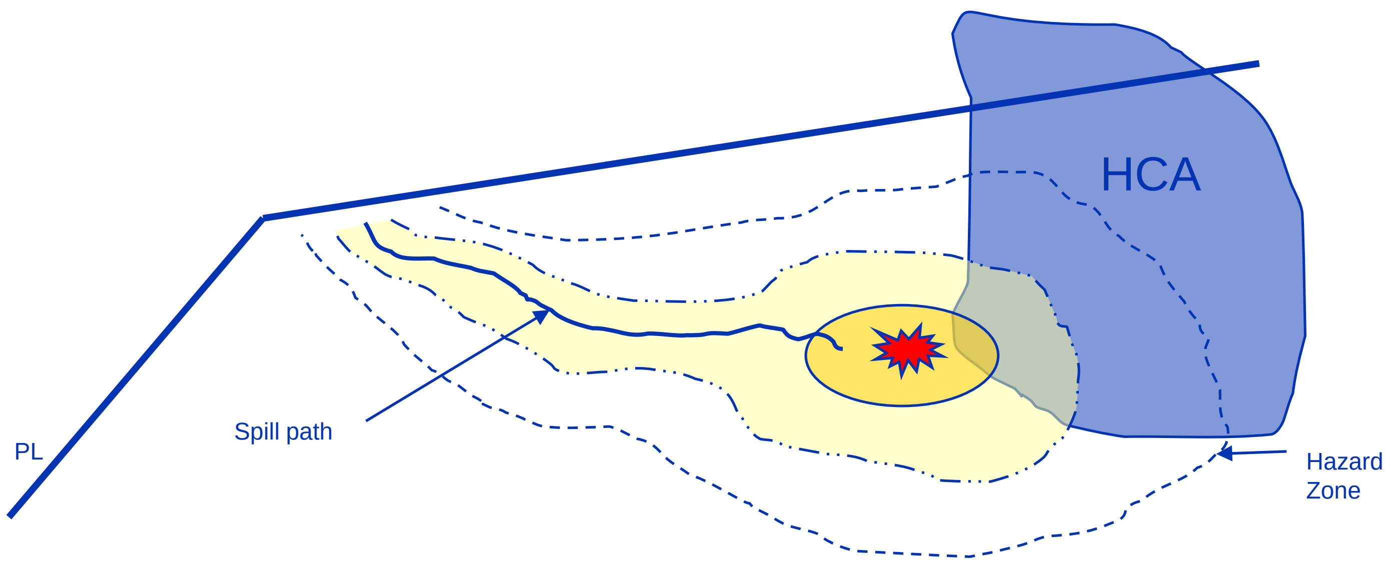
- Exposure (events per year)
- Mitigation (% of avoided events)
- Resistance (% damage events that do not result in failure)

	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

Fully Characterize Consequence of Failure

Measure in Verifiable Units | Probability of Failure Grounded in Engineering Principles | **Fully Characterize Consequence of Failure** | Profile the Risk Reality | Integrate Pipeline Knowledge | Incorporate Sufficient Granularity | Control the Bias | Unmask Aggregation

- Must identify and acknowledge the full range of possible consequence scenario hazard zones
- Must consider ‘most probable’ and ‘worst case’ scenarios



Common Consequences of Interest

Fully Characterize Consequence of Failure

- Human health
- Environment
- Costs

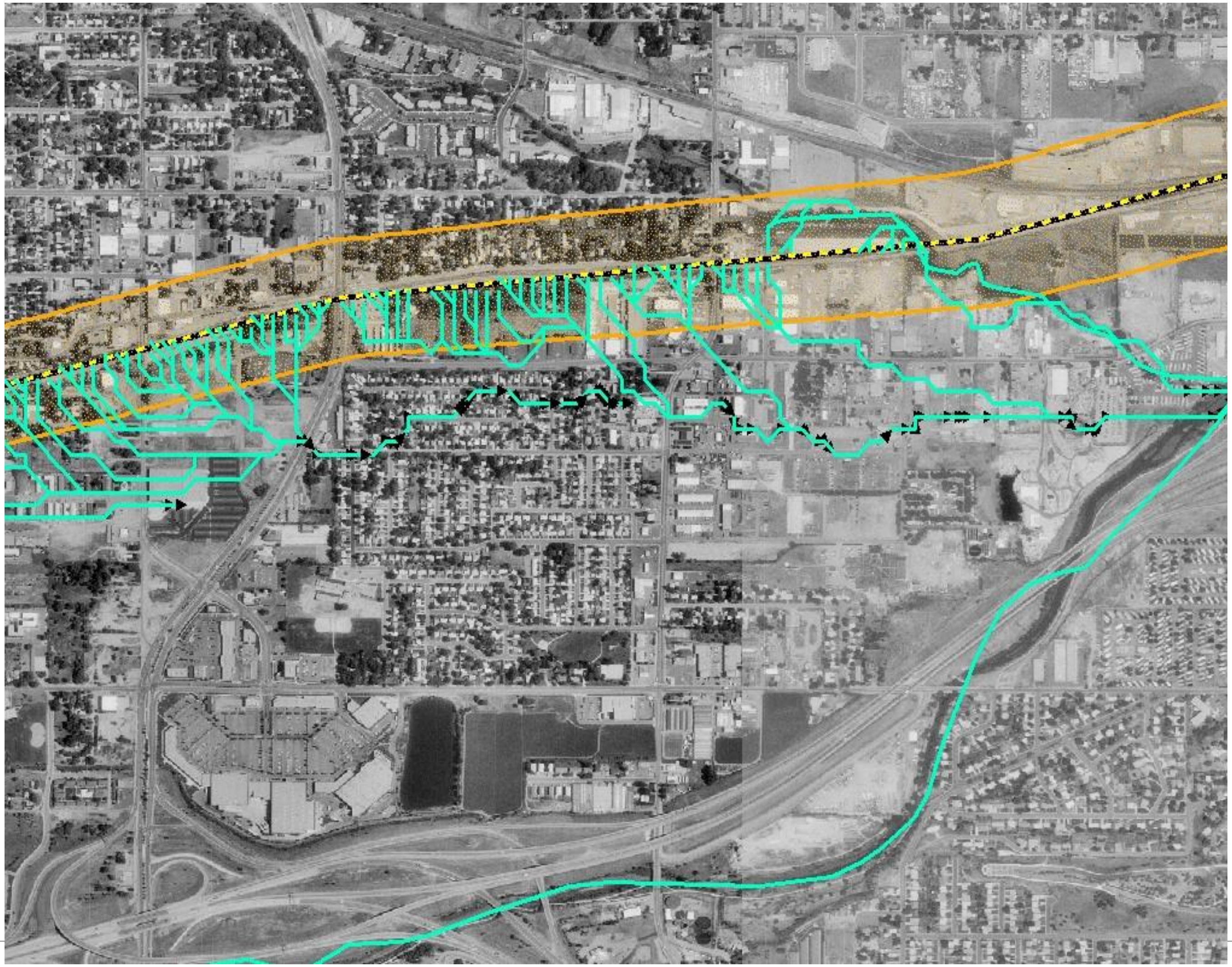
Choose receptors and CoF units

A Guiding Equation

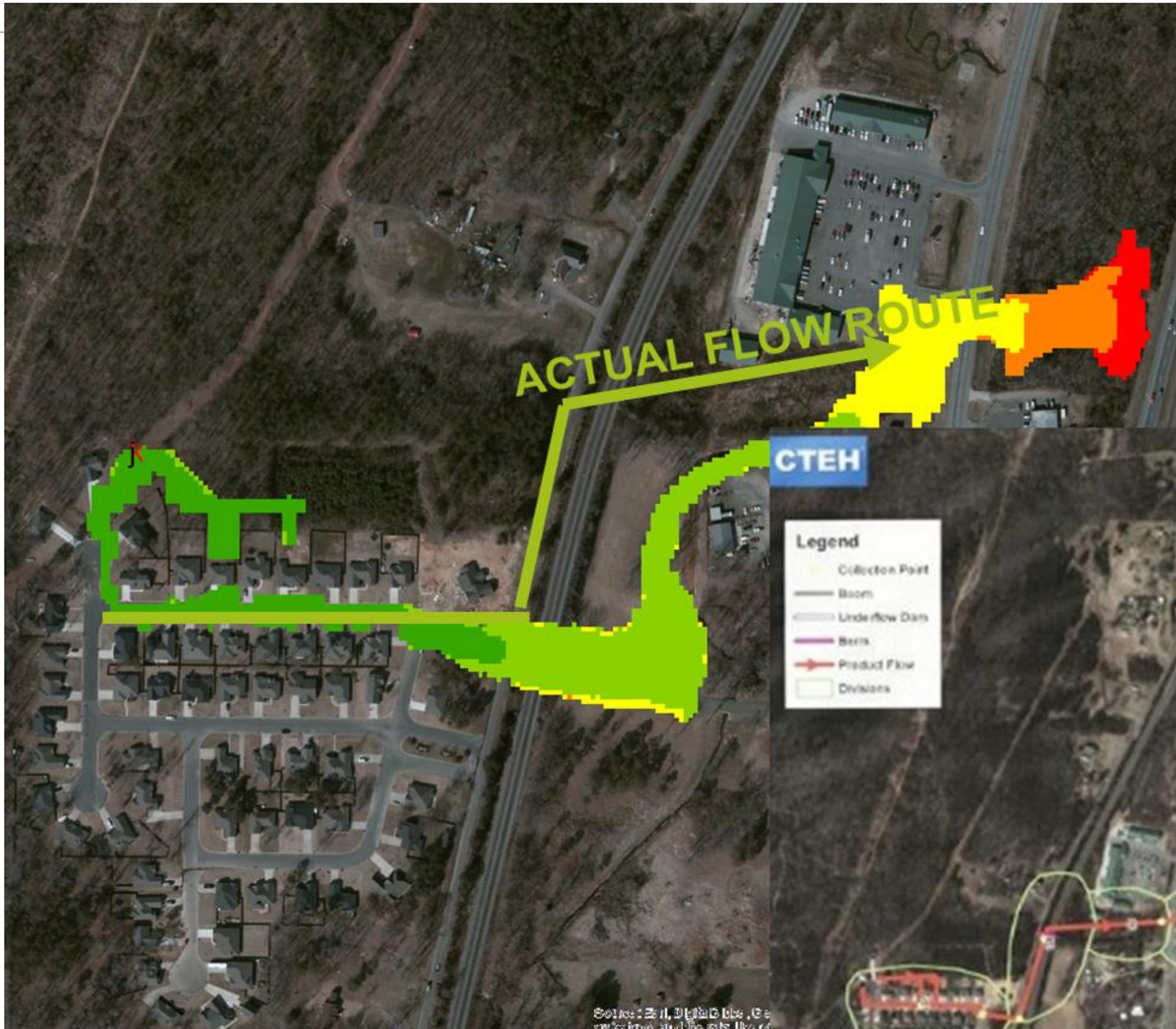
CoF = ProdHaz x Spill x Spread x Receptors

Liquid Releases

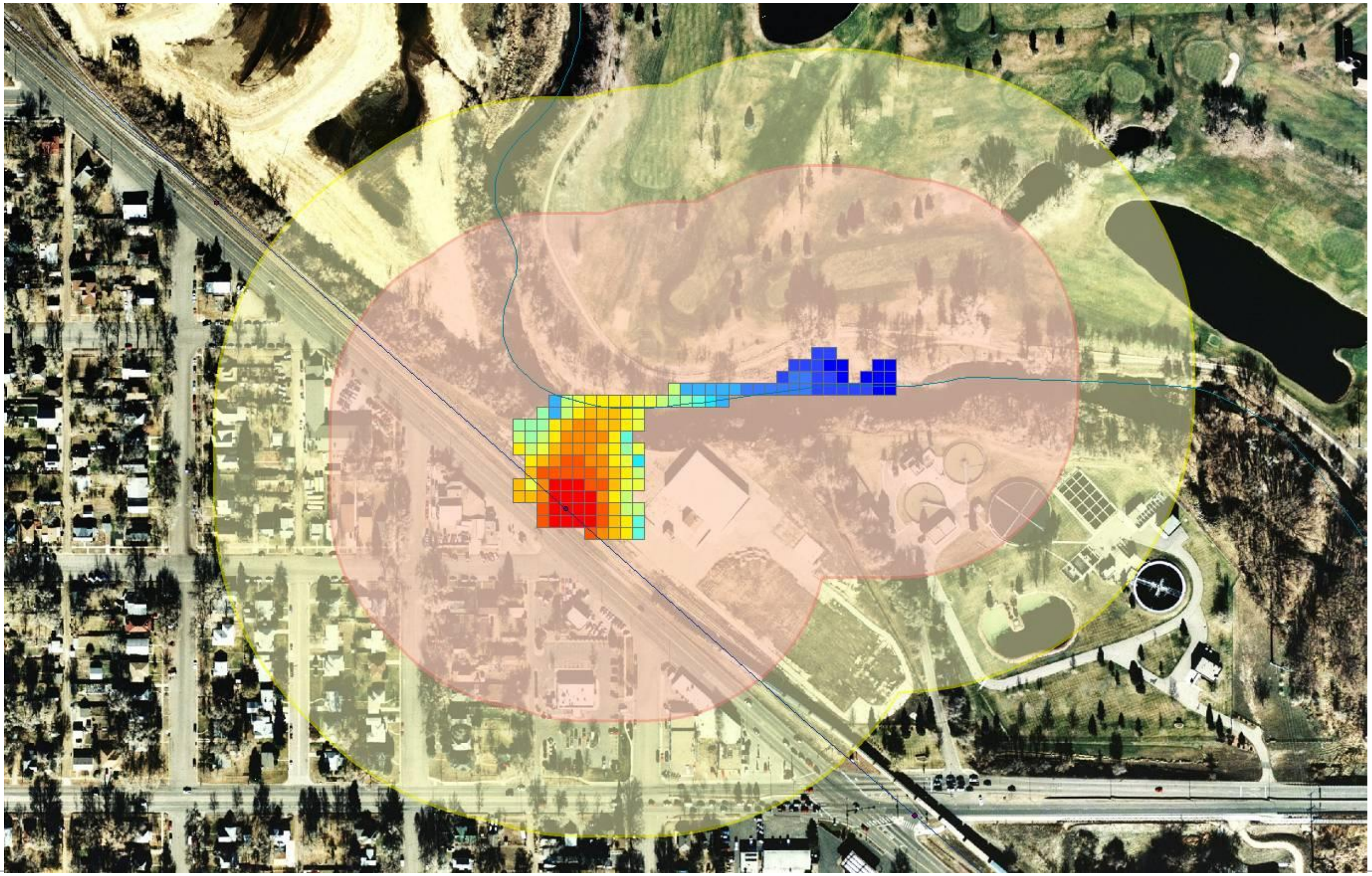
Particle Trace Analysis



Why are DEM and structures so important??

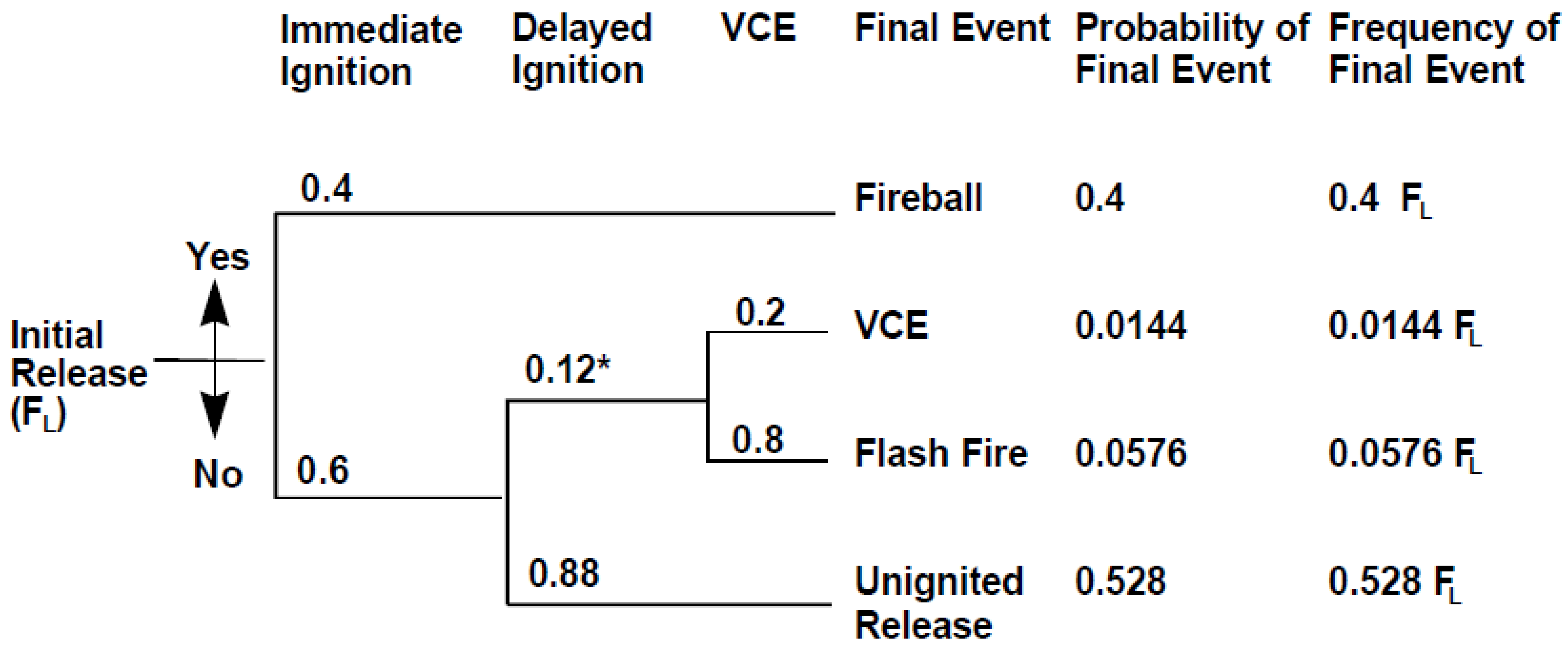


Thermal Radiation—Pool Fire



Hazard Zone Scenarios

Figure 5-4 **Example of a Post-Incident Event Tree**



* Example for Suburban Population Density

GRI PIR Documentation

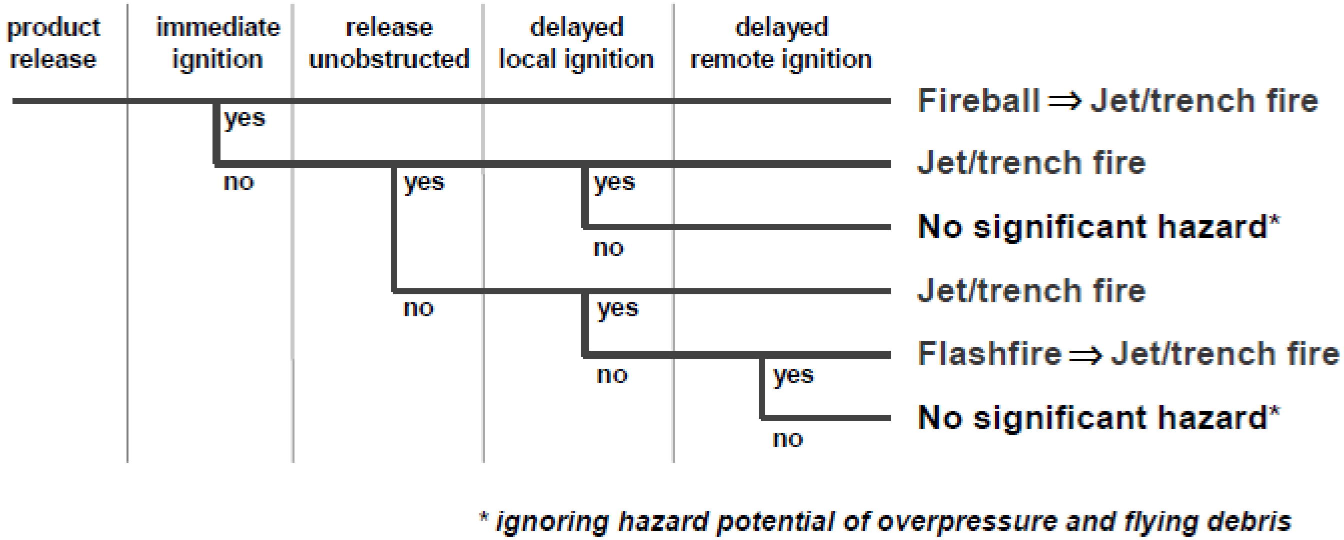


Figure 1.1 Event tree for high pressure gas pipeline failure (adapted from Bilo and Kinsman 1997).

Hazard Zone Criteria

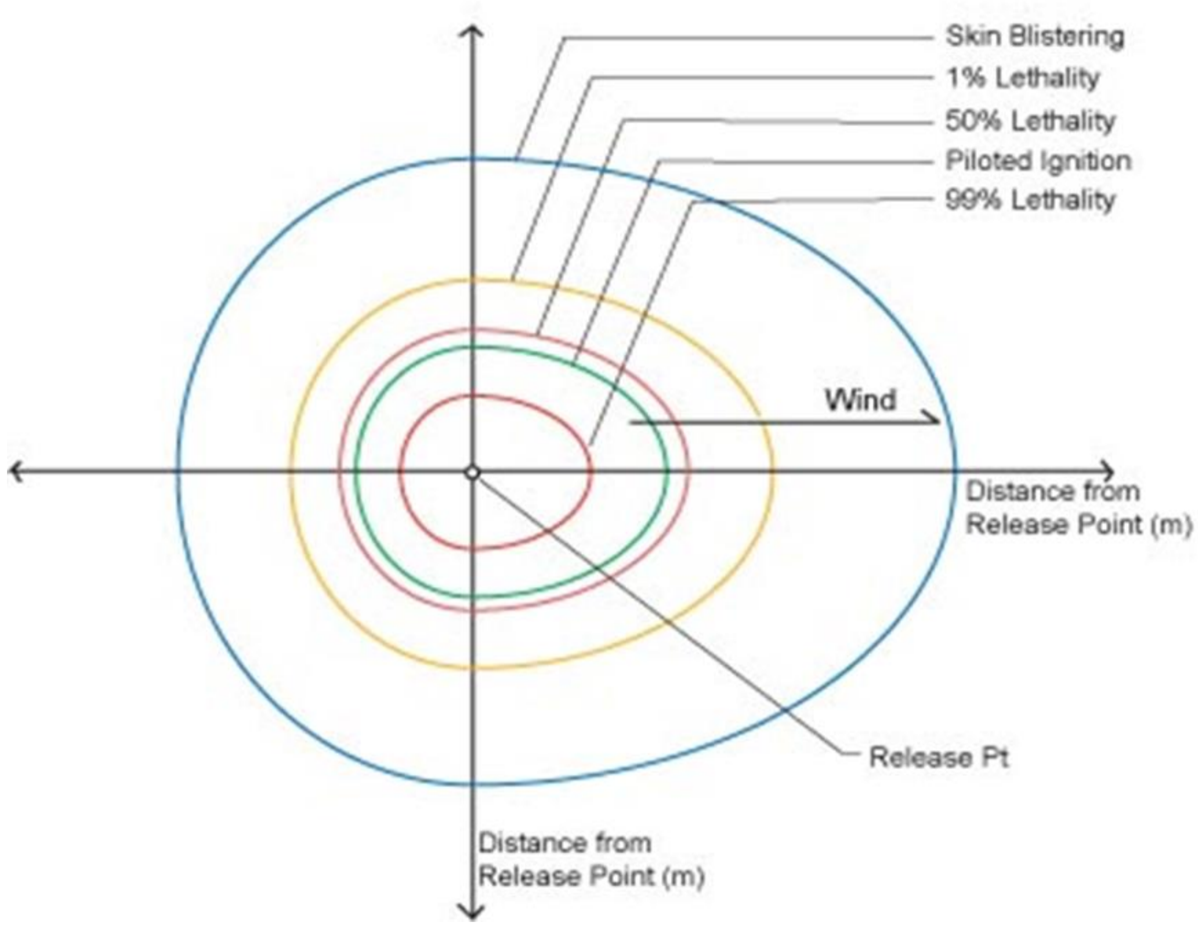


Table A2.2 Effects of Thermal Radiation (CCPS, 1989a)

Radiation intensity (kW/m^2)	*Observed effect*
37.5	Sufficient to cause damage to process equipment
12.5	Minimum energy required for piloted ignition of wood, melting of plastic tubing
9.5	Pain threshold reached after 8 s; second degree burns after 20 s
4	Sufficient to cause pain to personnel if unable to reach cover within 20 s; however, blistering of the skin (second degree burns) is likely; 0% lethality
1.6	Will cause no discomfort for long exposure

Table A2.3 Exposure Time Necessary to Reach the Pain Threshold (API 521)

Radiation intensity ($Btu/hr/ft^2$)	*kW/m^2*	*Time to pain threshold (s)*
500	1.74	60
740	2.33	40
920	2.90	30
1500	4.73	16
2200	6.94	9
3000	9.46	6
3700	11.67	4
6300	19.87	2

PIR Flame Jet

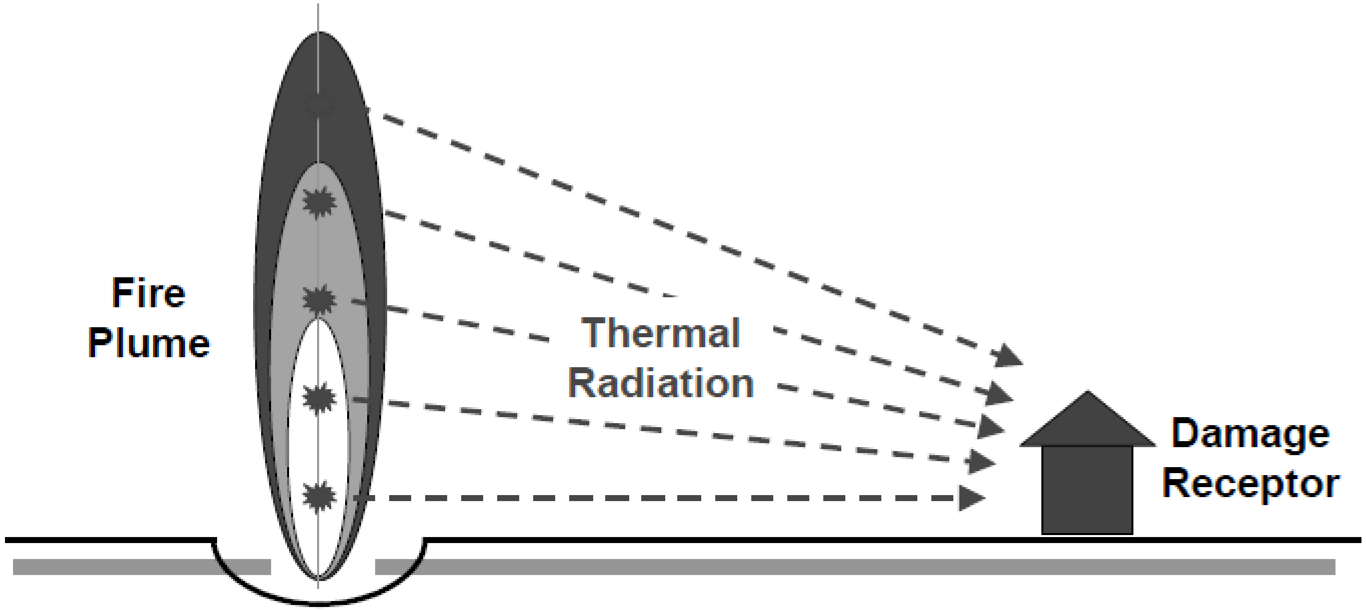


Figure 2.1 Conceptual fire hazard model.

PIR Calculations

TTO13 & TTO14

Table 7.1 Summary of Potential Impact Radius Formulae

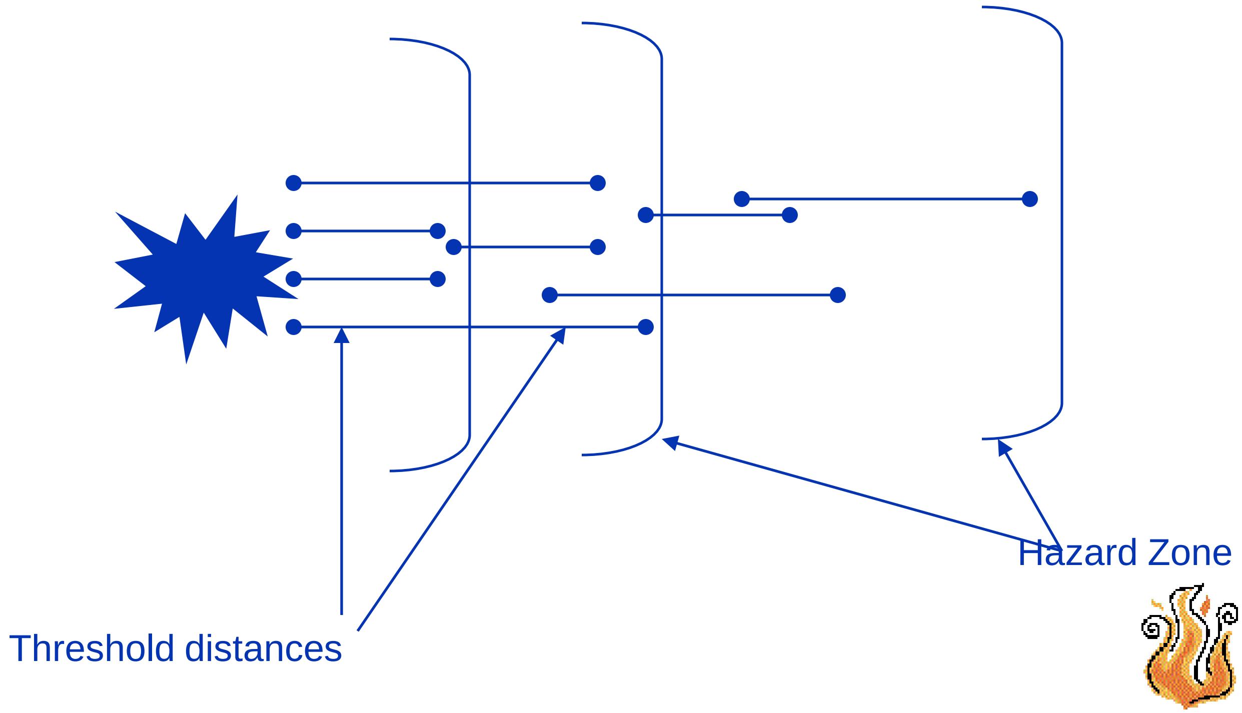
Product	PIR Formula
Ethylene	$r = 1.04 \cdot \sqrt{p \cdot d^2}$
Hydrogen	$r = 0.47 \cdot \sqrt{p \cdot d^2}$
Natural Gas (Lean)	$r = 0.69 \cdot \sqrt{p \cdot d^2}$
Natural Gas (Rich)	$r = 0.73 \cdot \sqrt{p \cdot d^2}$
Syngas	$r = 0.49 \cdot \sqrt{p \cdot d^2}$ Note 1

Note 1 See discussion in Section 4.8.5

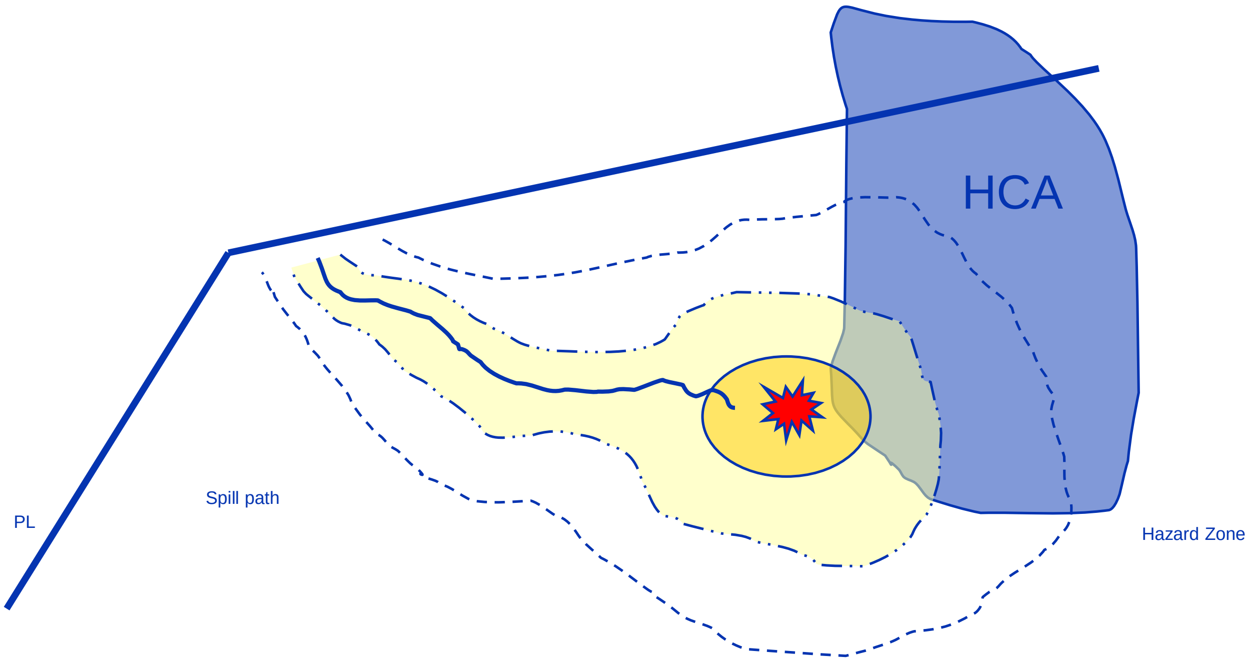
Table 8.1 Summary of PIR Formulae

Product		PIR Formula
Acetylene	1 psi Overpressure	$r = 0.021 \cdot (d^2 \cdot p)^{1/3}$
Anhydrous Ammonia (Liquefied under pressure)	1 psi Overpressure	$r = 0.014 \cdot (d^2 \cdot p)^{1/3}$
	Rural Conditions	$r = 0.08 \cdot (d^2 \cdot p)^{0.48}$
	Urban Conditions	$r = 0.07 \cdot (d^2 \cdot p)^{0.45}$
Carbon Monoxide	1 psi Overpressure	$r = 0.012 \cdot (d^2 \cdot p)^{1/3}$
	Rural Conditions	$r = 0.04 \cdot (d^2 \cdot p)^{0.5}$
	Urban Conditions	$r = 0.03 \cdot (d^2 \cdot p)^{0.45}$
Chlorine	Rural Conditions	$r = 0.38 \cdot (d^2 \cdot p)^{0.49}$
	Urban Conditions	$r = 0.16 \cdot (d^2 \cdot p)^{0.5}$
Ethylene	1 psi Overpressure	$r = 0.021 \cdot (d^2 \cdot p)^{1/3}$
Hydrogen Sulfide	1 psi Overpressure	$r = 0.015 \cdot (d^2 \cdot p)^{1/3}$
	Rural Conditions	$r = 0.37 \cdot (d^2 \cdot p)^{0.45}$
	Urban Conditions	$r = 0.27 \cdot (d^2 \cdot p)^{0.46}$
Methane	1 psi Overpressure	$r = 0.019 \cdot (d^2 \cdot p)^{1/3}$
Rich Gas	1 psi Overpressure	$r = 0.020 \cdot (d^2 \cdot p)^{1/3}$

Grouping of Distance Estimates



CoF = f {**Hazard Zones**}



Hazard Zone Exercise

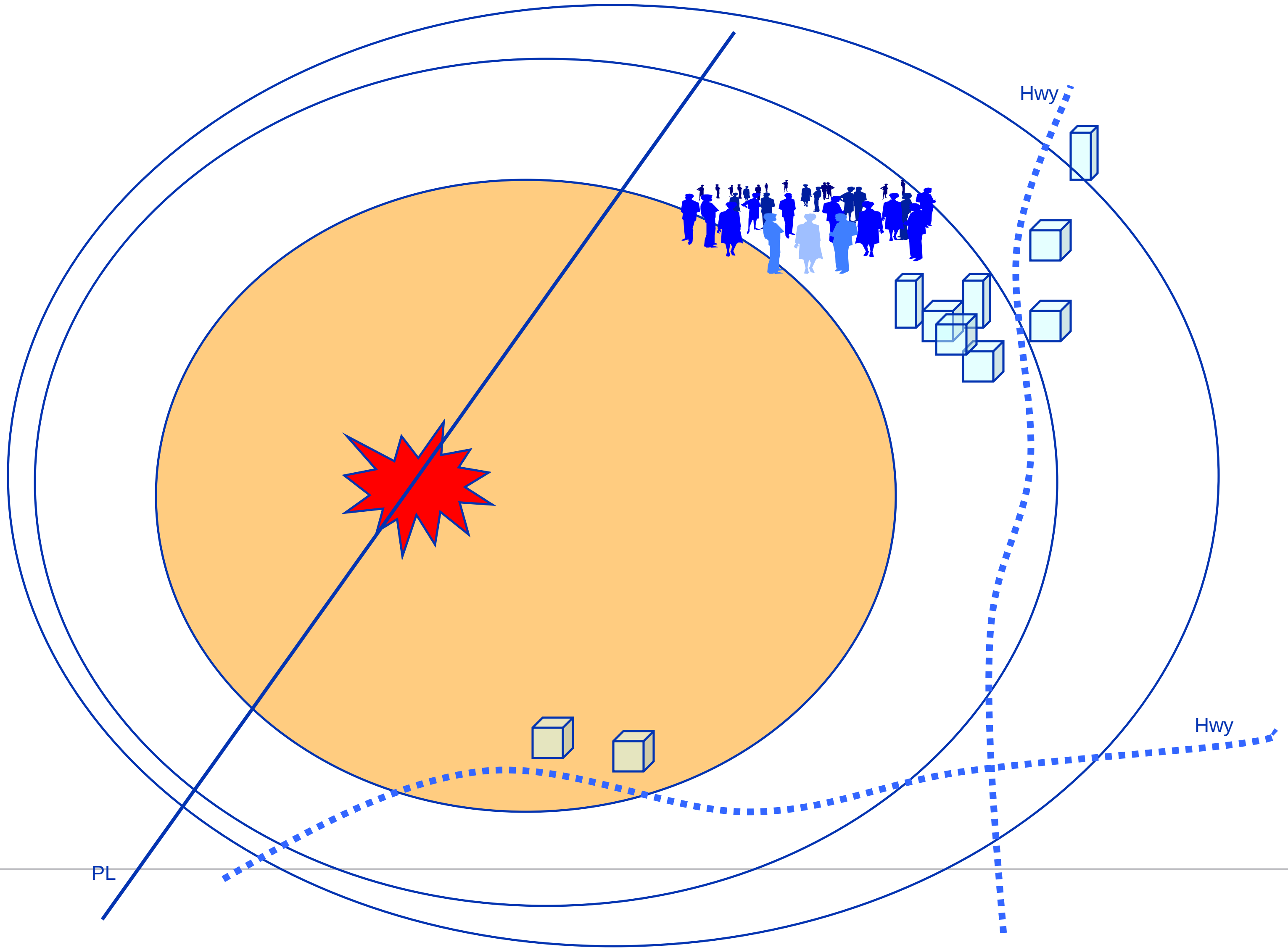
prod	hole size	hole size prob	ignition scenario	prob	dist source	therm haz zone	overpress haz	contam haz zone	haz zone	prob of haz zone
					ft	ft	ft	ft	ft	
fuel oil	rupt	2%	immediate ignition							
			delayed ig							
			no ignition							
	med	8%	immediate ignition							
			delayed ig							
			no ignition							
	small	90%	immediate ignition							
			delayed ig							
			no ignition							

Hazard Zones

Product	Hole size	Hole size probability	Ignition scenario	Ignition probability	Distance from source (ft)	thermal hazard zone (ft)	Contamination hazard zone (ft)	Total (ft)	probability of hazard zone
oil	rupture	4%	immediate ignition	5%	0	400	0	400	0.2%
			delayed ignition	10%	600	500	400	1100	0.4%
			no ignition	85%	600	0	900	1500	3.4%
	medium	16%	immediate ignition	2%	0	200	0	200	0.3%
			delayed ignition	5%	200	300	200	500	0.8%
			no ignition	93%	200	0	500	700	14.9%
	small	80%	immediate ignition	1%	0	50	0	50	0.8%
			delayed ignition	2%	80	100	0	180	1.6%
			no ignition	97%	80	0	80	160	77.6%
									100.0%
LPG	rupture	16%	immediate ignition	20%	0	400	0	400	3.2%
			delayed ignition	20%	500	2000	0	2500	3.2%
			no ignition	60%	500	0	0	500	9.6%
	medium	24%	immediate ignition	15%	0	200	0	200	3.6%
			delayed ignition	15%	200	1200	0	1400	3.6%
			no ignition	70%	200	0	0	200	16.8%
	small	60%	immediate ignition	10%	0	50	0	50	6.0%
			delayed ignition	10%	30	100	0	130	6.0%
			no ignition	80%	30	0	0	30	48.0%
									100.0%

Receptor Characterization

- •fatalities
- •injuries
- •prop damage
- •waterways
- •ground water
- •wetlands
- •T&E wildlife
- •preserves
- •historical sites



Population Characterization

- Building density
- Building characterization
- Occupancy rate
- Mobility

$O_f = D \times R$

Where,

O_f = The occupancy factor, which is an indication of the number of people within a hazard zone;

D = building density of land use areas within the hazard zone (includes buildings or other areas that define a class location or HCA); and,

R = The expected average occupancy rate per building within the land use area

Damage State Estimates

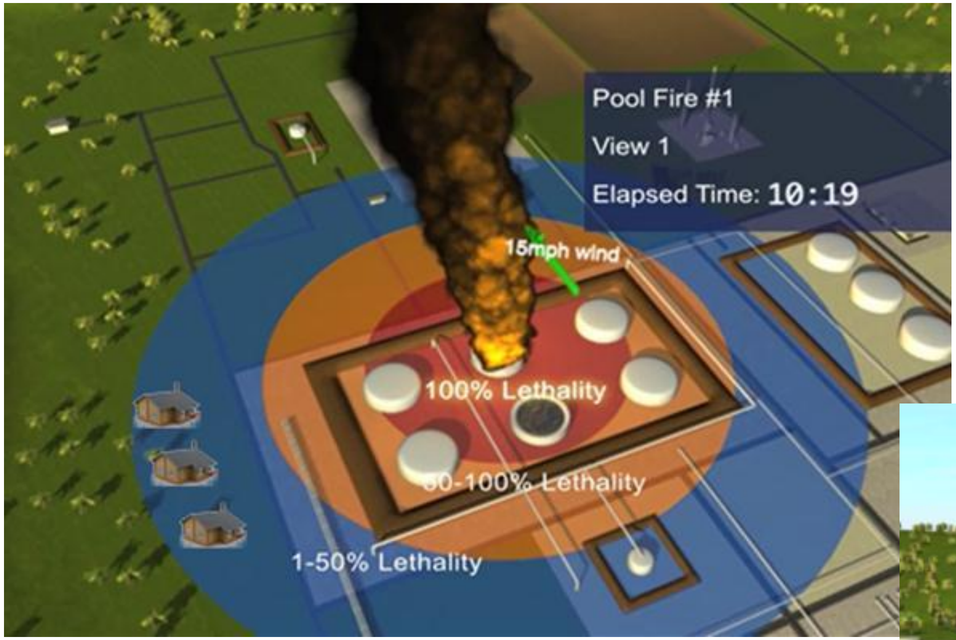
- Create Zones Based on Threshold Distances
- Estimate Damage States (or PoD) for Each Zone

Hazard Zone	injury rate	fatality rate	environ damage rate	service interruption rate
<100'	80%	8%	50%	100%
100'-50% PIR	50%	5%	30%	90%
50% -100% PIR	20%	2%	10%	80%

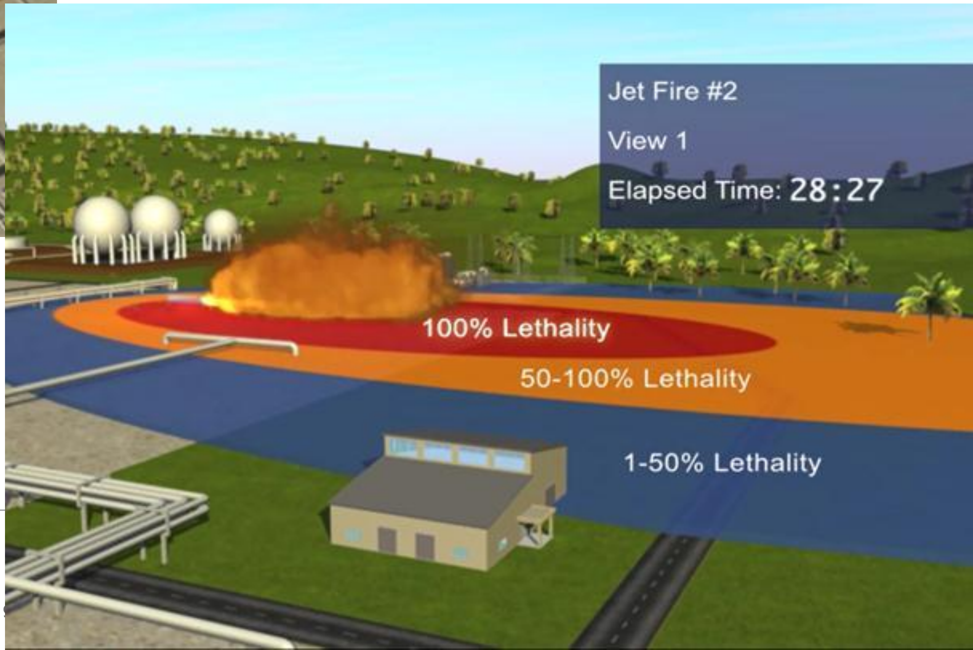
CoF at Facilities

- Hazard Zone Assessment

$$Potential\ Loss = Hazard\ Area^{*}\ x\ \Sigma(receptor\ unit\ value\ x\ receptor\ density\ x\ receptor\ damage\ rate)$$



* Probability-adjusted area



Sample CoF Calculations

						unit cost	*unit cost*		*unit cost*	
						$100,000	*$3,500,000*		*$ 50,000*	**Expected Loss**
Hole Size	**Ignition Scenario**	**Maximum Distance (ft)**	**Probability of Maximum Distance**	**Hazard Zone Group**	**# people**	**Human injury costs**	**Human fatality costs**	**# environ units**	**Environ Damage Costs**	**Probability weighted dollars per failure**
rupture	immediate	400	4.8%	100'-50% PIR	5	$ 3,600	$ 12,600	1	$ 720	$ 16,920
	delayed	1500	1.6%	50% -100% PIR	10	$ 960	$ 3,360	1	$ 80	$ 4,400
	no ignition	300	1.6%	100'-50% PIR	5	$ 1,200	$ 4,200	1	$ 240	$ 5,640
medium	immediate	300	1.8%	100'-50% PIR	5	$ 1,350	$ 4,725	1	$ 270	$ 6,345
	delayed	600	1.8%	100'-50% PIR	5	$ 1,350	$ 4,725	1	$ 270	$ 6,345
	no ignition	100	8.4%	100'-50% PIR	5	$ 6,300	$ 22,050	1	$ 1,260	$ 29,610
small	immediate	50	8.0%	<100'	1	$ 1,920	$ 6,720	0.5	$ 1,000	$ 9,640
	delayed	80	8.0%	<100'	1	$ 1,920	$ 6,720	0.5	$ 1,000	$ 9,640
	no ignition	30	64.0%	<100'	1	$15,360	$ 53,760	0.5	$ 8,000	$ 77,120
			100.0%	Total expected loss per failure at this location						$165,660

Final EL Value

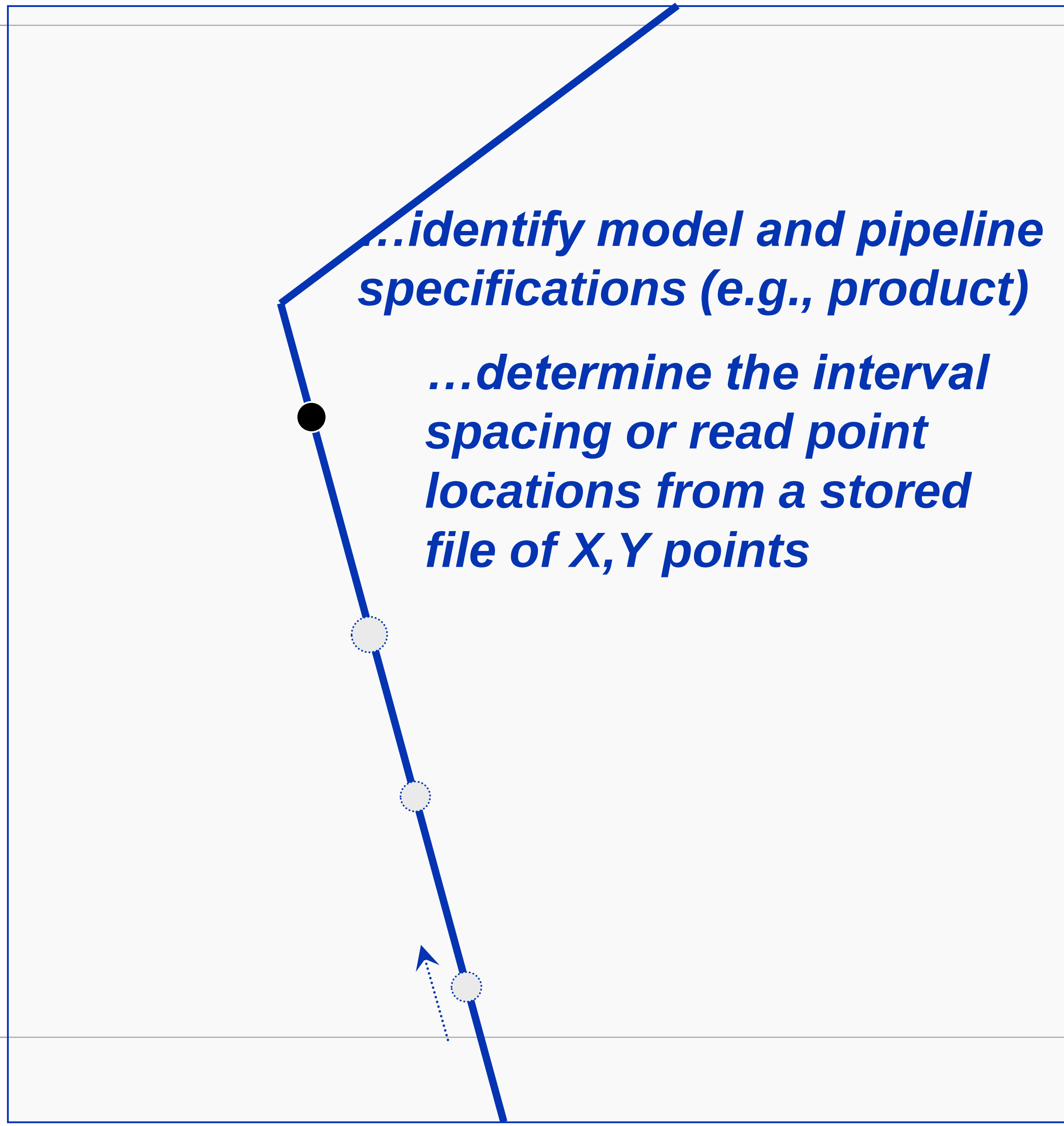
At a specific location along a pipeline:

Expected Loss			
Failure Rate (failures per mile-year)	**Probability of Hazard Zone[1,2]**	**Probability weighted dollars[2,3]**	**Probability weighted dollars per mile-year**
0.001	4.80%	$16,920	$0.81
	1.60%	$4,400	$0.07
	1.60%	$5,640	$0.09
	1.80%	$6,345	$0.11
	1.80%	$6,345	$0.11
	8.40%	$29,610	$2.49
	8.00%	$9,640	$0.77
	8.00%	$9,640	$0.77
	64.00%	$77,120	$49.36
	100.00%	**$165,660**	**$54.59**

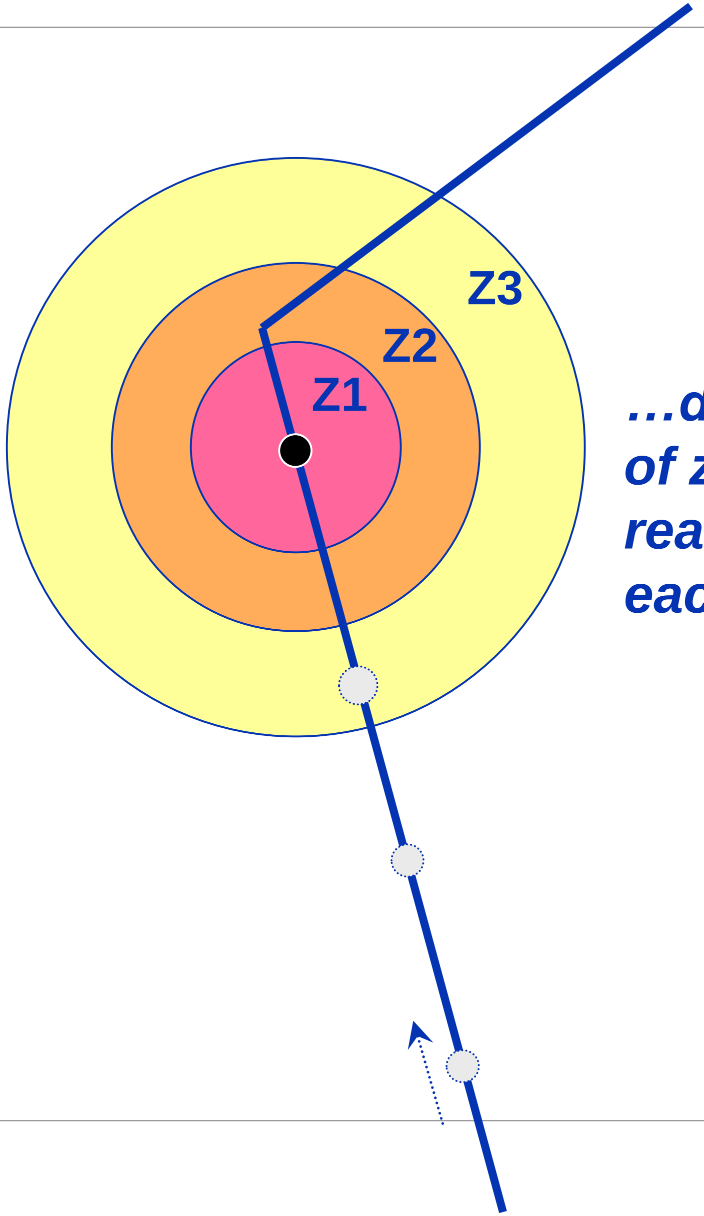
Table Notes

1. *after a failure has occurred*
2. *from Table 2 above, per event*
3. *(damage rate) x (value of receptors in hazard zone), per event*

Step 1: **Determine On-Line Sampling Interval**

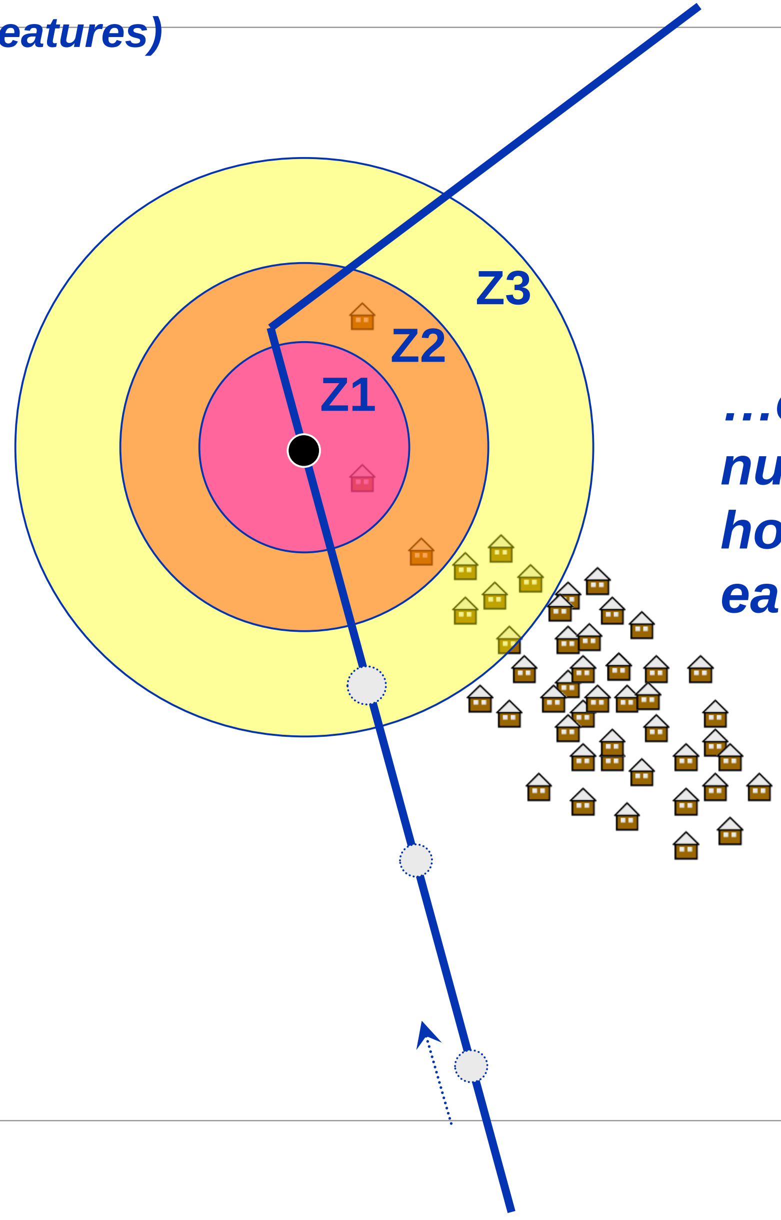


Step 2: Establish Hazard Zones



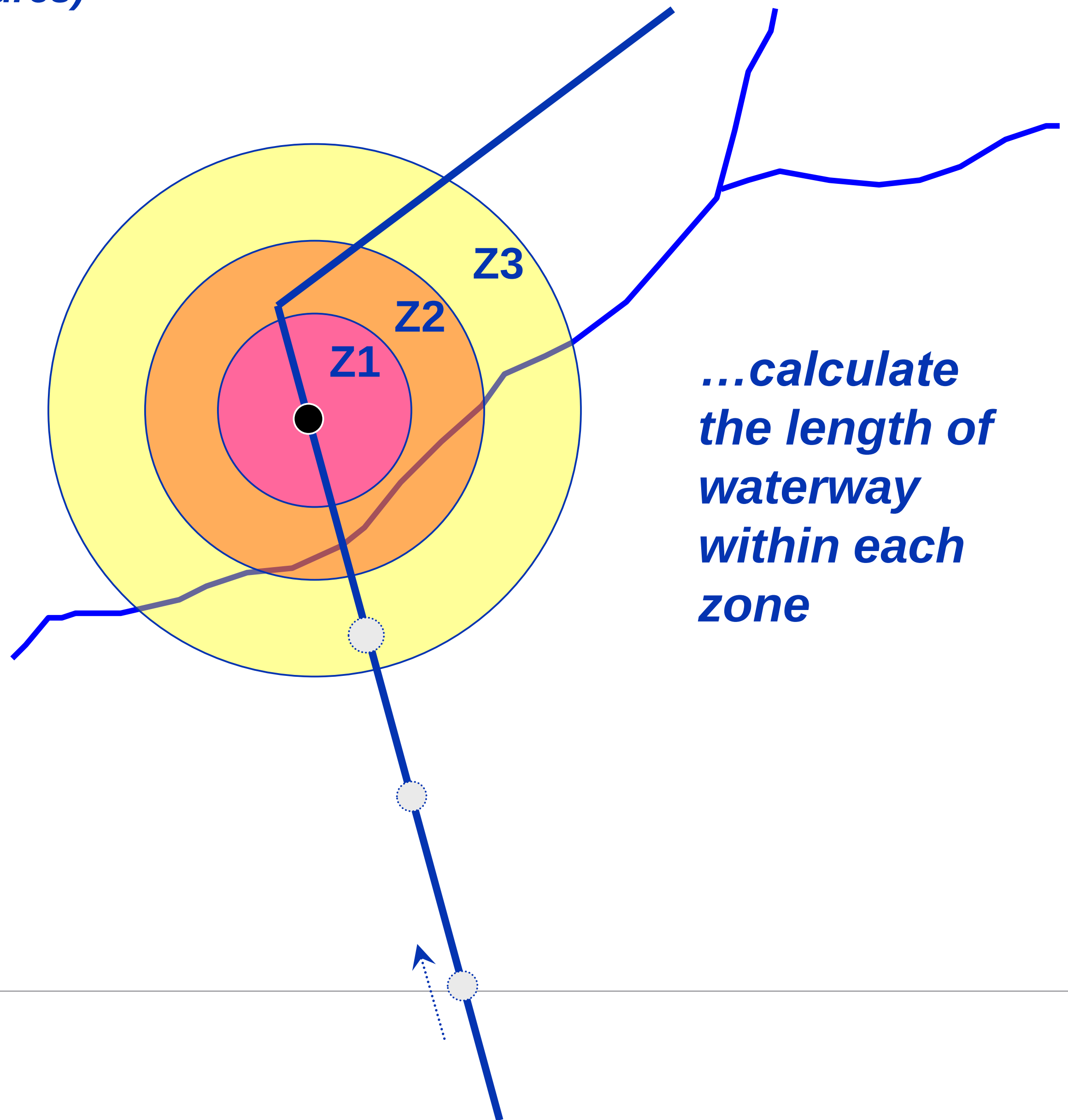
…determine the # of zones and reach defining each zone

Step 3: Determine Number of Houses in Each Zone *(Point Features)*



…count the number of houses within each zone

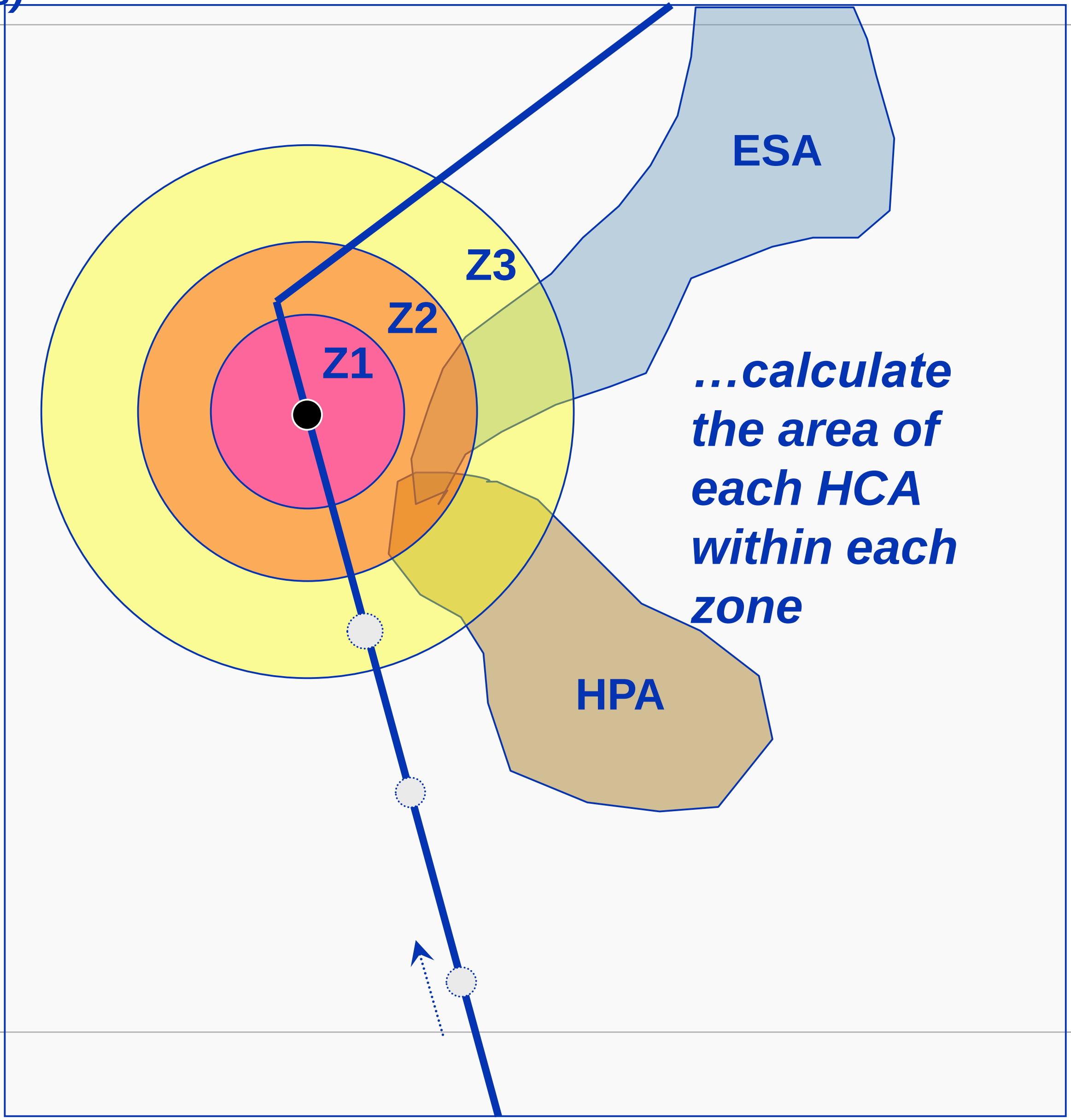
Step 4: Determine Length of Waterways in Each Zone *(Line Features)*



…calculate the length of waterway within each zone

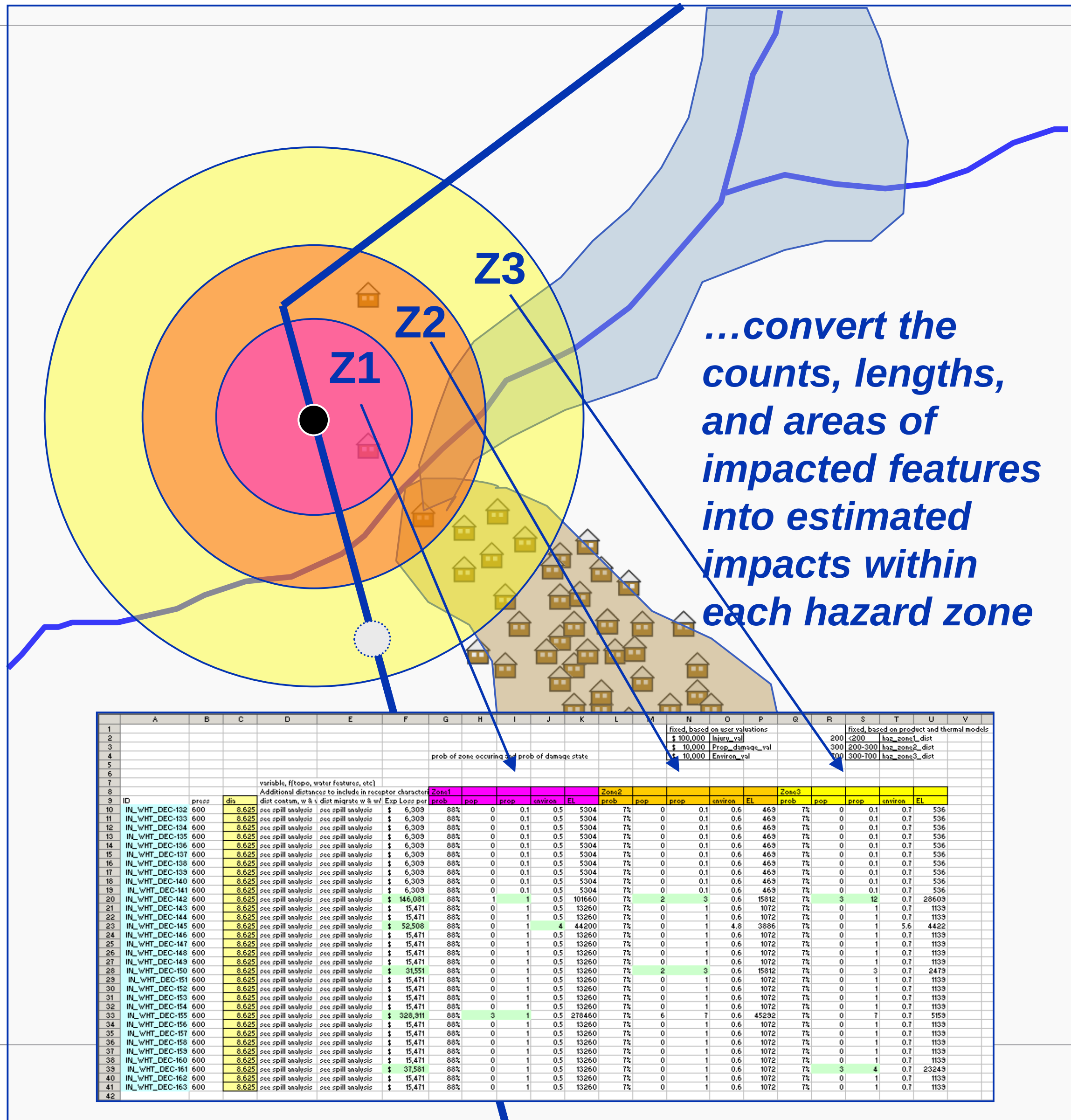
Step 5: Determine Area of HCAs in Each Zone

(Polygon Features)



…calculate the area of each HCA within each zone

Summarize Impacted Receptors *(Data Table)*



Expected Loss Calcs *(Probability * Impacted Feature Valuation)*

	Expected Loss per failure	Zone 1					Zone 2					Zone 3				
		Probability	Population	Property	Environ.	Potential Loss	Probability	Population	Property	Environ.	Potential Loss	Probability	Population	Property	Environ.	Potential Loss
10	$ 6,309	88%	0	0.1	0.5	5304	7%	0	0.1	0.6	469	7%	0	0.1	0.7	536
11	$ 6,309	88%	0	0.1	0.5	5304	7%	0	0.1	0.6	469	7%	0	0.1	0.7	536
12	$ 6,309	88%	0	0.1	0.5	5304	7%	0	0.1	0.6	469	7%	0	0.1	0.7	536
13	$ 6,309	88%	0	0.1	0.5	5304	7%	0	0.1	0.6	469	7%	0	0.1	0.7	536
14	$ 6,309	88%	0	0.1	0.5	5304	7%	0	0.1	0.6	469	7%	0	0.1	0.7	536
15	$ 6,309	88%	0	0.1	0.5	5304	7%	0	0.1	0.6	469	7%	0	0.1	0.7	536
16	$ 6,309	88%	0	0.1	0.5	5304	7%	0	0.1	0.6	469	7%	0	0.1	0.7	536
17	$ 6,309	88%	[illegible]	[illegible]	0.5	5304	7%	[illegible]	[illegible]	0.6	469	7%	[illegible]	[illegible]	0.7	536
18	$ 6,309	88%	0	0.1	0.5	5304	7%	0	0.1	0.6	469	7%	[illegible]	0.1	0.7	536
19	$ 6,309	88%	[illegible]	[illegible]	0.5	5304	7%	0	[illegible]	0.6	469	7%	[illegible]	[illegible]	0.7	536
20	$ 146,081	88%	1	1	0.5	101660	7%	2	3	0.6	15812	7%	3	12	0.7	28609
21	$ 15,471	88%	0	1	0.5	13260	7%	0	1	0.6	1072	7%	0	1	0.7	1139
22	$ 15,471	88%	0	1	0.5	13260	7%	0	1	0.6	1072	7%	0	1	0.7	1139
23	$ 52,508	88%	0	1	4	44200	7%	0	1	4.8	3886	7%	0	1	5.6	4422
24	$ 15,471	88%	0	1	0.5	13260	7%	0	1	0.6	1072	7%	0	1	0.7	1139

Probability of zone occuring and Probability of damage state

fixed, based on user valuations

$ 100,000	Injury_val
$ 10,000	Prop_damage_val
$ 10,000	Environ_val

fixed, based on product & thermal models

200	<200	haz_zone1_dist
300	200-300	haz_zone2_dist
700	300-700	haz_zone3_dist

One injury
One property damaged

Two injuries
Three properties damaged

Three injuries
Twelve properties damaged

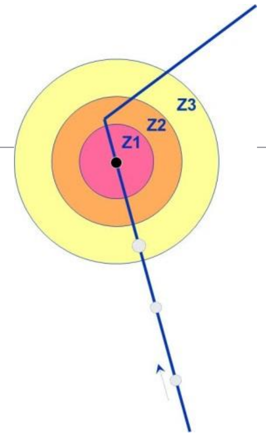
sum / TTF / thd pty / **conseq calc** / conseq / dyn seg / data dictionary / notes

Each row represents one pipeline release location

Expected Loss is a function of each Zone's Probability of occurring and the Zone's Potential Loss
Expected Loss = (Z1_Prob * Z1_PLoss) + (Z2_Prob * Z2_PLoss) + (Z3_Prob * Z3_PLoss)

EL_{20} = (.88 * 101660) + (.07 * 15812) + (.07 * 28609) = $146,081 …*considerable risk exposure at this lo*

Consequence Estimation Overview



Sequence of Analysis

1. Chance of failure (threat models)
2. Chance of failure hole size

From Probability Assessment

3. Spill size (considering leak detection and reaction scenarios)
   - *Volume Out*
4. Chance of ignition
   - Immediate
   - Delayed
   - None
5. Spill dispersion
   - Pipeline/product characteristics
   - Topography (if liquid release)
   - Meteorology (if gaseous release)

		2		4	5			6	
Product	Hole size	Hole size probability	Ignition scenario	Ignition probability	Distance from source (ft)	thermal hazard zone (ft)	Contaminati on hazard zone (ft)	Total (ft)	probability of hazard zone
oil	rupture	4%	immediate ignition	5%	0	400	0	400	0.2%
			delayed ignition	10%	600	500	400	1100	0.4%
			no ignition	85%	600	0	900	1500	3.4%
	medium	16%	immediate ignition	2%	0	200	0	200	0.3%
			delayed ignition	5%	200	300	200	500	0.8%
			no ignition	93%	200	0	500	700	14.9%
	small	80%	immediate ignition	1%	0	50	0	50	0.8%
			delayed ignition	2%	80	100	0	180	1.6%
			no ignition	97%	80	0	80	160	77.6%

6. Hazard area size and probability (for each scenario)
7. Chance of receptor(s) being in hazard area (counts, density, or area)
8. Chance of various damage states to various receptor (including consequence mitigation)
9. Calculate Expected Loss (Prob x Consequence $)

Other Consequences

- Service Interruption
- Production/transportation loss
- Repair costs
- Resumption of service
- Contract penalties
- Legal costs
- Increased regulatory oversight
- Corp reputation

Risk Of Service Interruption

Service interruption risk

= (Upset potential) X (impact factor)

Where:

Upset potential = (PSD + DPD)

Service Interruptions

- Product spec deviation (PSD)
  - Product origin
  - Equipment
  - Dynamics
  - Other
- Delivery parameter deviation (DPD)
  - Pipeline failures
  - Blockages
  - Equipment
  - Operator error
- Intervention adjustment
- Upset potential

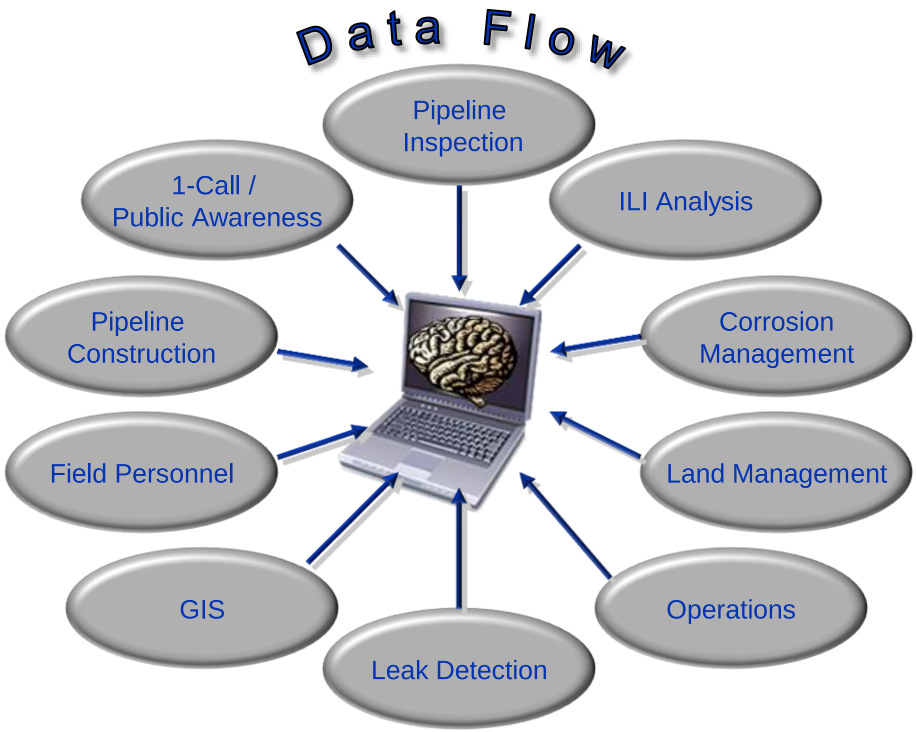
Integrate Pipeline Knowledge

- The assessment must include complete, appropriate, and transparent use of all available information
- ‘Appropriate’ when model uses info as would an SME

How much is enough?

Integrate Pipeline Knowledge

- The risk assessment should use all the information in substantially the same way that an SME uses information to improve the understanding of risk



Integrate Pipeline Knowledge

External Corrosion Model

EC POF (prob/mile-yr)

↑

EC TTF (Years –assuming a per mile basis)

- Available Pipe Wall (in)
  Estimate x Adjustment
  - Estimate (in)
    - Max based on:
      1. NOP
      2. Hydrotest
      3. NDE/ILI

      2&3 adjusted for mpy growth since measurement
  - Adjustments (%)
    - Cumulative:
      1. Joint Type
      2. Reinforcements
      3. Manuf & Const
      4. Pipe Type
      5. Toughness
      6. Flaws
      7. External Loads
      8. Spans
- Growth Rate (mpy)
  - Estimate (mpy)
    Total mpy x (1-Mitigation)
    - Environment (mpy)
      Sum
      1. Above/Below Ground
      2. Atmospheric CGR (mpy)
      3. Electrical Isolation (%)
      4. Soil based CGR (mpy)
         1. Corrosivity
         2. Moisture Content
         3. MIC
      5. Mitigated AC Induced CGR (mpy)
    - Mitigation (%) based on Active Corrosion Locations
      - CP Gaps (Prob of gaps/ft)
        Sum of gaps/mi converted to probability
        - CP Effectiveness
          - Measured Gaps /mi
            1. CP Readings adjusted by confidence
          - Estimated Gaps/mi
            1. Distance from test station
            2. PL Age
            3. Criteria
            4. Rectifier out of service history
        - CP Interference
          - Locations/mi:
            1. DC Sources (mitigated)
            2. Coating Shielding
            3. Casing Shielding
      - External Coating Holiday Rate
        - Estimated (defects/mi)
          1. Defects/mi adjusted by confidence
        - Measured (defects/mi)
          1. Defects/mi adjusted by confidence and age
  - Measured (mpy)
    - Direct measurements adjusted by Confidence

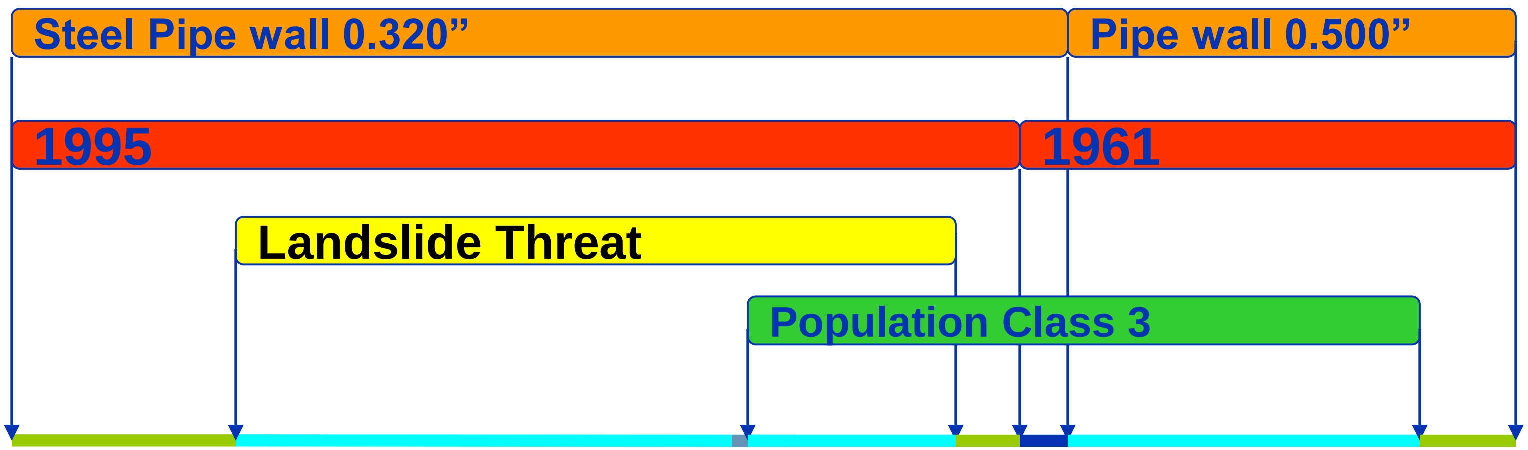
Incorporate Sufficient Granularity

- Risk assessment must divide the pipeline into segments where risks are unchanging
- Compromises involving the use of averages or extremes can significantly weaken the analysis and are to be avoided

Dynamic Segmentation

Incorporate Sufficient Granularity

Due to the numerous and constantly-varying factors effecting the risk to the pipeline, proper analysis will require at least 10-100 segments per mile*



*thousands of segments per mile is not unusual today

Facility Risks

Truck Loading

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

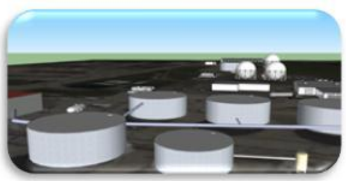
Pig Launchers

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

Pumps

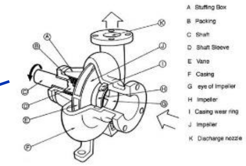
Expected Loss ($/yr)	$23
Total PoF	2.26E-03
Max CoF	$32,000

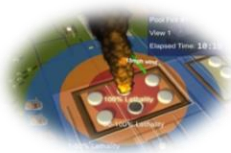
Tankage



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

Control the Bias

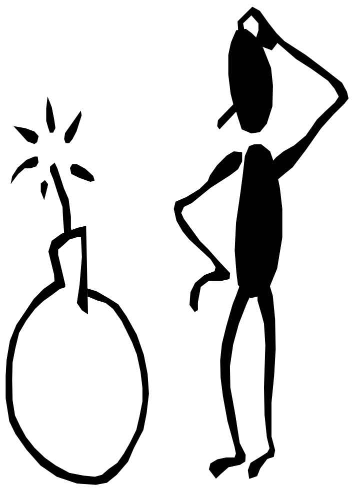
- Risk assessment must state the level of conservatism employed in all of its components
- Assessment must be free of inappropriate bias that tends to force incorrect conclusions

Certainty

Control the Bias

"Absolute certainty is the privilege of fools and fanatics."

Dealing With Uncertainty



Error 1: call it ‘good’ when its really ‘bad’

Error 2: call it ‘bad’ when its really ‘good’

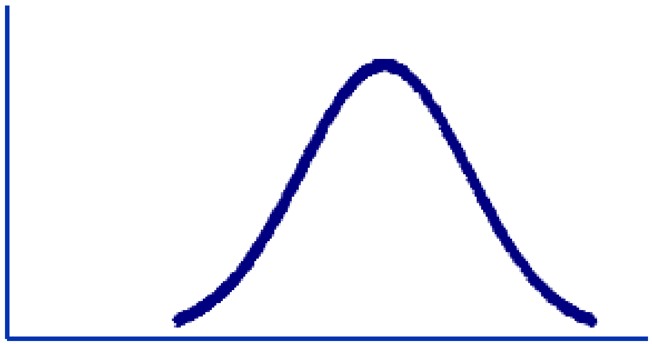
Understanding Conservatism and Uncertainty

Control the Bias

A way to measure and communicate conservatism in risk estimates

- PXX
  - P50
  - P90
  - P99.9

Useful in conveying intended level of conservatism



The Role of Historical Incidents

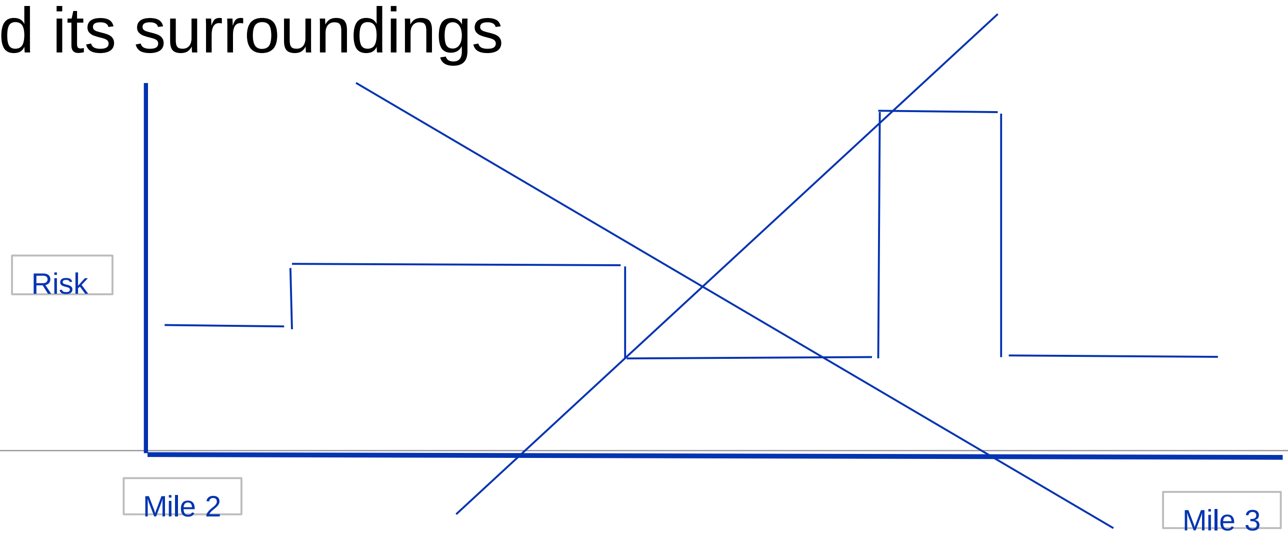
Control the Bias

Problems:

- Historical data usefulness in current situation
- Small amount of data in rare-event situations
- Representative population
- Behavior of the individual vs population

Profile the Risk Reality

- The risk assessment must be performed at all points along the pipeline
- Must produce a continuous profile of changing risks along the entire pipeline
- Profile must reflect the changing characteristics of the pipe and its surroundings



Profile to Characterize Risk

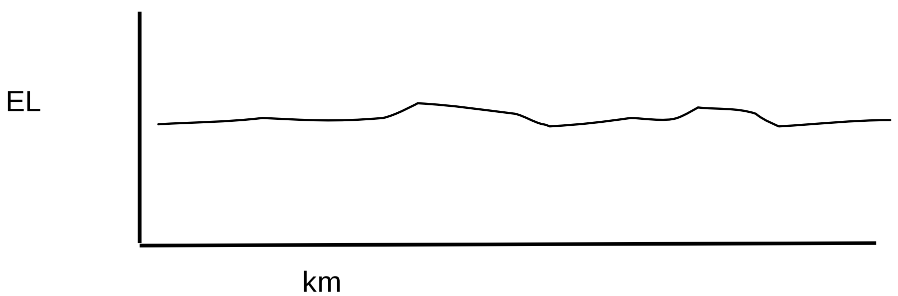
<u>Scenario 1</u>
100 km oil pipeline
widespread coating failure
river parallel
remote

<u>Scenario 2</u>
50 km gas pipeline
2 shallow cover locations
high population density
high pressure, large diameter

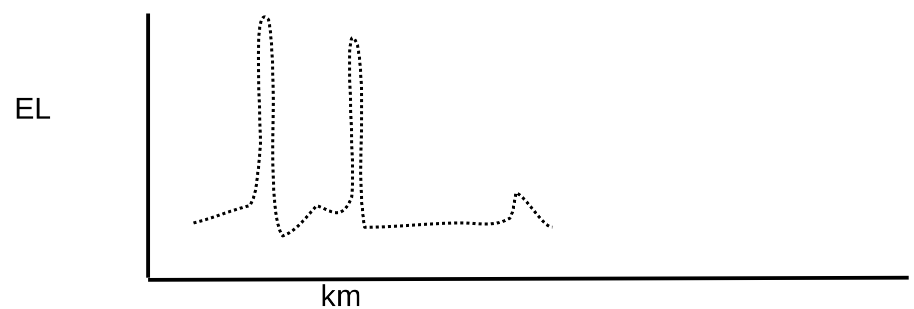
Profile the Risk Reality

Risk Characterization

<u>Scenario 1</u>
100 km oil pipeline
widespread coating failure
river parallel
remote location



<u>Scenario 2</u>
50 km gas pipeline
2 shallow cover locations
high population density
high pressure, large diameter

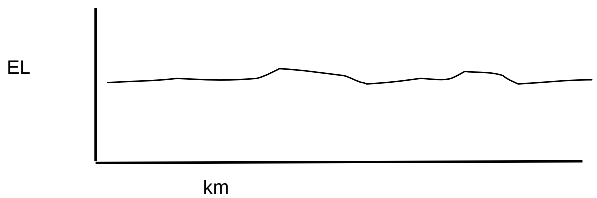


Very different risk profiles

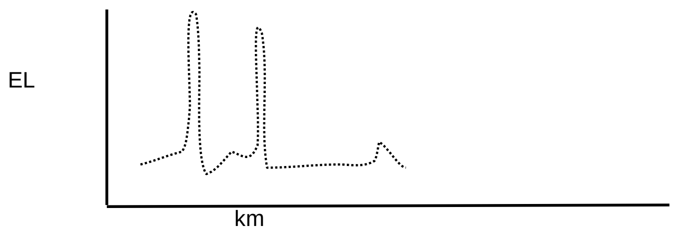
Profile the Risk Reality

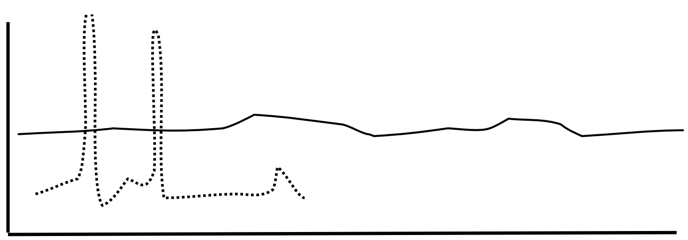
Risk Characterization

Scenario 1
100 km oil pipeline
widespread coating failure
river parallel
remote location



Scenario 2
50 km gas pipeline
2 shallow cover locations
high population density
high pressure, large diameter





What is best action to take?

ProperAggregation

- Proper process for aggregation of the risks from multiple pipeline segments must be included
- Summarization of the risks from multiple segments must avoid simple statistics or weighted statistics that mask the actual risks

Aggregating Risks for Collection of Pipe Segments

Unmask Aggregation

PoF total = PoF1 + PoF2 + PoF3 + PoF4 + …. PoFn

PoF total = 137% . . . ?

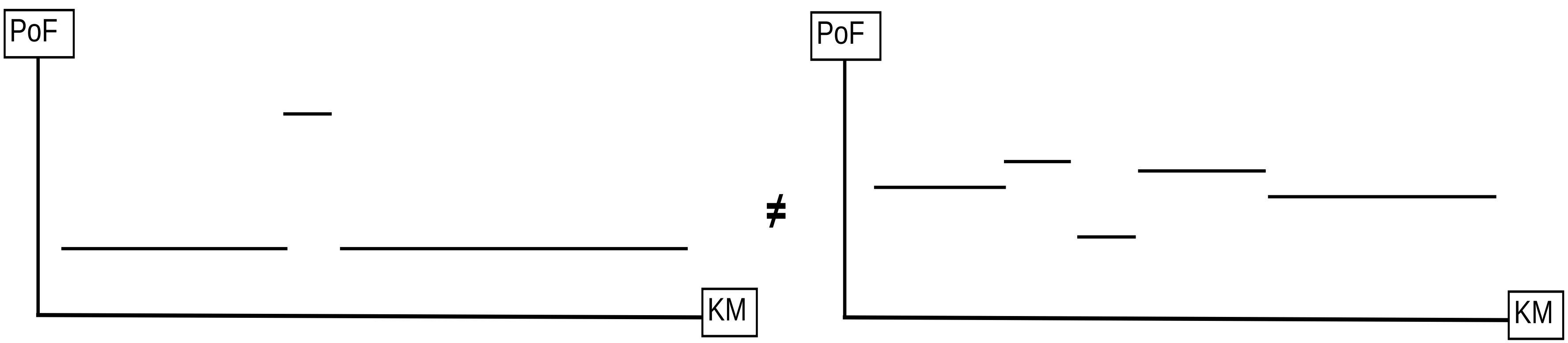
Simple sum only works when values are very low.

Aggregating Risks

Unmask Aggregation

~~PoF total = Avg(PoF1, PoF2, …PoFn)~~

Avg PoF = Avg PoF
But



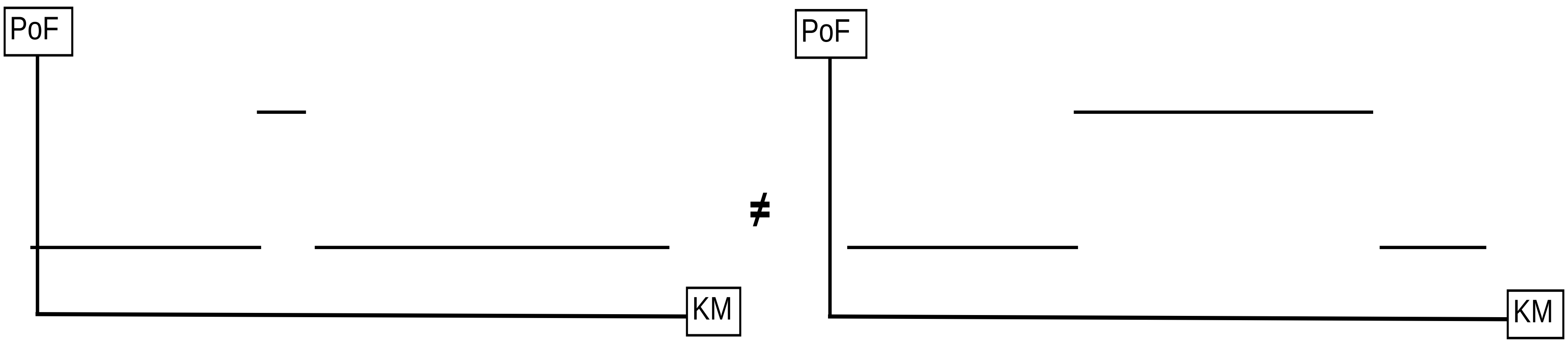
Aggregating Risks

Unmask Aggregation

~~PoF total = Max(PoF1, PoF2, …PoFn)~~

Max PoF = Max PoF

But

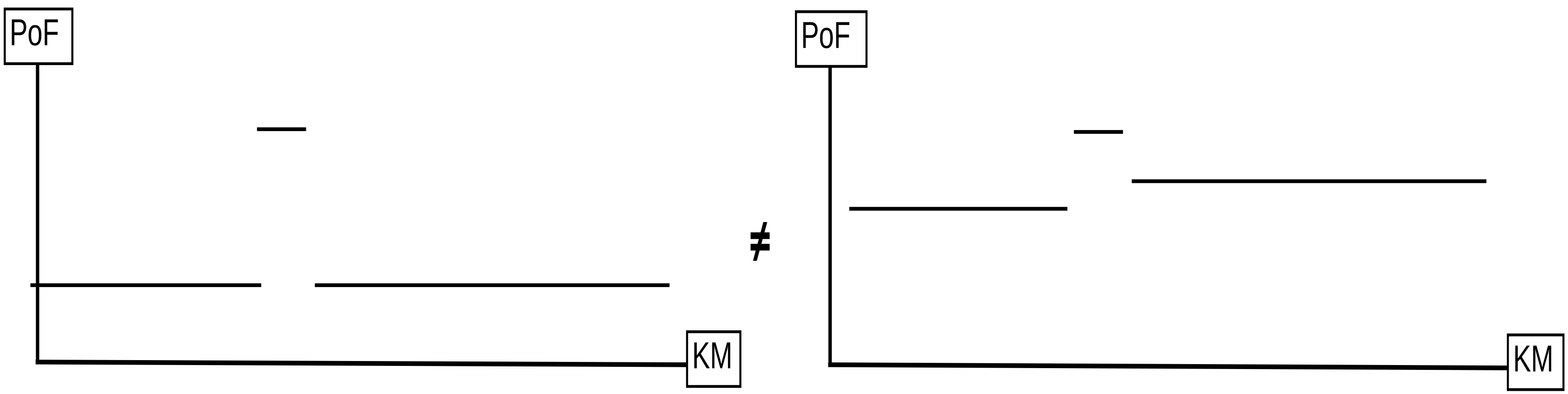


Aggregating Risks

~~PoF total = Max(PoF1, PoF2, …PoFn)~~

Max PoF = Max PoF

But



Aggregating Failure Probabilities

Overall pf is prob failure by [(thd pty) OR (corr) OR (geohaz)…]

Ps = 1 - pf

Overall ps is prob surviving [(thd pty) AND (corr) AND (geohaz)….]

So…

$$Pf_{overall} = 1-[(1-pf_{thdpty}) \times (1-pf_{corr}) \times (1-pf_{geohaz}) \times (1-pf_{incops})]$$

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 Risk
- Proper Aggregation

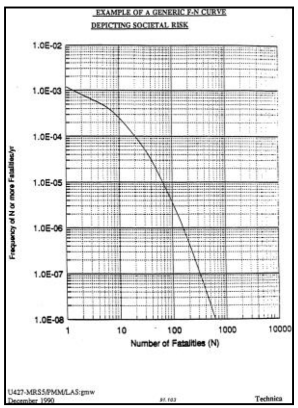
Managing Risks

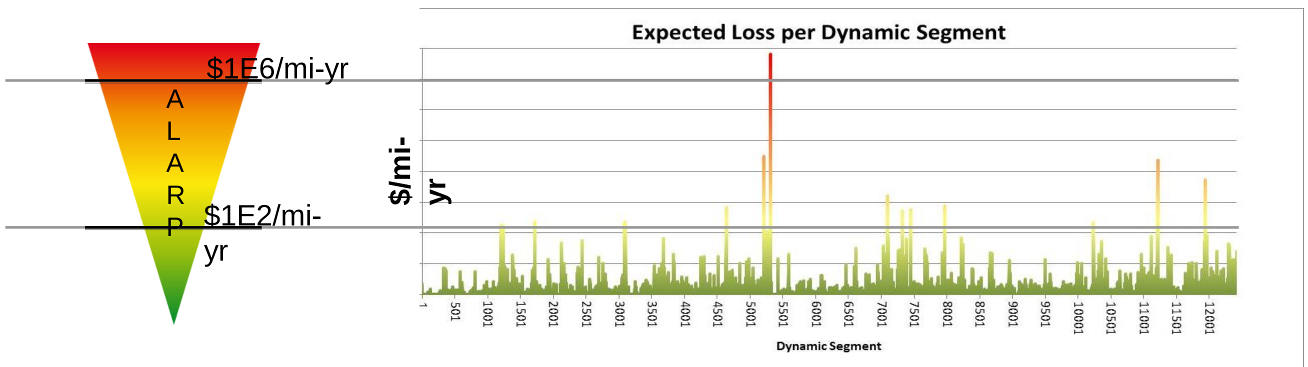
Situations in life often permit no delay; and when we cannot determine the action that is certainly the best, we must follow the action that is probably the best.

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

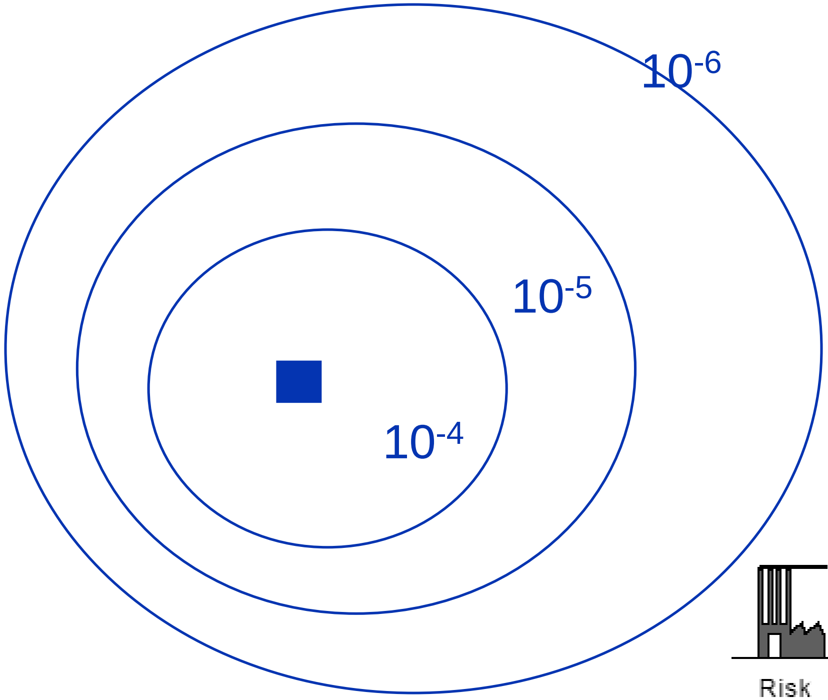
Participating in Important Discussions

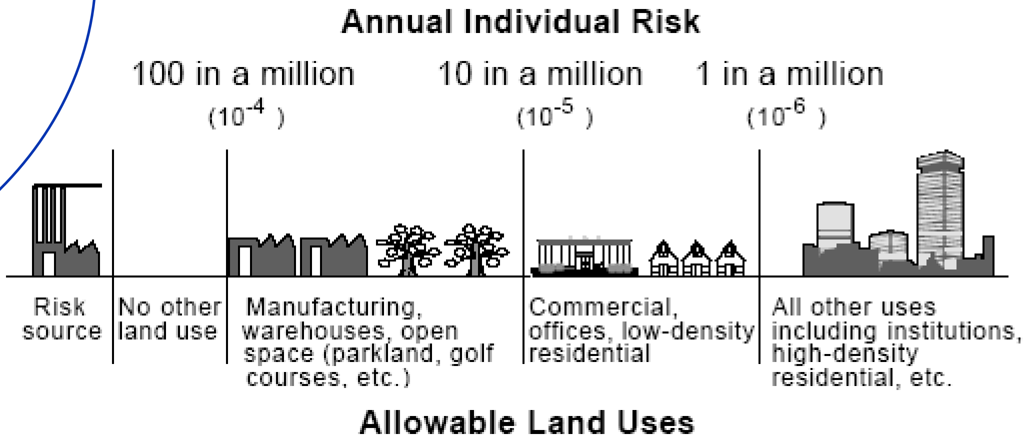
How safe is 'safe enough'?





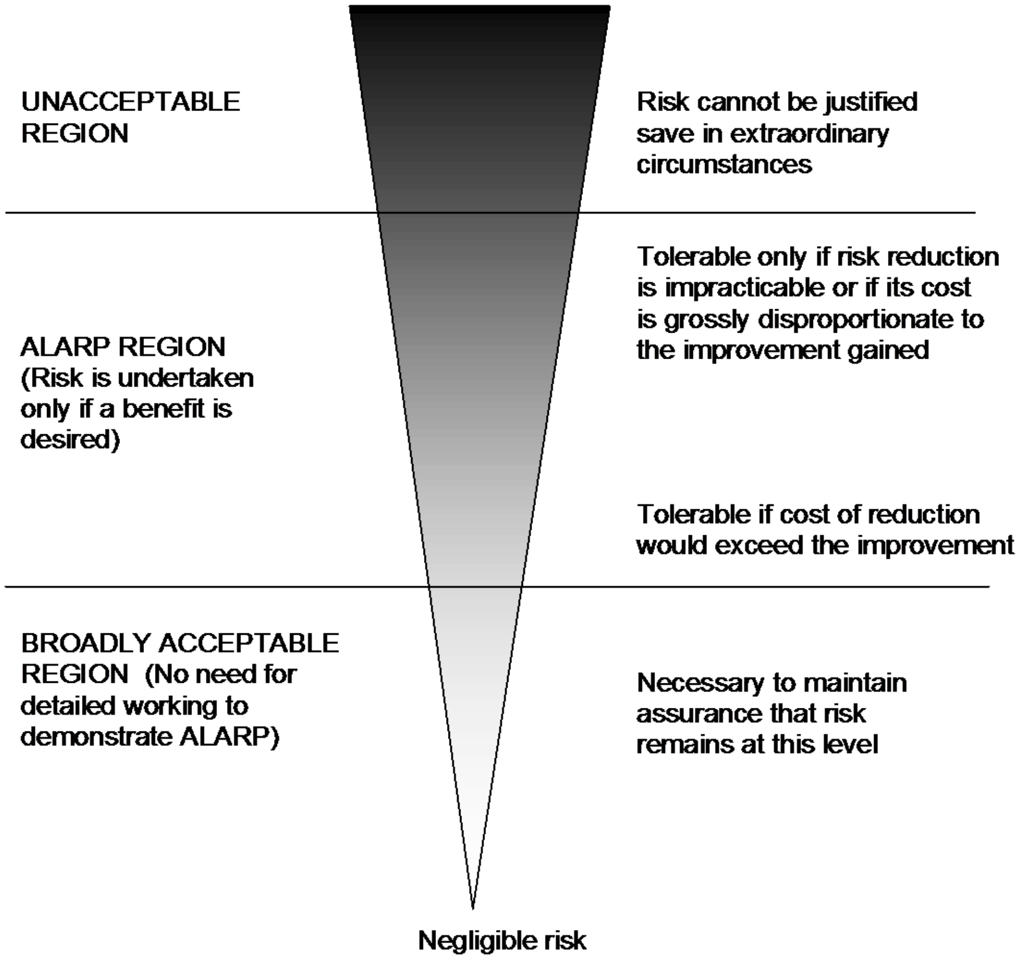
Canadian Risk-Based Land Uses



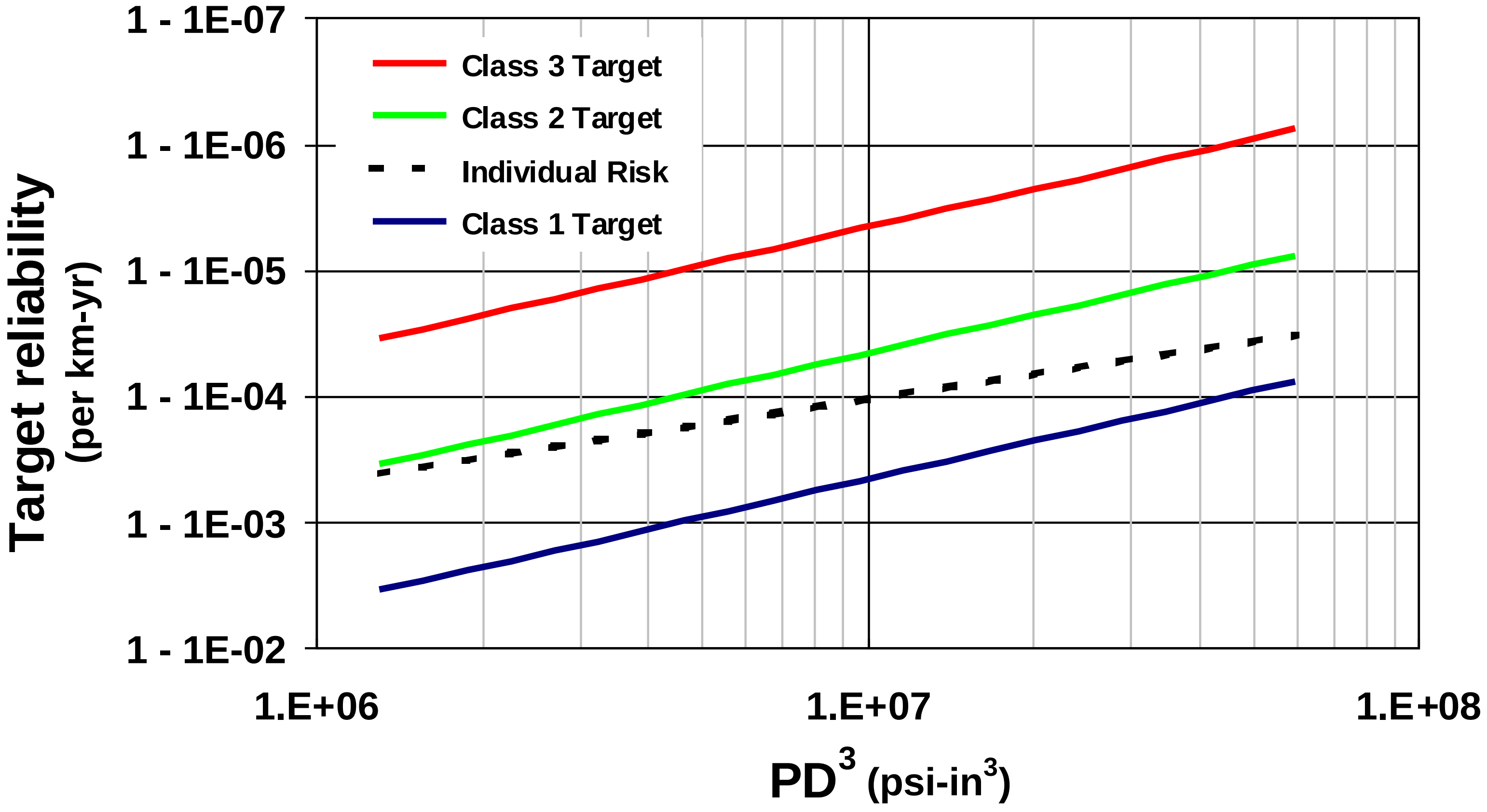


CSChE Risk Assessment – Recommended Practices,
MIACC risk acceptability

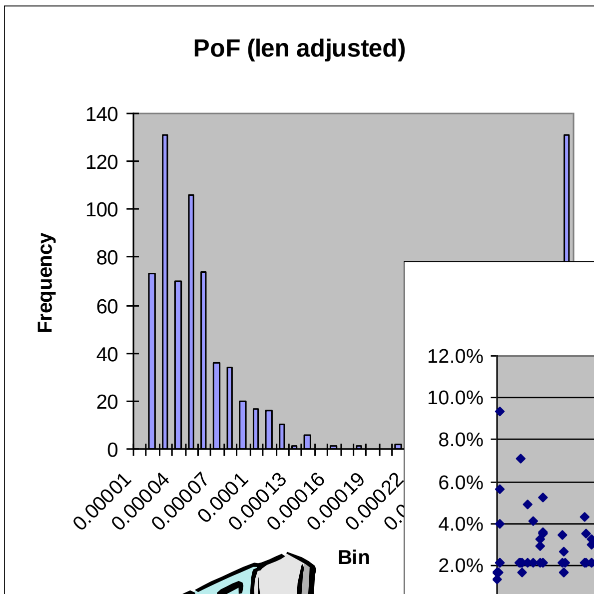
Acceptable Risk

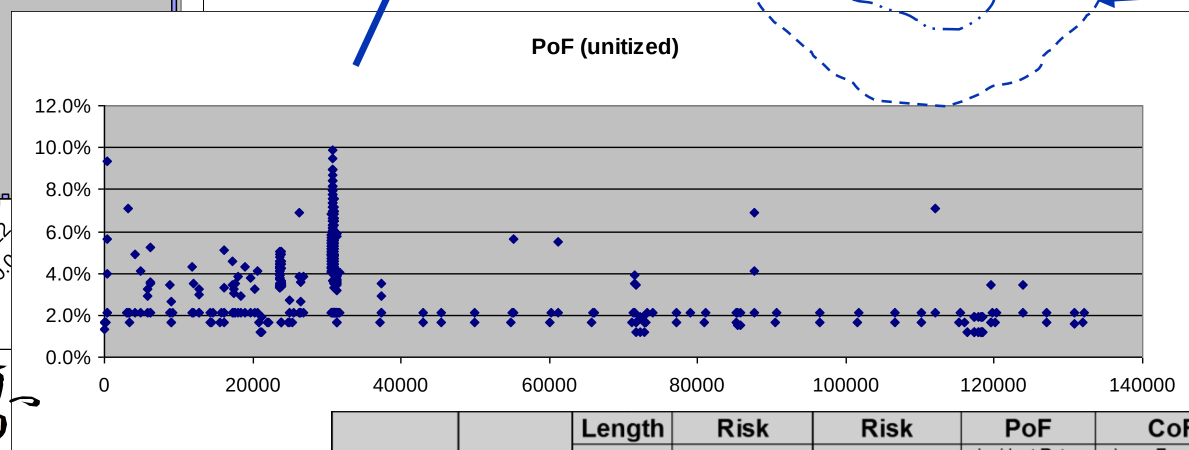


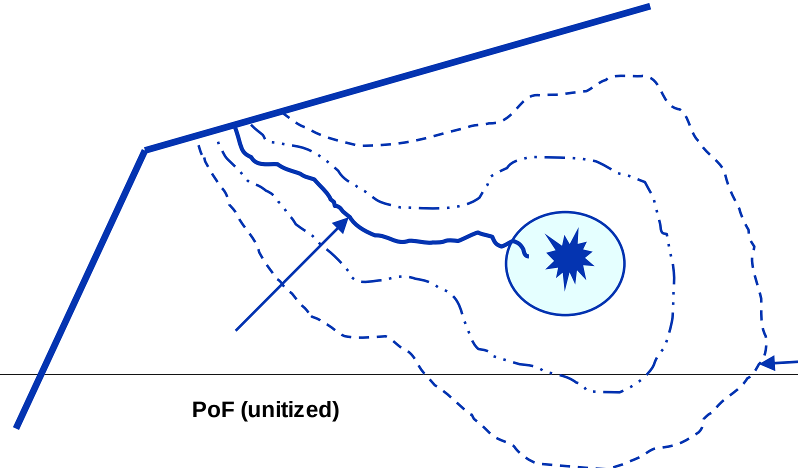
Reliability Targets

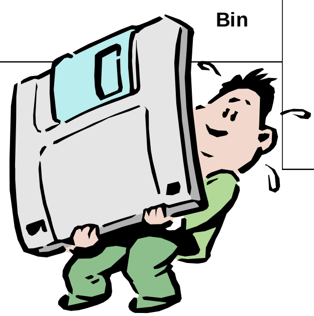


Modern PL RA is Specialized QRA-PRA





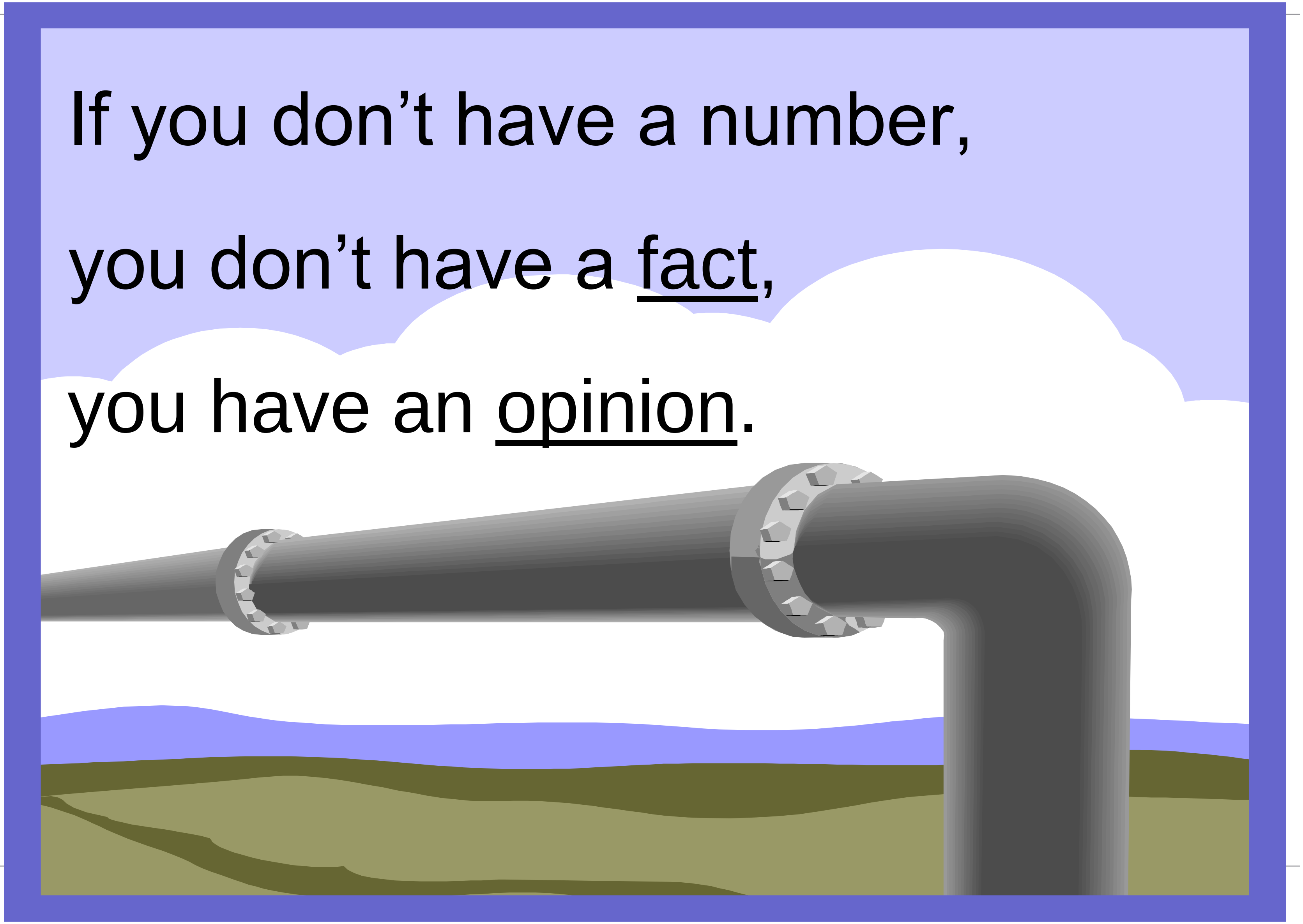




System	Product	Length	Risk	Risk	PoF	CoF
		miles	Total Annual Exposure	Expected Loss $/mi-yr	Incident Rate, failures per mi-yr	Loss Exposure, Probability-weighted $/failure
Elvira	gasoline	120	$ 142,080	$ 1,184	0.001	$ 1,184,000
Scaramonga	crude oil	408	$ 342,720	$ 840	0.0015	$ 560,000
Perseus	natural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

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


If you don’t have a number,
you don’t have a fact,
you have an opinion.

Key Takeaways

- 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

Hawthorne Effect

"Anything that is studied, improves."

Anticipate enormously more useful information

Appendix

Protocols

- **C.03.c.** Verify that the risk assessment explicitly accounts for factors that could affect the likelihood of a release and for factors that could affect the consequences of potential releases, and that these factors are combined in an appropriate manner to produce a risk value for each pipeline segment

- The risk assessment approach contains a defined logic and is structured to provide a complete, accurate, and objective analysis of risk [ASME B31.8S-2004, Section 5.7(a)];
  - ii. The risk assessment considers the frequency and consequences of past events, using company and industry data [ASME B31.8S-2004, Section 5.7(c)];
  - iii. The risk assessment approach integrates the results of pipeline inspections in the development of risk estimates [ASME B31.8S-2004, Section 5.7(d)];
  - ~~iv. The risk assessment process includes a structured set of weighting factors to indicate the relative level of influence of each risk assessment component [ASME B31.8S-2004, Section 5.7(i)];~~
  - v. The risk assessment process incorporates sufficient resolution of pipeline segment size to analyze data as it exists along the pipeline [ASME B31.8S-2004, Section 5.7(k)].

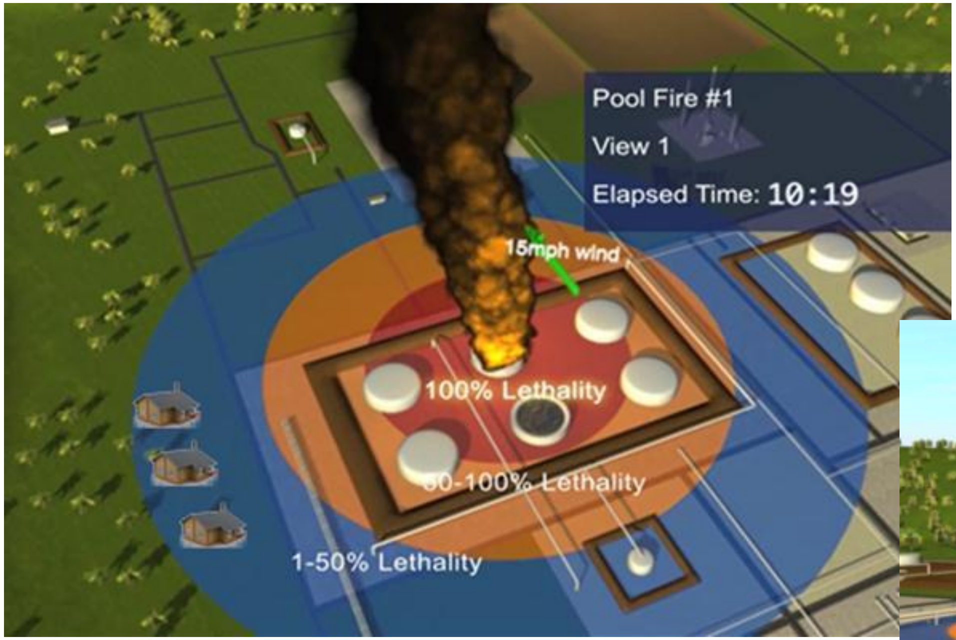
Surface Facilities Assessment

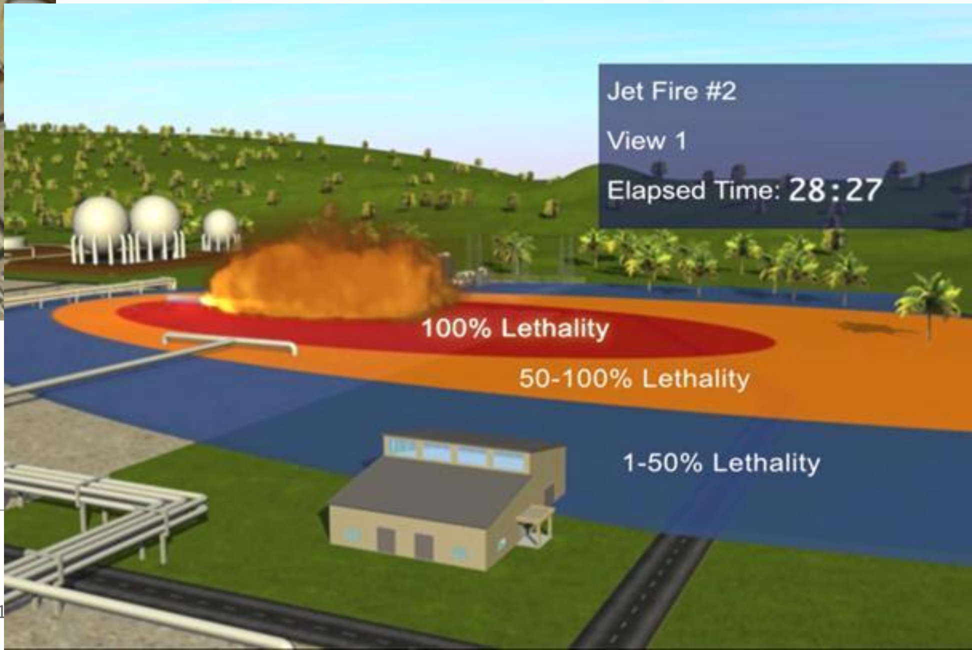
CoF at Facilities

Hazard Zone Assessment

$$Potential\ Loss = Hazard\ Area^{*}\ x\ \Sigma(receptor\ unit\ value\ x\ receptor\ density\ x\ receptor\ damage\ rate)$$

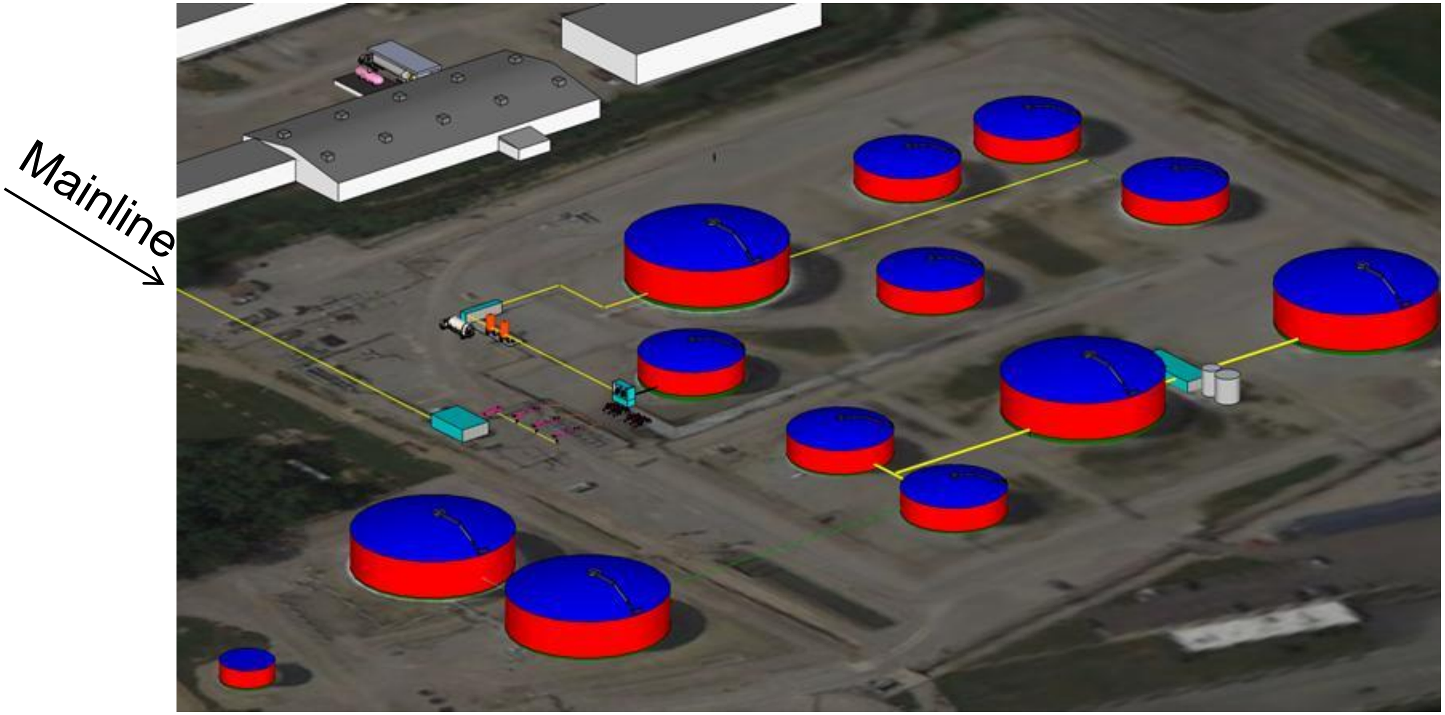
* Probability-adjusted area





Application to Facilities

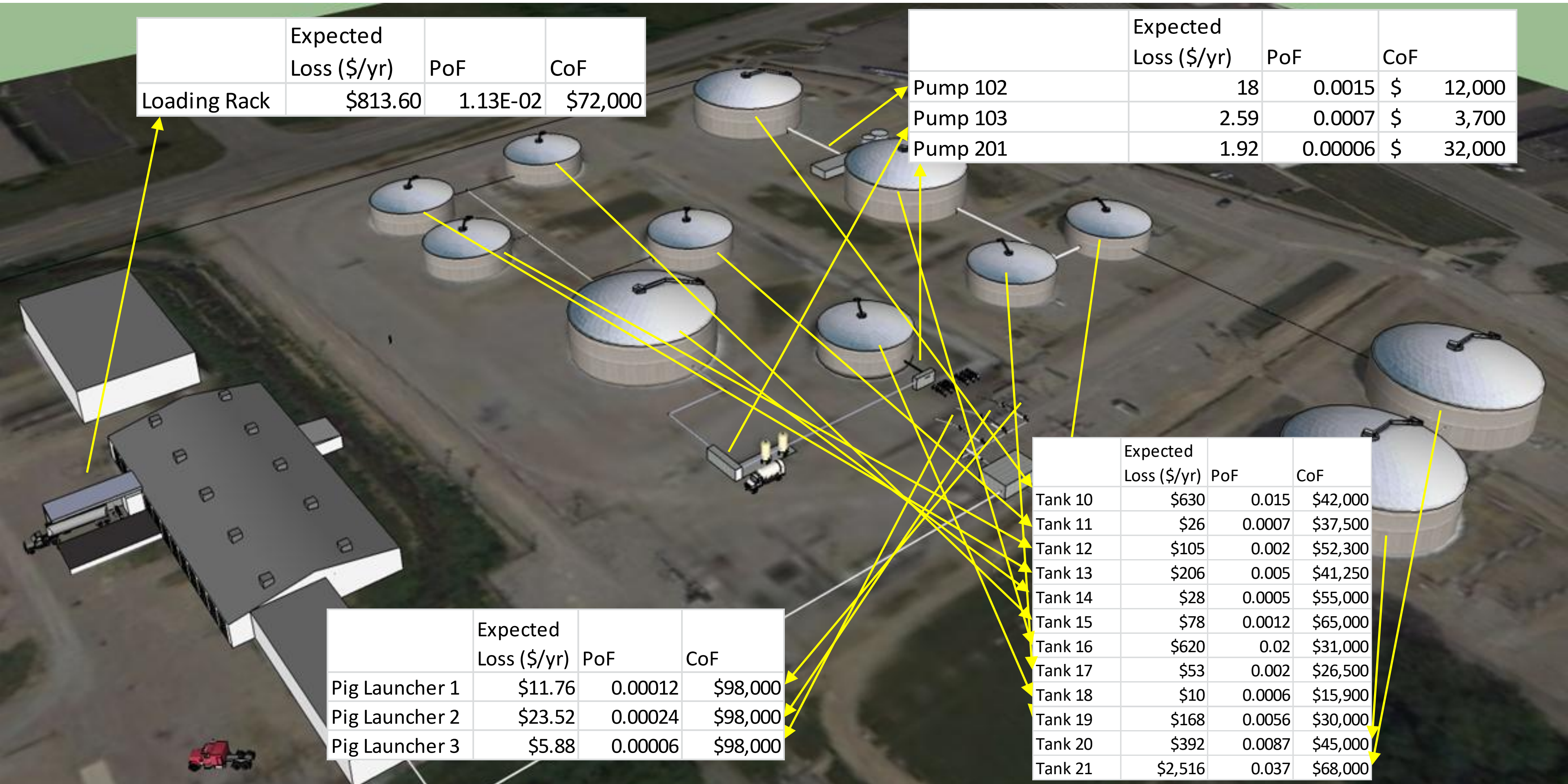
- Dynamic Segmentation is applied to find equipment items with similar characteristics



- Using the same assessment methodology for pipelines and facilities ensures apples-to-apples comparisons

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
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

	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

Application to Facilities

- Total Risk from a facility

Truck Loading

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

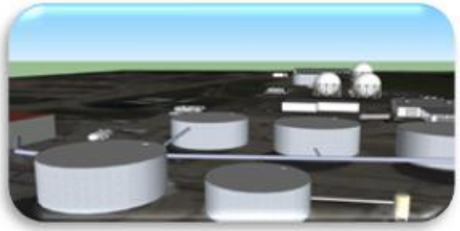
Pig Launchers

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

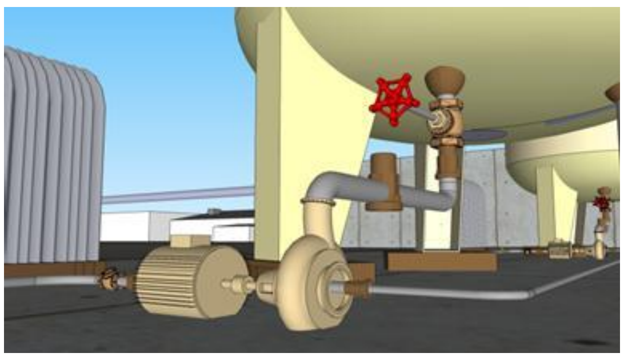
Total Facility

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

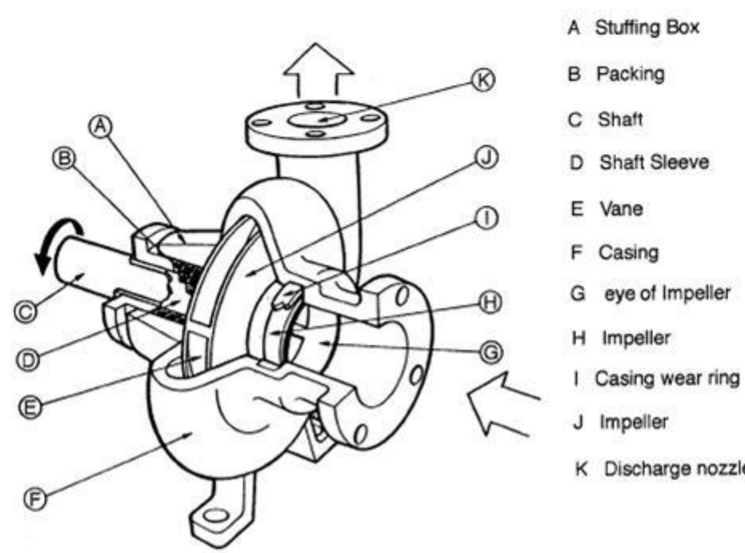
Application to Facilities

- Utilizes the same models developed for pipelines
- Each equipment item is assessed for threats that may lead to a loss of containment

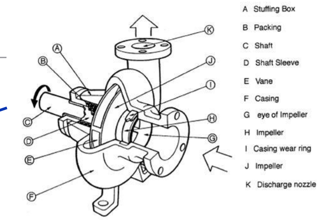
Example



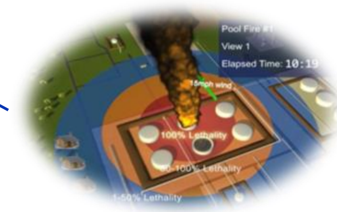
1) *What components can lead to a loss of containme*
2) *What threats apply to those components?*



Absolute Facility Risk



Same models used in PLs



Truck Loading

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Total PoF	4.20E-04
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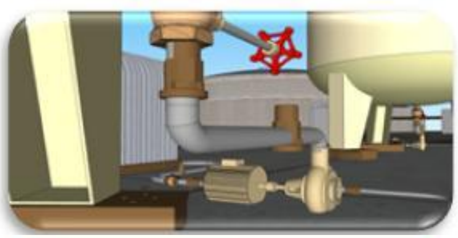
Pumps



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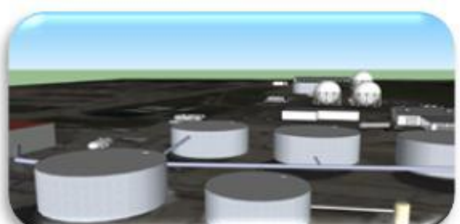
Tankage



Expected Loss ($/yr)	$4,831
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Max CoF	$68,000

Total Facility

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

“…when you can measure what you are speaking about, and express it in numbers, you know something about it; but when you cannot measure it, when you cannot express it in numbers, your knowledge is of a meagre and unsatisfactory kind; it may be the beginning of knowledge, but you have scarcely in your thoughts advanced to the state of Science, whatever the matter may be.”

Lord Kelvin

Sample Audit Questions

- What is maximum and average segment length?
  - If less than 20 segs per mile, then only appropriate if very low variations along route, including hydraulic profile
- How do you discriminate between low-exp and low-mit vs high-exp and high-mit?
- Show how non-HCA data is being used.
- Obtain counts and ranges (min, max, average):
  - Inputs
  - Defaults & assignments
  - Threats
  - Equations
- What is target level of conservatism? P50? P90? P99.9? For various uses of results.
- Show how risk assessment is driving risk management (P&M).
- Show where remaining life (TTF) is used to set integrity re-assessment intervals.

Practice PoD, PoF

What is PoD and PoF when . . .

- Exposure = 10 events/mile-year
- Mitigation = 99%
- Resistance = 90%

PoD = Exposure x (1 - mitigation)

= 10 x (1 - 0.99)

= 0.1 damages/mile-year = damage incident every 10 yrs

PoF = PoD x (1 - resistance)

= 0.1 x (1 - 0.9)

= 0.01 failures/mile-year = failure every 100 years

Practice PoD, PoF

What is PoD and PoF when . . .

- Exposure = 1 events/mile-year
- Mitigation = 50%
- Resistance = 50%

- Exposure = 2 events/mile-year
- Mitigation = 90%
- Resistance = 80%

- Exposure = 10 events/mile-year
- Mitigation = 99.9%
- Resistance = 90%

- Exposure = 0.01 events/mile-year
- Mitigation = 99.99%
- Resistance = 95%

Practice TTF, PoF

What is TTF and PoF when . . .

- Exposure = 10 mpy
- Mitigation = 50%
- Resistance = 0.100”

Damage rate = Exposure x (1 - mitigation)

= 10 x (1 - 0.5)

= 5 mpy

TTF = Resistance / Damage rate

= 100 mils / 5 mpy = 20 years

PoF = 1 / TTF

= 1 / 20 years = 0.05 / year = 5% prob failure in year one

Practice TTF, PoF

What is TTF and PoF when . . .

- Exposure = 5 mpy
- Mitigation = 80%
- Resistance = 0.100”

- Exposure = 10 mpy
- Mitigation = 90%
- Resistance = 0.100”

Example

Ext Corr

1995 4" steel, 0.250", coated, CP

Exposure (mpy)		10
Mitigation (%)		80%
	coat	50%
	CP	60%
Resistance (in)		0.22
TTF (yrs)		110
PoF (%/yr)		0.9%

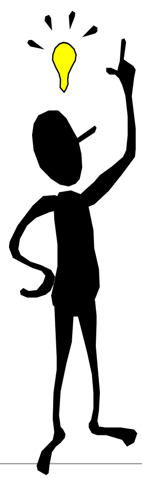
Risk

Ext Corr	0.9%
Thd Pty	5%
CoF	$ 5,000
PoF (%/yr)	5.9%
EL ($/yr)	$ 293
Risk (relative)	scaled from EL

Thd Pty

Excavations 2/yr in this area

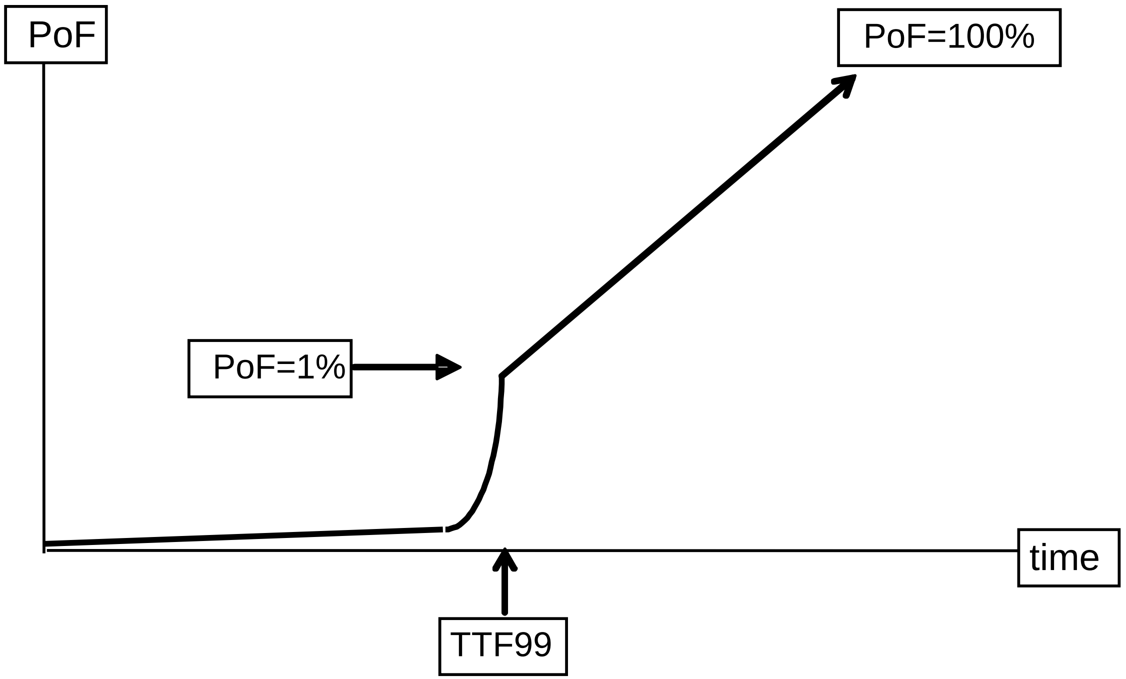
Exposure (events/yr)		2
Mitigation (%)		95%
	cover	90%
	one-call	50%
Resistance (%)		50%
PoD (%/yr)		10.0%
PoF (%/yr)		5%



CoF

Hazard Zone (ft2)	1000
Receptors ($/ft2)	$ 500
Damage Rate (%)	1%
EL ($/incid)	

PoF: TTF & TTF99



Examples

- TTF = 0.160” / [(16 mpy) x (1 - 0.9)] = 100 years
- TTF99 = 0.160” / (16 mpy) = 10 years
- PoF => lognormal or other =>0.001% for year 1

- TTF = 0.016” / [(16 mpy) x (1 - 0.9)] = 10 years
- TTF99 = 0.016” / (16 mpy) = 1 year
- PoF = 1/TTF = 10% for year 1

Final Pof

$$Pof_{overall} = pof_{thdpty} + pof_{ttf} + pof_{theftsab} + pof_{incops} + pof_{geohazard}$$

$$Pof_{overall} = 1-[(1-pof_{thdpty}) \times (1-pof_{ttf}) \times (1-pof_{theftsab}) \times (1-pof_{incops}) \times (1-pof_{geohazard})]$$

Guess pof if 1%, 4%, 2%, 2%, 0%

Calc: