Are vintage polyethylene pipelines really ageing out of the natural gas system?

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Fuelling the Future

Outline

- About ATCO
- Systems Overview & History
- Sample Collection & Testing
- Risk Profile Development
- Operationalizing Risk Profile
- Slow Crack Growth Characteristics
- Risk Model Implementation Process
- Monte Carlo Simulation
- Asset Attribution
- DIMP Incorporation

About ATCO

19,000

Employees Throughout ATCO and all Subsidiary and Affiliate Companies

100+

Countries Throughout our History

105,000

Kilometers of Electrical Powerlines

64,000+

Kilometers of Natural Gas Pipelines

About ATCO

Own and operate approximately

9,100 km

of natural gas transmission pipelines in Alberta

Deliver a peak of

3.7 billion cubic feet

of natural gas per day

We are Alberta's largest natural gas distribution company

Transport clean and efficient energy from producers and other pipelines to utilities, power generators and major industries.

55,000 km

of gas distribution lines that serve more than 1.3 million customers across Alberta

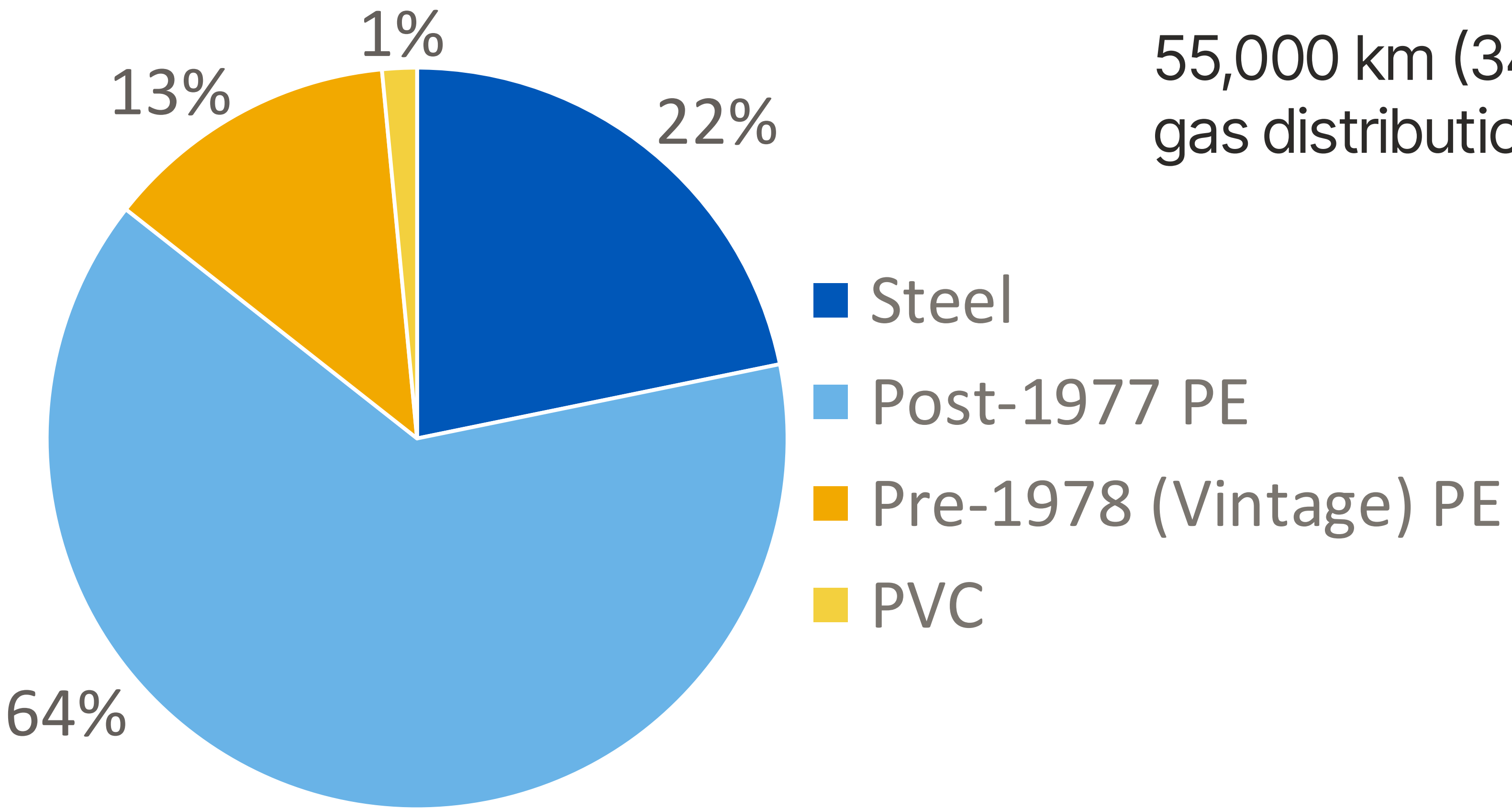
For more than 100 years, ATCO Gas has delivered clean, safe and reliable natural gas to homes and businesses in Alberta.

Delivers safe, reliable and cost-effective natural gas to over

1.3 million customers

in homes and businesses across 300 Alberta communities

Systems Overview & History



55,000 km (34,000 mi) of gas distribution lines in Alberta

Systems Overview & History

- First PVC and PE pipe installations in 1960
- In 2011, Plastic Mains Replacement (PMR) Program formally started
    - Targets pre-1978 installations
    - Over-pressure, PE vs. PVC, leak history
    - Service density, urban vs. rural
- In 2020, hired GTI Energy and started PE pipe sample collection and testing
- In 2024, implemented quantitative probabilistic model for pre-1978 PE pipelines

Systems Overview & History

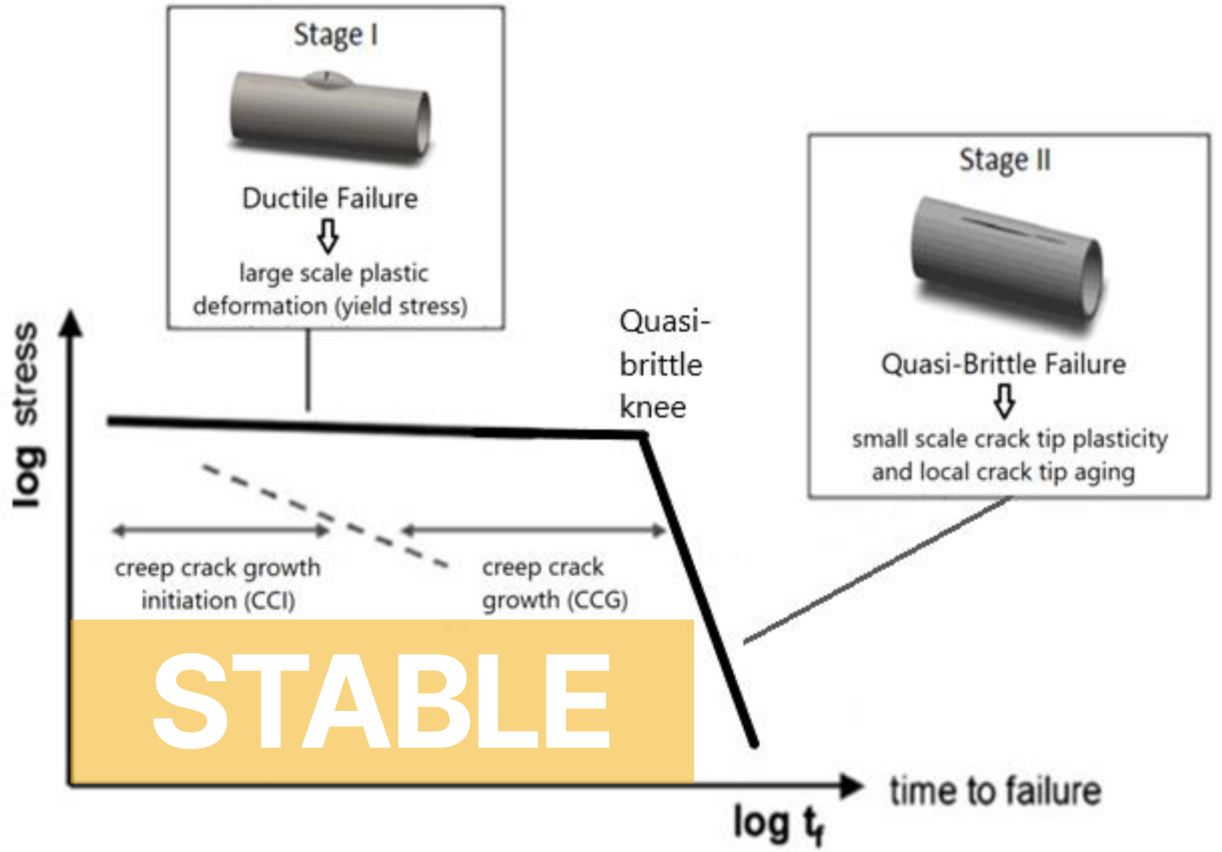
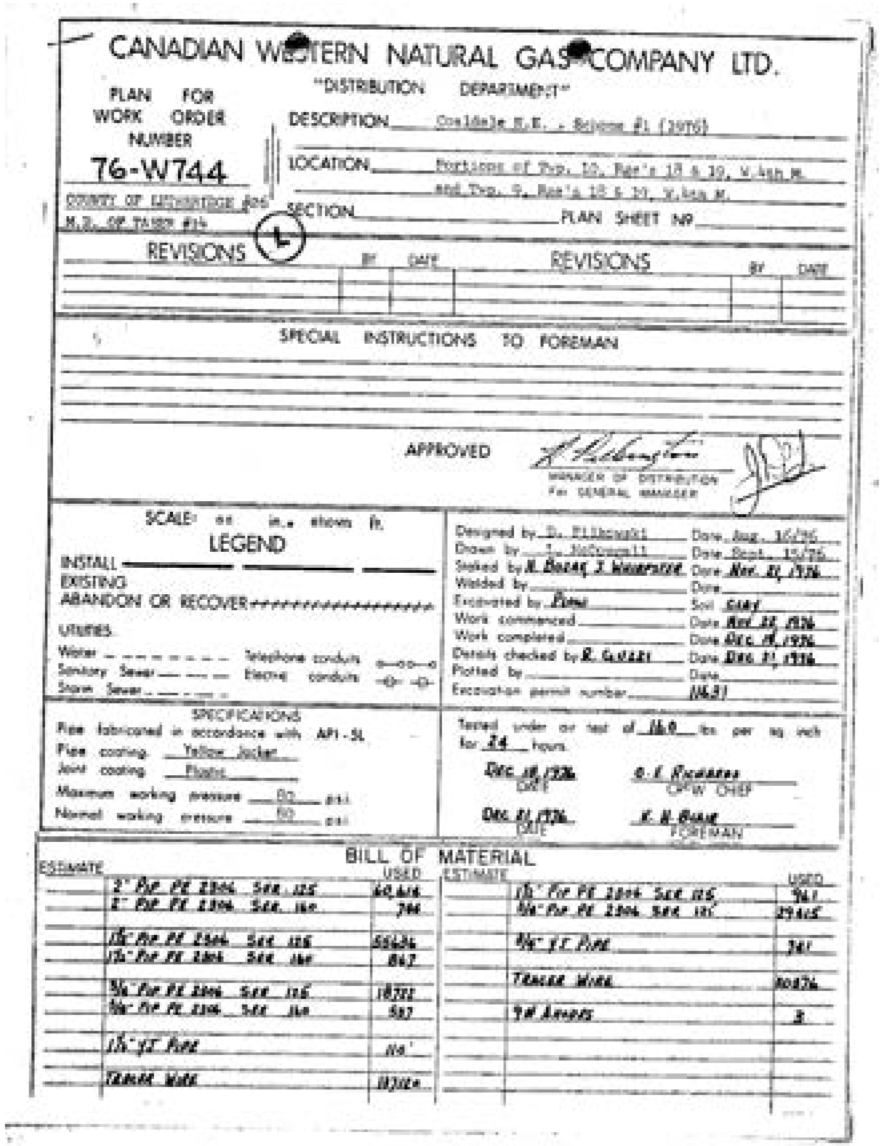


Figure modified from sources: [1] Frank, Andreas & Pinter, Gerald & Lang, R.W.. (2009). *Prediction of the remaining lifetime of polyethylene pipes after up to 30 years in use*. Polymer Testing. 28. 737-745. 10.1016/j.polymertesting.2009.06.004. [2] Wee, Jung-Wook & Choi, Byoung-Ho. (2016). *Modeling of axisymmetric slow crack growth of high-density polyethylene with circularly notched bar specimen using crack layer theory*. International Journal of Solids and Structures. 97-98. 189-199.

Sample Collection & Testing

Sample Collection & Testing



Sample Collection & Testing

Creep Rig

Hydrostatic Pressure Test

Dynamic Thermomechanical Analysis (DTMA)

- Oxidation inductive time (OIT) testing
- Carbonyl index testing (by FTIR-ATR)
- Tensile testing

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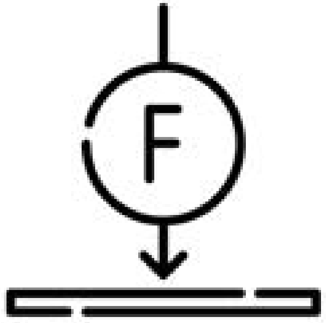
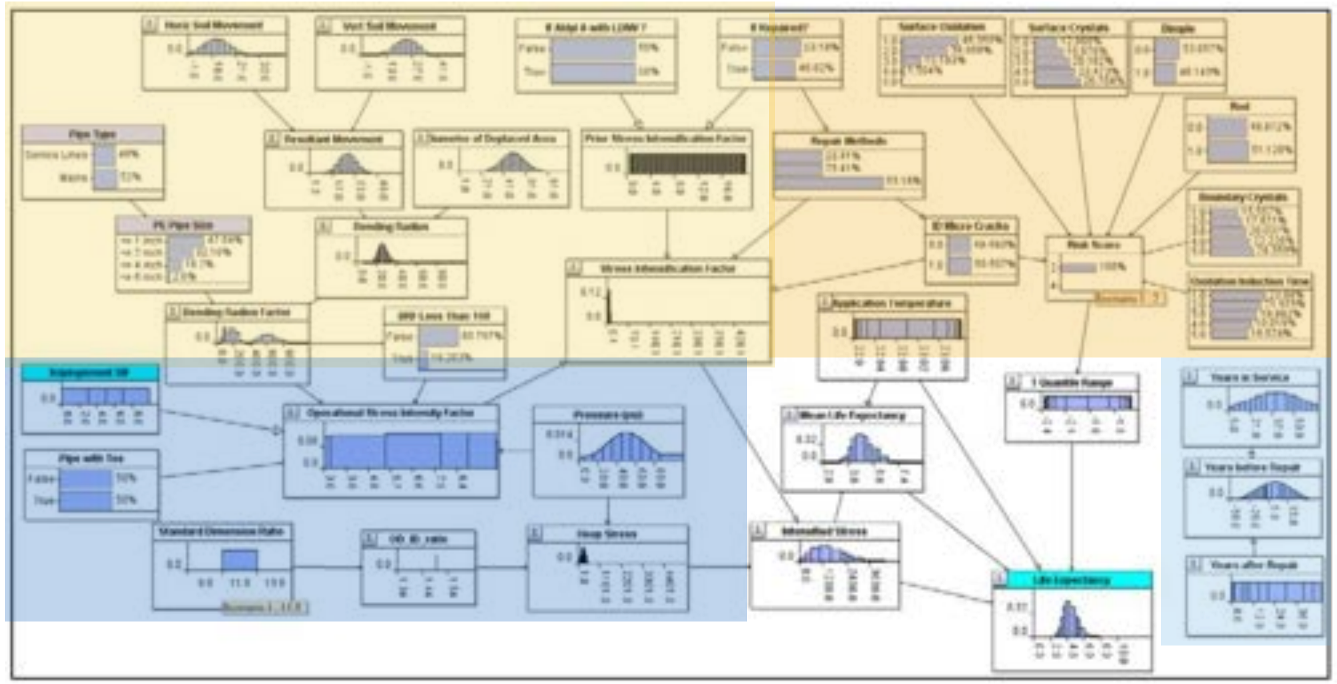
Risk Profile Development

Material Properties



Stress Distribution



Bayesian Network

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Risk Profile Development

The GTI Energy Lifetime Prediction Model Equation:

$$S = C \cdot exp\left[\frac{V \cdot exp\left(k(T - T_{ref})\right) + \frac{H}{n}}{R}\left(\frac{1}{T} - \frac{1}{T_{ref}}\right)\right] t^{-\frac{1}{n}}$$

Where,

S = Test stress at test temperature, [psi]

t = Test time at test temperature, [h]

T_{ref} = Reference temperature, [K]

T = Test temperature, [K]

C = Stress that will result in a failure in one (1) hour @ T_{ref}, [psi]

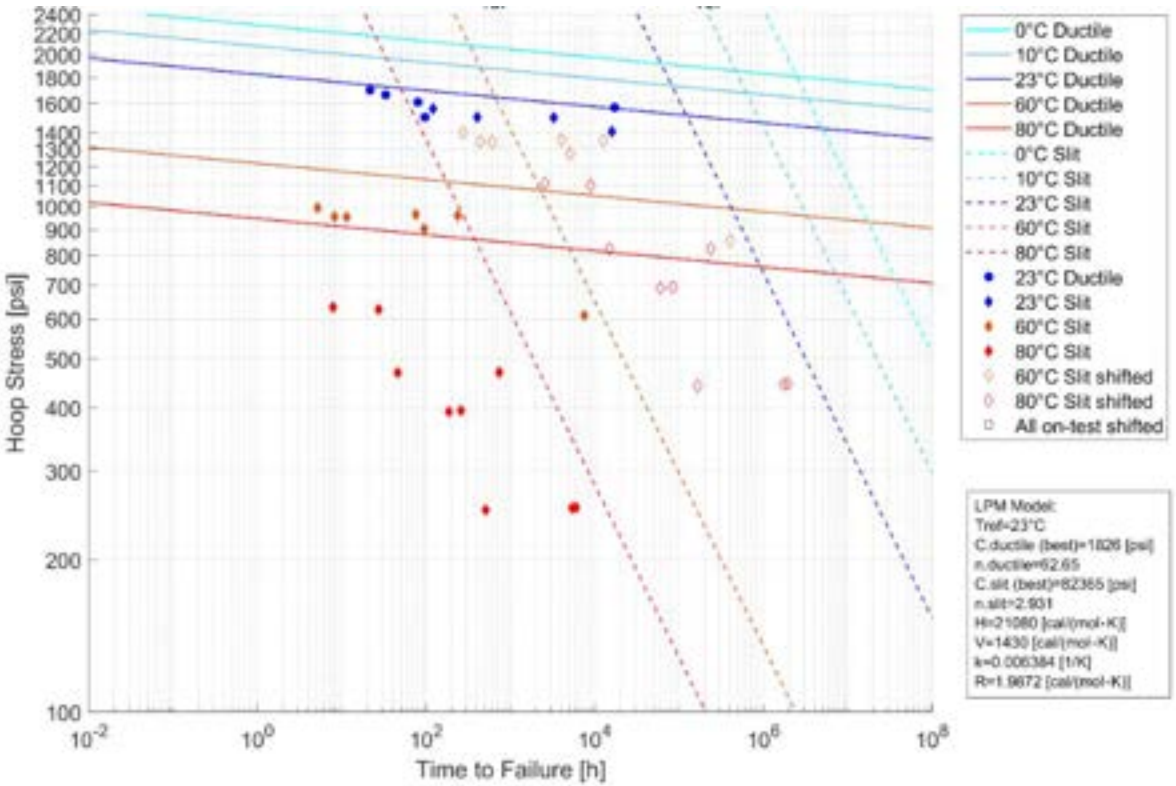
n = Characteristic creep rate exponent, [unitless]

H = Horizontal activation energy, [cal/(mol*K)]

V = Vertical activation energy @ T_{ref}, [cal/(mol*K)]

k = Temperature dependence factor of the vertical activation energy, [K^{-1}]

R =Ideal gas constant, 1.9872042586 [cal/(mol*K)]



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Risk Profile Development

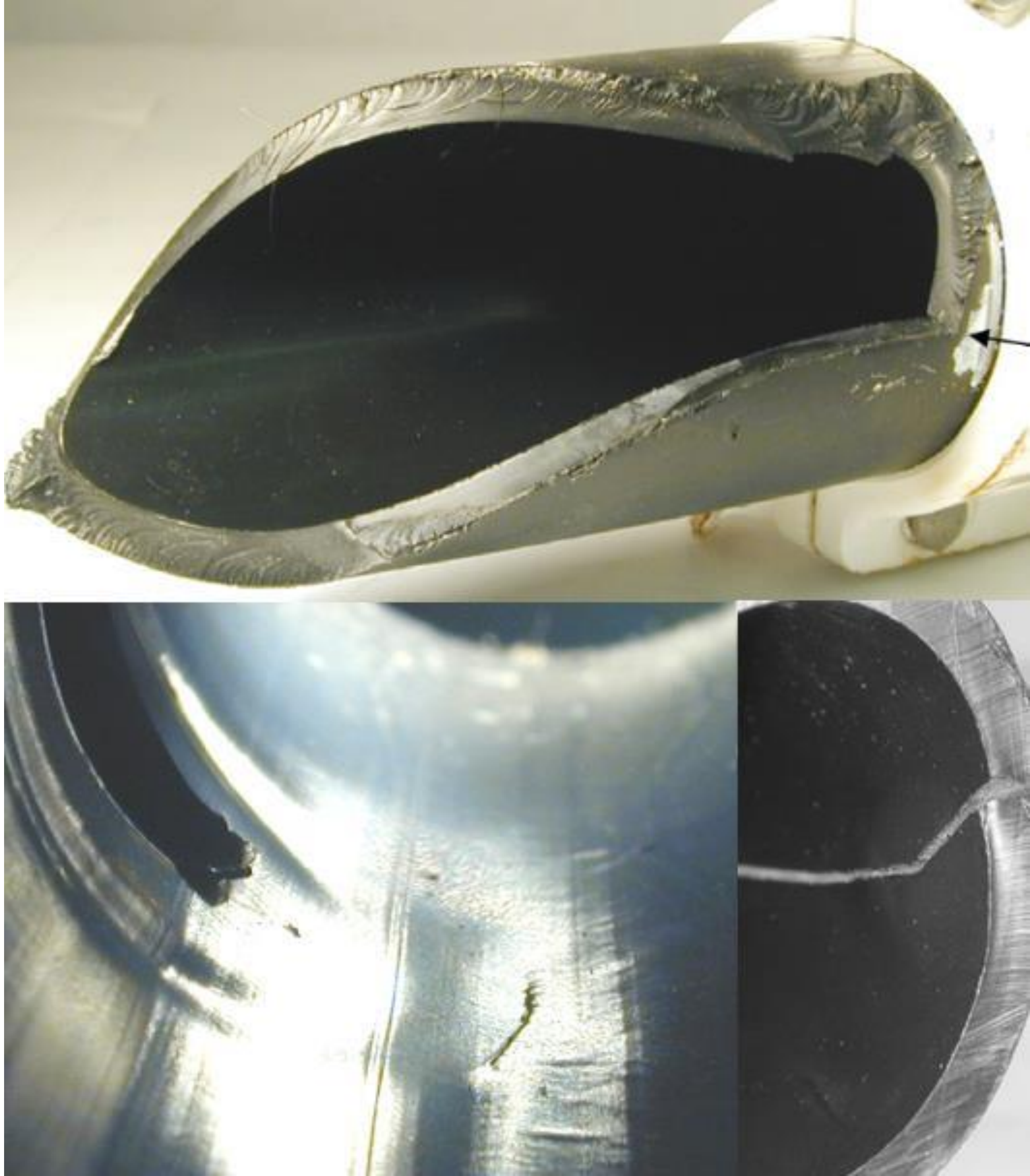
Resins with predicted remaining lifetimes of hundreds – or even thousands – of years do not account for the inevitable bulk depletion of stabilizers.

Testing of resins from ATCO's system show that the salient difference between them, in terms of remaining lifetime, lies in their remaining capacity of stabilizers.

Risk Model – Factors Affecting Slow Crack Growth (SCG)

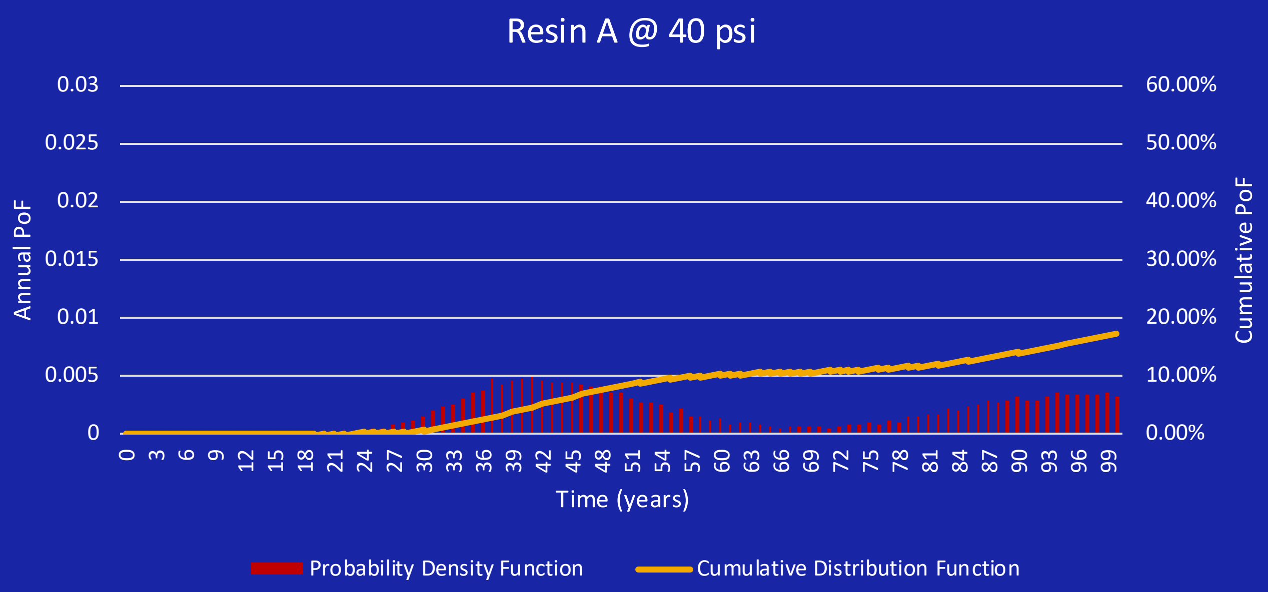
The most relevant factors affecting SCG rates include

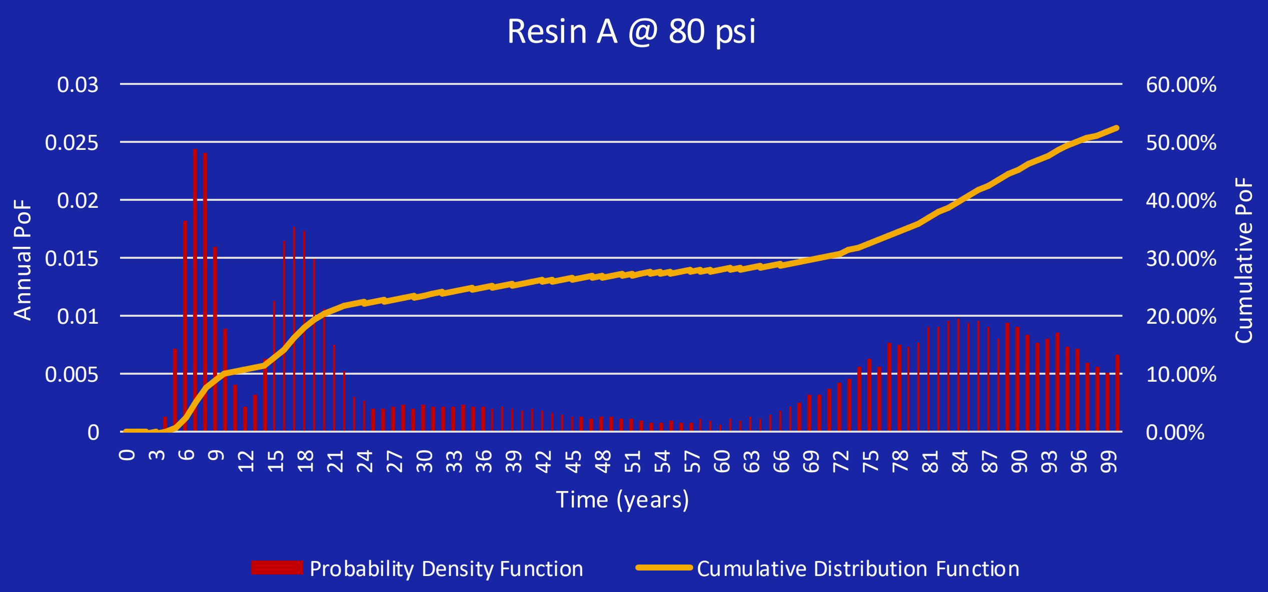
- Resin
- Time-in-Service
- Temperature
- Stress



Impact of Pressure

- Fixed Values:
  - Resin A
  - Temperature = 10.6°C
  - SDR = 11
- Variable Pressure:
  - Pressure 1: 40 psi
  - Pressure 2: 80 psi

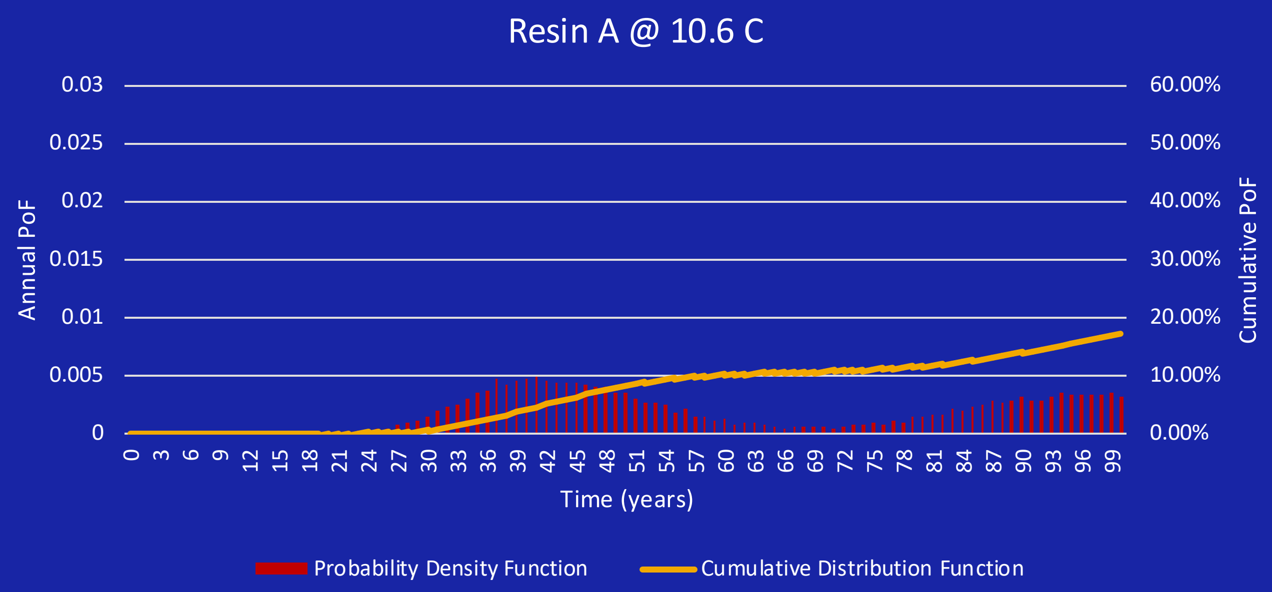


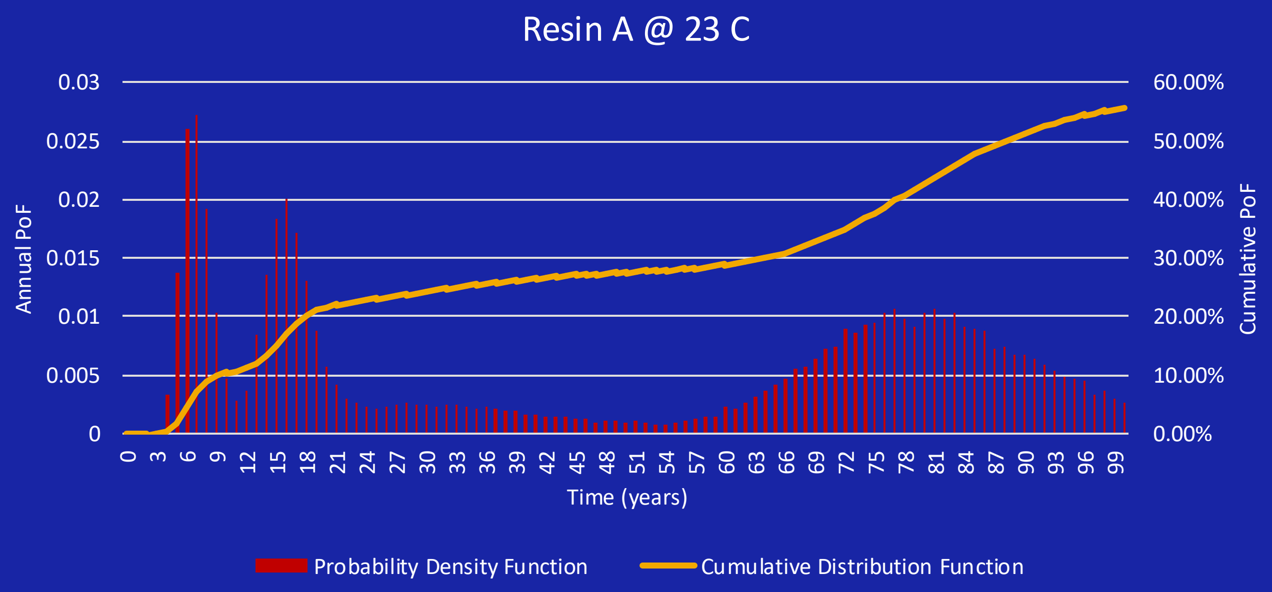


ATCO Energy Systems™

Impact of Temperature

- Fixed Values:
  - Resin A
  - SDR = 11
  - Pressure = 40 psi
- Variable Temperature
  - Temp 1: 10.6 °C
  - Temp 2: 23 °C





Risk Model – Operationalization

We Know:

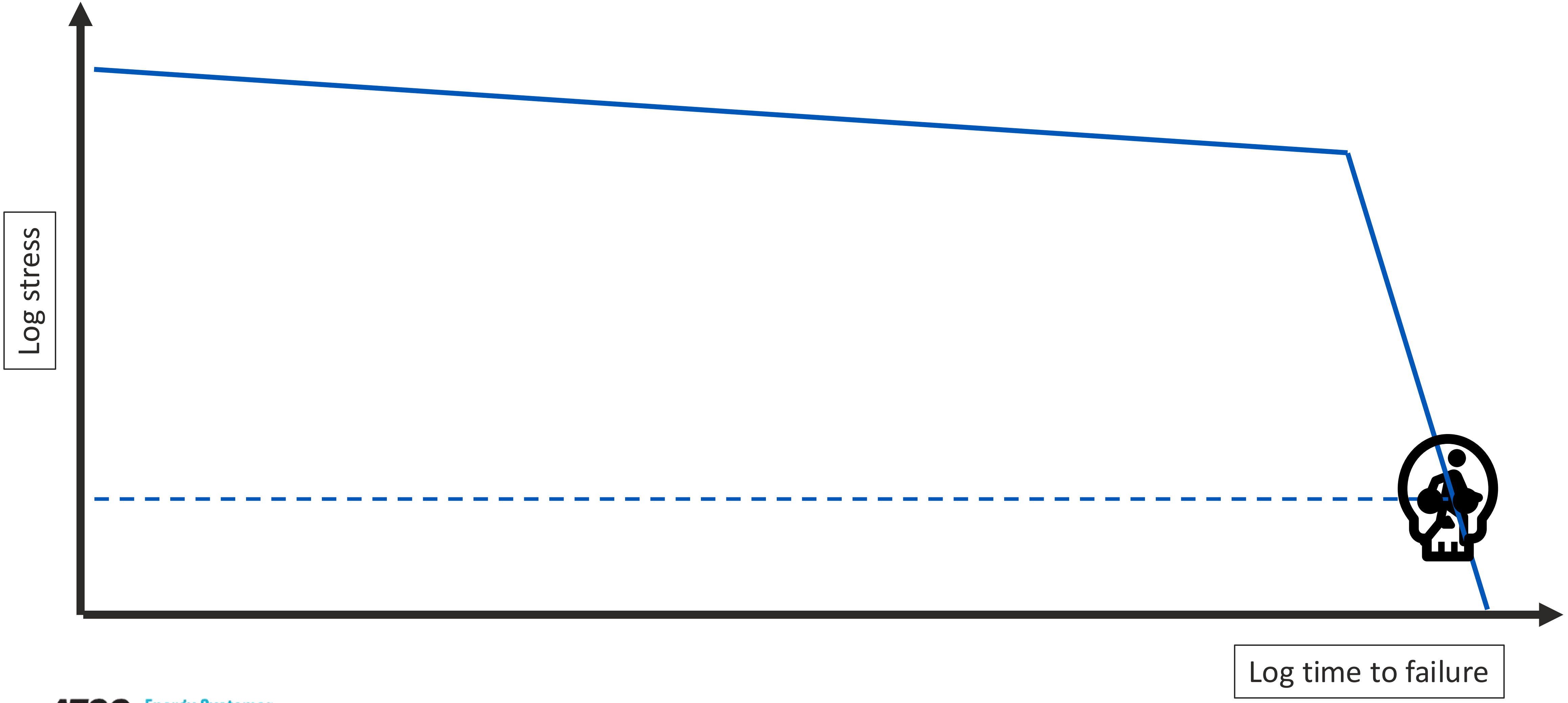
- Current condition
- Temperature and pressure
- Non-material stress intensification factor (SIFs)
- Resin-specific remaining useful life (RUL) curves

Risk Model – Operationalization

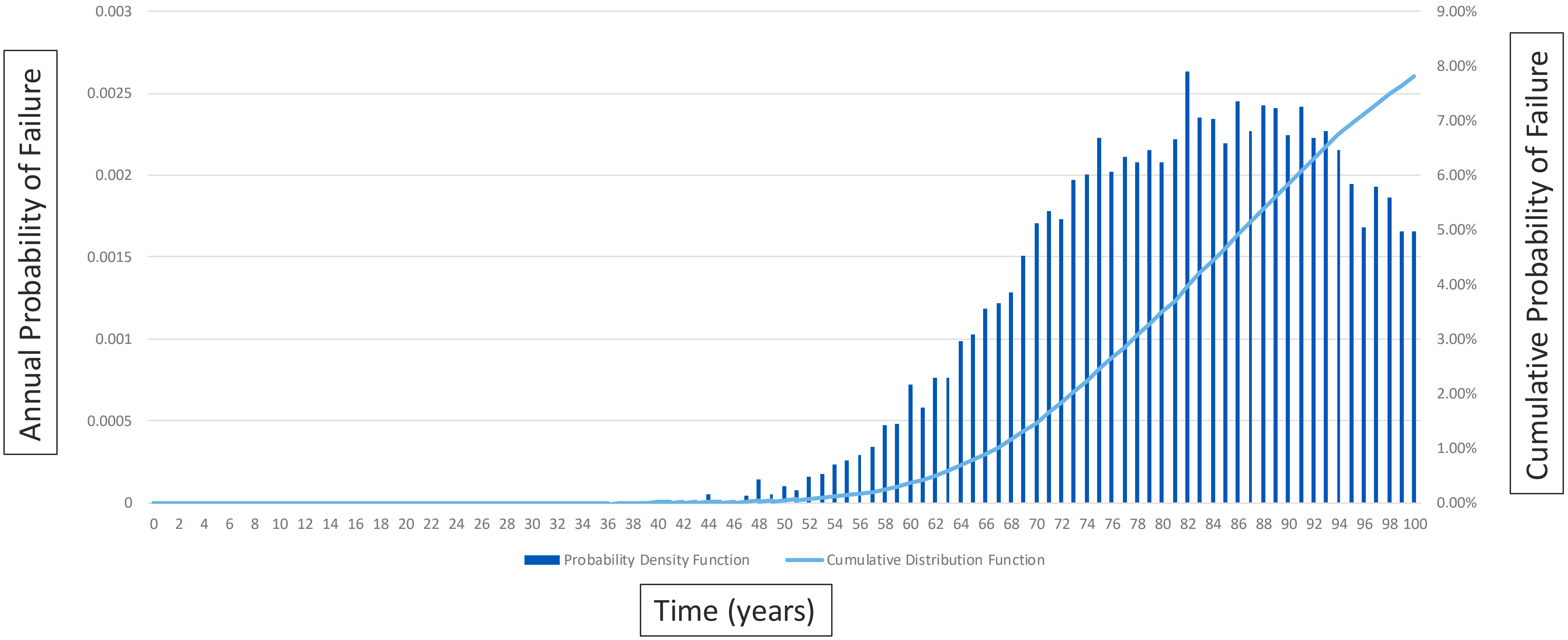
We Still Need:

- Actual operating conditions
- Knowns and unknowns
- Field observations
- Distribution Integrity Management Program (DIMP)

Risk Model – Why Monte Carlo?



Risk Model – Why Monte Carlo?

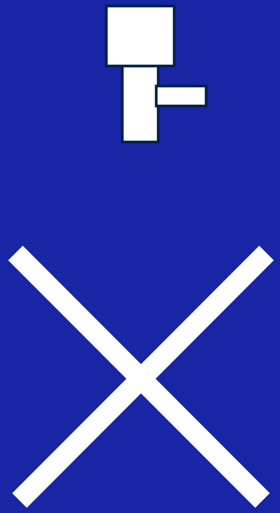


Risk Model – Monte Carlo Simulation

For each resin

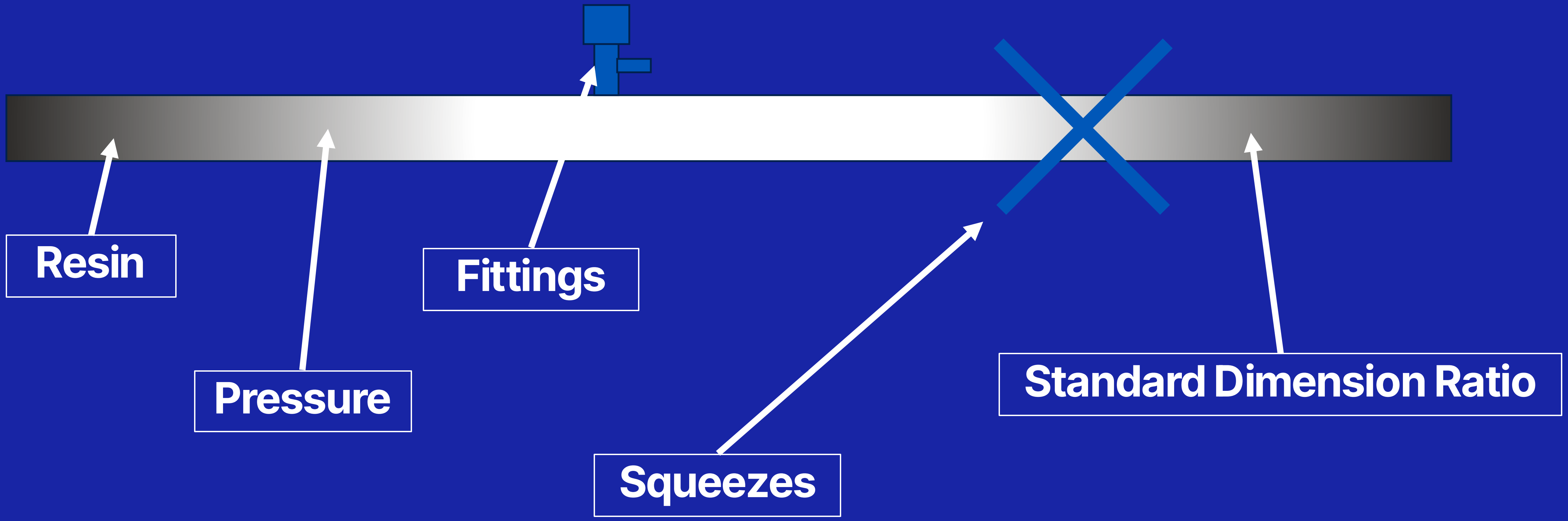
			Performance for Resin A				
			Worst	→			Best
			1	2	3	4	5
Pipe Stress Level	Lowest	1	Curve 1A	Curve 2A	Curve 3A	Curve 4A	Curve 5A
	↓	2	Curve 1B	Curve 2B	Curve 3B	Curve 4B	Curve 5B
		3	Curve 1C	Curve 2C	Curve 3C	Curve 4C	Curve 5C
		4	Curve 1D	Curve 2D	Curve 3D	Curve 4D	Curve 5D
		5	Curve 1E	Curve 2E	Curve 3E	Curve 4E	Curve 5E
		6	Curve 1F	Curve 2F	Curve 3F	Curve 4F	Curve 5F
	Highest	7	Curve 1G	Curve 2G	Curve 3G	Curve 4G	Curve 5G

Non-material SIFS

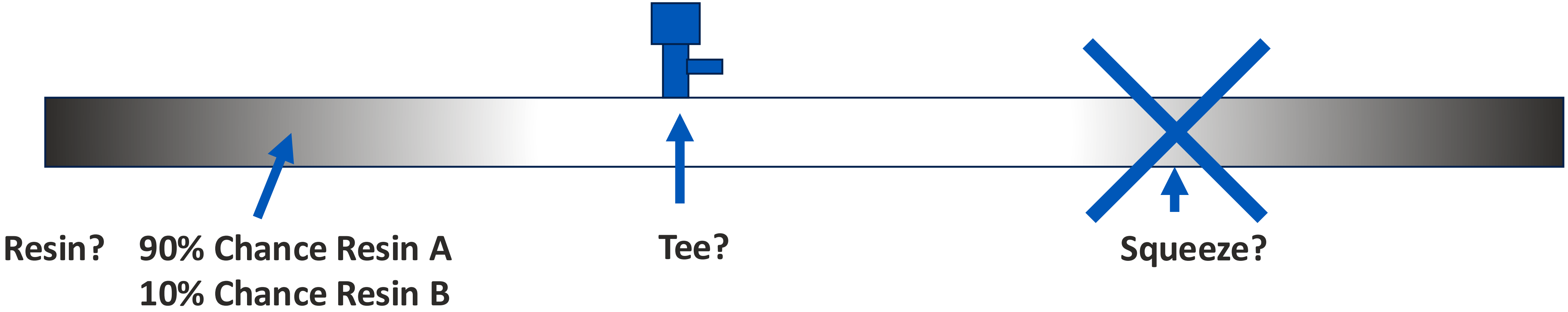


Temperature

Risk Model – Pipe Attributes



Risk Model – Uncertainty



1. Uncertainty in what/where

2. Uncertainty in how this affects performance

Risk Model – Calibration

Why calibrate?

- Field observations
- Discrete samples vs. continuous pipes

Calibration principles

- Sampling data + real-world experience
- Ongoing requirement

Risk Model – DIMP Incorporation

Other threats per ASME B31.8S

- Time dependent
  - Internal/external corrosion (can be extended to other degradation mechanisms
  - SCC (extended to fatigue)
- Stable
  - Manufacturing defects
  - Construction defects
  - Equipment failure
- Time independent
  - External interference
  - Incorrect operations
  - Natural forces

Consequence of failure

- Not every failure created equal
- Key consequence factors:
  - Leak size
  - Pressure
  - Diameter
  - Leak location
  - Distance to structures
  - Ground cover
  - Services

Poor performing resins

Strong performing resins

The broader risk picture

Are vintage PE pipeline assets really ageing out?

Data-informed

Remaining uncertainty

Path forward

ATCO Energy Systems™

Thank you

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