

Risk and Reliability in a Changing World



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CENTER FOR
RISK AND RELIABILITY

University of Maryland (UMD)

- Strong Research Focus
- Offers over 200 degree programs
- 40,000 students: 30,000 Undergraduate, 10,000 graduate
- 50.7% male and 49.2% female students
- About 4000 faculty and 10,000 staff and administration
- 4,000 engineering undergraduate, 2,000 graduate students
- Around 180 engineering faculty and 150 administrative staff members



UMD Center for Risk and Reliability in a Nutshell

- 40+ years of research and educational leadership in risk & reliability research at A.J. Clark School of Engineering
- Broad research areas: Systems, structures, and processes
- Core expertise in Theory and Applications
- Applications across industries: Energy, Civil infrastructure, manufacturing, aerospace, defense, and IT
- 500+ master and PhD alumni



Reliability Engineering Contributions

Definition:

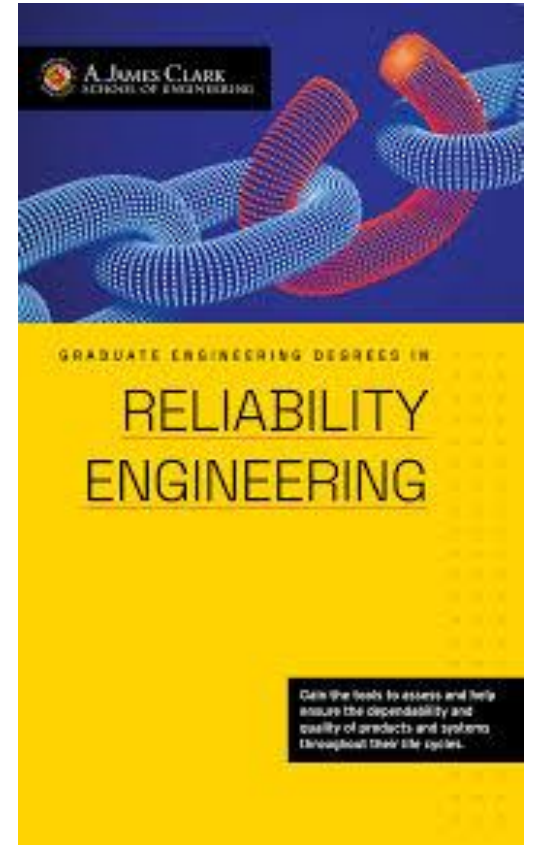
Reliability Engineering ensures a system, or a component work as intended, without failure, for a required time in a specific environment.

Key Focus Areas:

- Preventing failures
- Predicting failures
- Improving system longevity
- Minimizing downtime with cost-effective maintenance

Why It Matters:

- Ensures durability, safety and efficiency in industries like energy, aerospace, manufacturing, healthcare, and IT.



Applications & Benefits of Reliability Engineering

- **Industries Using Reliability Engineering:**
 - **Energy:** Ensures safety, equipment reliability and effective maintenance.
 - **Aerospace & Automotive:** Ensures mission safety and minimize errors.
 - **Manufacturing:** Reduce downtime and improve production efficiency.
 - **IT & Software:** Enhancing system resilience and cybersecurity.
 - **Healthcare & Medical Devices:** Ensuring life-critical equipment function reliably.
- **Main Benefits:**
 - Reduces failure risks and maintenance costs.
 - Enhances product quality and customer satisfaction.
 - Improves safety and regulatory compliance.

Probabilistic Risk Assessment Contributions

Probabilistic Risk Assessment (PRA) is a systematic, quantitative approach to evaluating risks by estimating the frequency and consequences of adverse events.

Why Use PRA?

- Helps in decision-making under uncertainty.
- Quantifies risks rather than subjective judgment.



HOW TO CARRY OUT A
**RISK
ASSESSMENT**

Basic Steps in PRA:

- **Hazard Identification** – Recognizing potential risks.
- **Probability Analysis** – Estimating how often failures occur.
- **Consequence Analysis** – Evaluating the impact of failures.
- **Risk Characterization** – Combining data to assess overall risk.

Applications & Benefits of PRA

Examples of Applications;

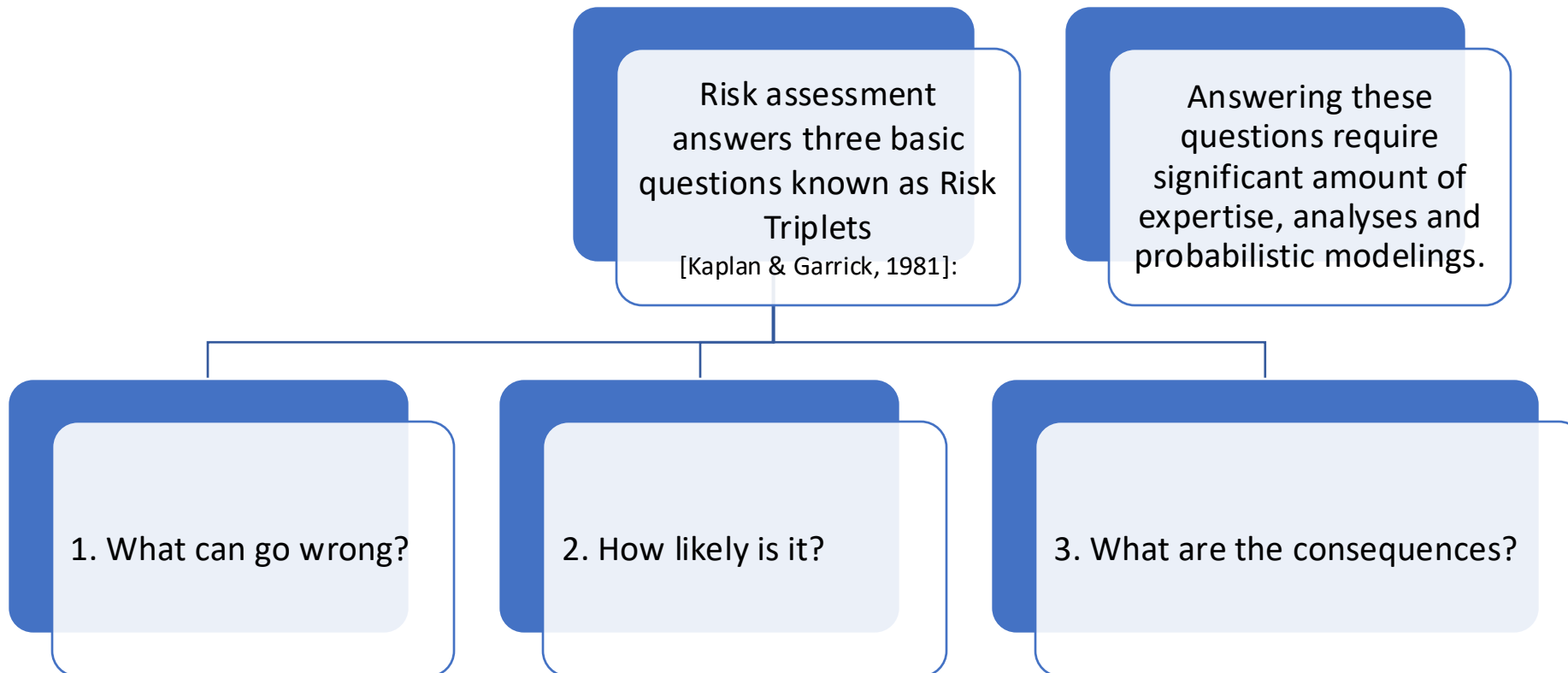
- **Nuclear Power:** Assessing reactor safety risks.
- **Transportation:** Accident risks, autonomy risks.
- **Aerospace:** Predicting failure rates in aircraft components.
- **Healthcare:** Evaluating medical treatment risks.
- **Food Safety:** Estimating contamination risks in food production.

Main Benefits:

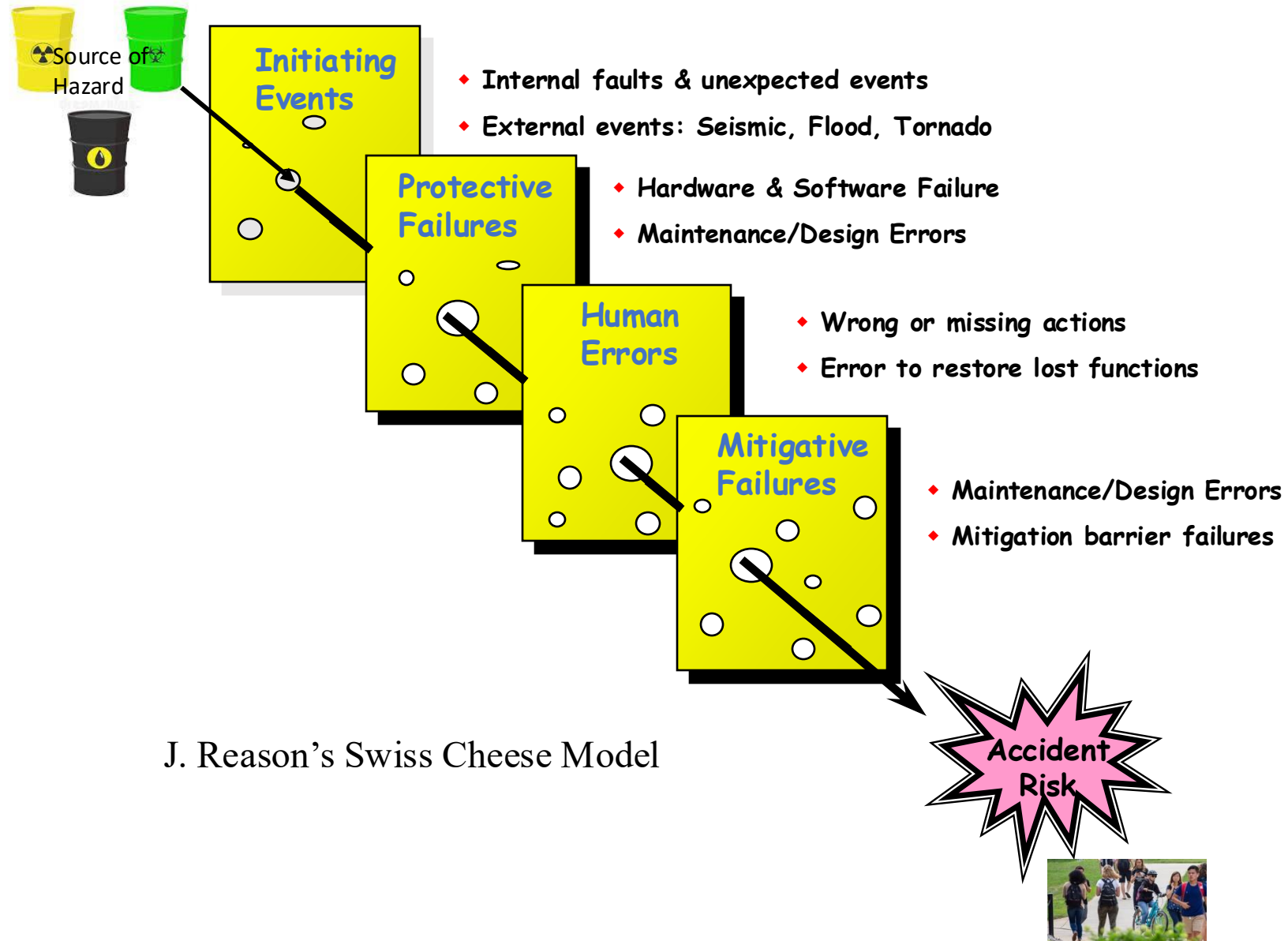
- Identifies and prioritizes high-risk scenarios.
- Improves safety.
- Supports cost-effective risk mitigation strategies.
- Optimize maintenance



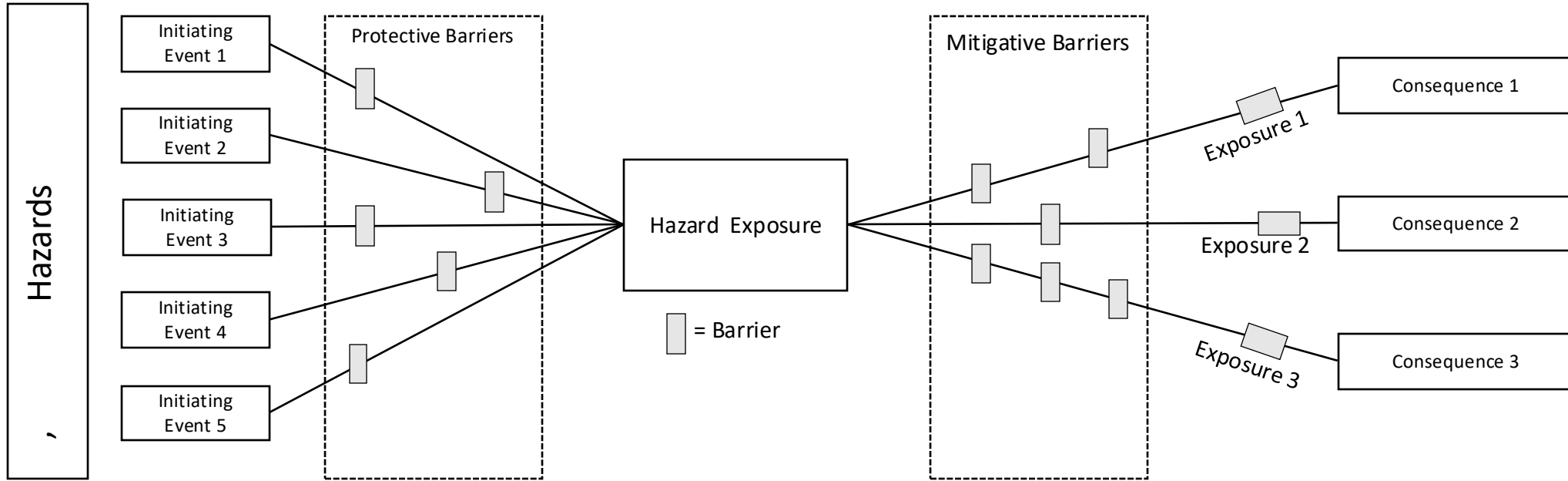
Risk Assessment Preliminaries: Risk Triplets



Probabilistic Risk Assessment Process



The Bowtie Construct in Risk Assessment



Design/Engineering
Maintenance
Operations

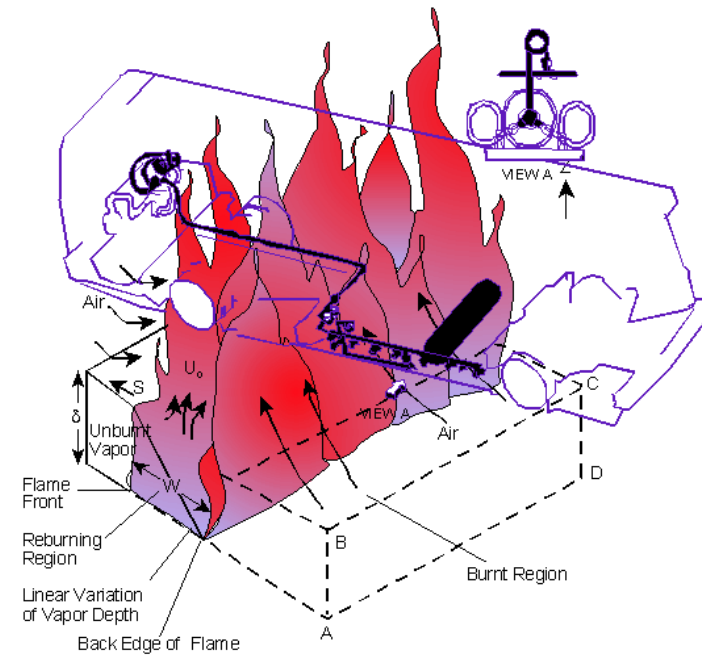
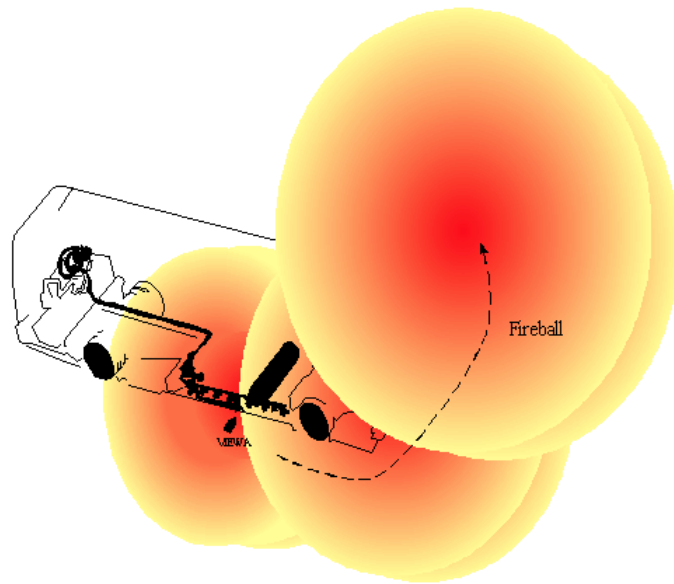
Example 1: Fire Risk Assessment of Compressed Natural Gas Buses



Also See: <https://www.youtube.com/watch?v=vHf2o9oVY24>

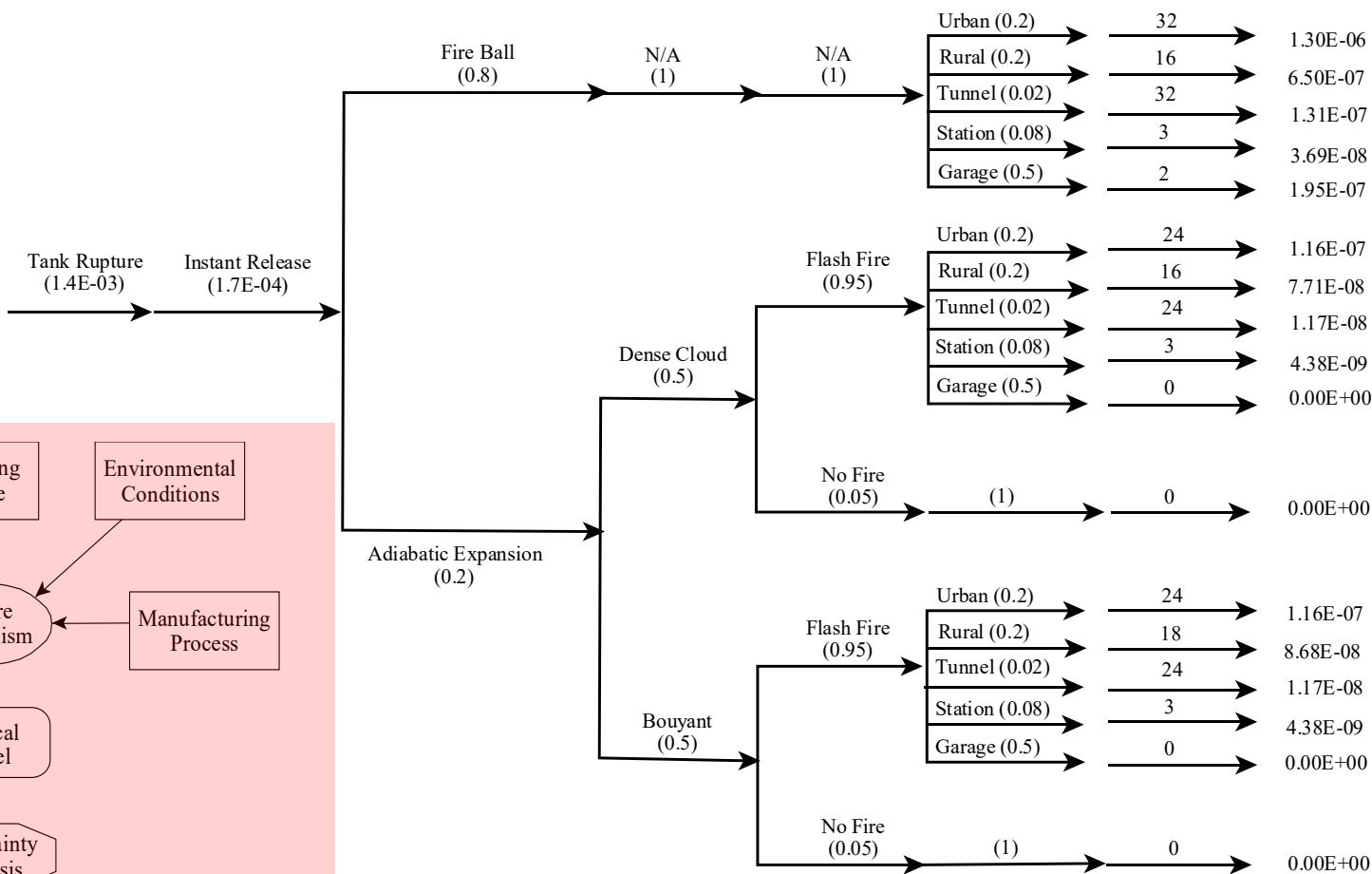
Example 1: Modeling Fire Growth & Consequences

Fireball
Vapor cloud explosion or flash fire
Jet flame



Fire Scenarios Initiated from the Gas Tank

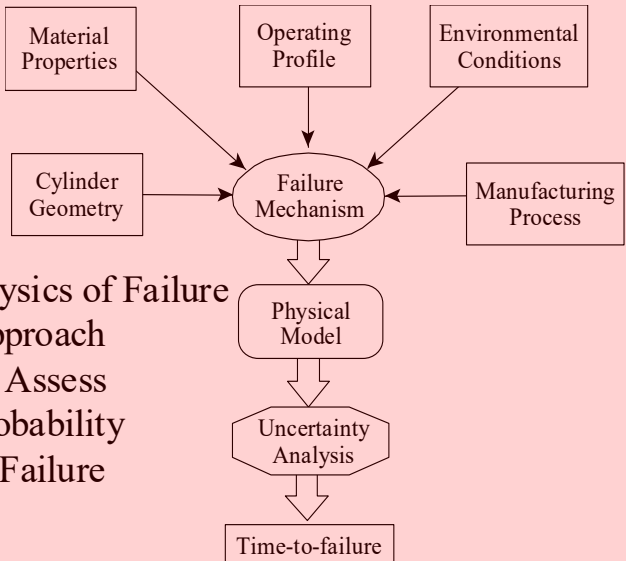
Barrier Failure	Gas Release Mode	Expansion and Ignition	Disperion Type	Fire Type	Fire Location	Consequence (fatalities)	Risk
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Example of Risk Results:

- Calculated an average of ~3 bus fire fatalities per 1-Billion miles (1.6 Billion Km) in CNG buses.
- Considering Additional Cancer-Caused Deaths in Diesel-Fueled Buses, the total Fatality Risk in Natural Gas Buses is lower than Diesel Buses

Physics of Failure
Approach
To Assess
Probability
of Failure



Example: Applications of PRA to Food Safety

Main Elements:

1. Hazard Identification

Biological contaminant.

2. Exposure Assessment

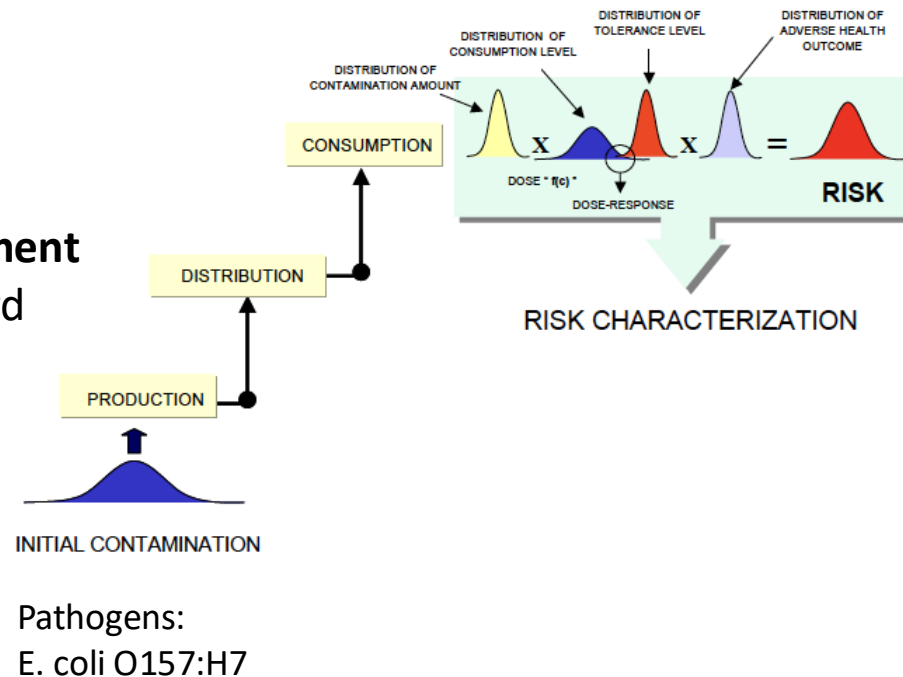
How much of the hazard consumers receive.

3. Dose-Response Assessment

Relating exposure to hazard with health effects.

4, Risk Characterization

Estimate overall risk.

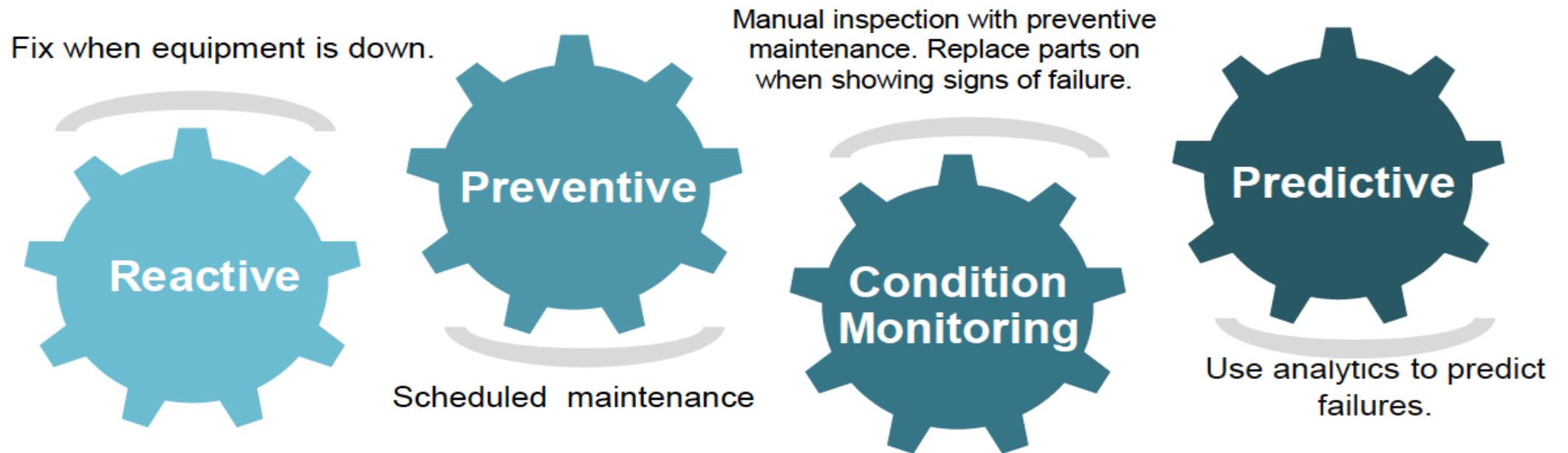


Event Tree and Possible Outcomes

Initiating Event I	Fecal Status F	Carcass Status C	First Decontam. D ₁	Evisceration R	Second Decontam. D ₂	Chiller D ₃	Overall System State
I	F ⁺	C ⁺	D ₁ ⁺	R ⁺	D ₂ ⁺	D ₃ ⁺	S1
						D ₃ ⁻	S2 S3
			D ₁ ⁺	R ⁻	D ₂ ⁺	D ₃ ⁺	S4
						D ₃ ⁻	S5 S6
			D ₁ ⁻	R ⁺	D ₂ ⁺	D ₃ ⁺	S7
						D ₃ ⁻	S8 S9
	F ⁺	C ⁻	D ₁ ⁺	R ⁺	D ₂ ⁺	D ₃ ⁺	S11
						D ₃ ⁻	S12 S13
			D ₁ ⁺	R ⁻	D ₂ ⁺	D ₃ ⁺	S15
						D ₃ ⁻	S16 S17
			D ₁ ⁻	R ⁺	D ₂ ⁺	D ₃ ⁺	S18
						D ₃ ⁻	S19
	F ⁻	C ⁻	D ₁ ⁺	R ⁺	D ₂ ⁺	D ₃ ⁺	S15
						D ₃ ⁻	S16 S17
			D ₁ ⁺	R ⁻	D ₂ ⁺	D ₃ ⁺	S18
						D ₃ ⁻	S19
			D ₁ ⁻	R ⁺	D ₂ ⁺	D ₃ ⁺	S15
						D ₃ ⁻	S16 S17

Reliability & Maintenance

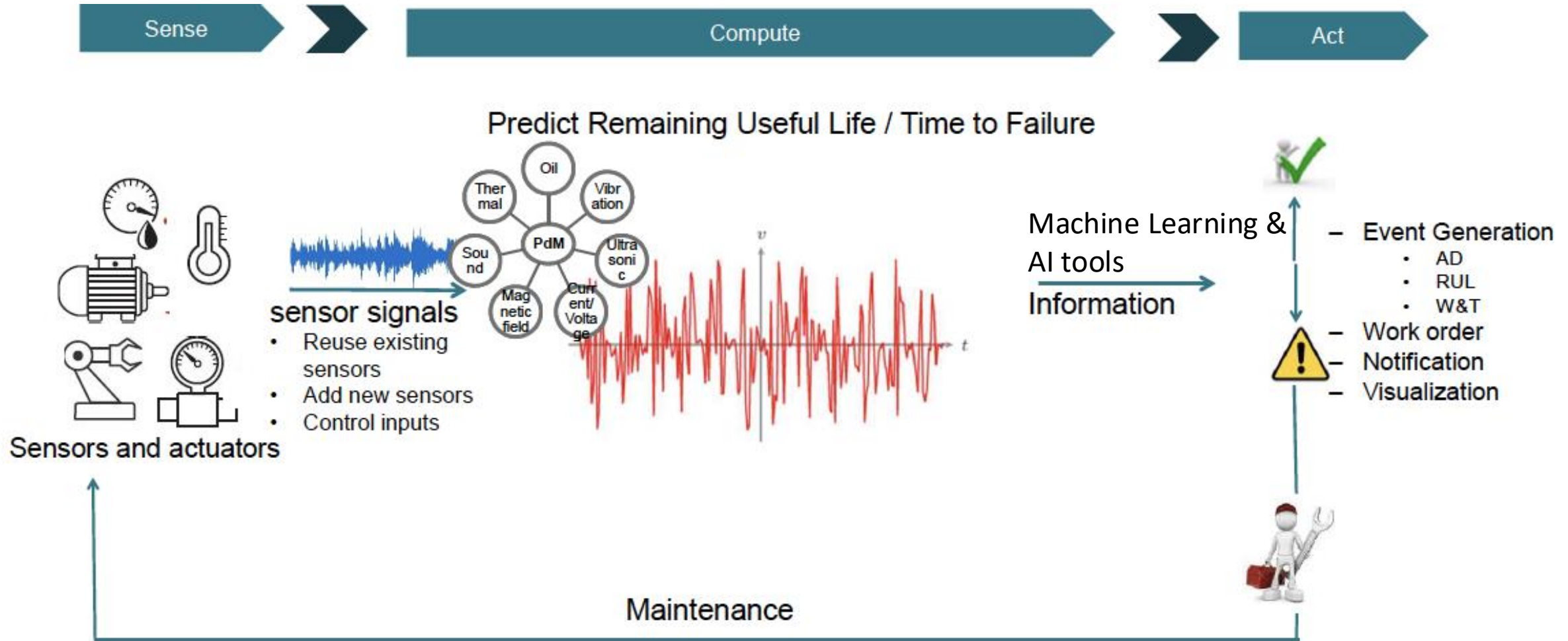
Reliability and Maintenance are critical for prevention, protection and mitigation of complex systems risks



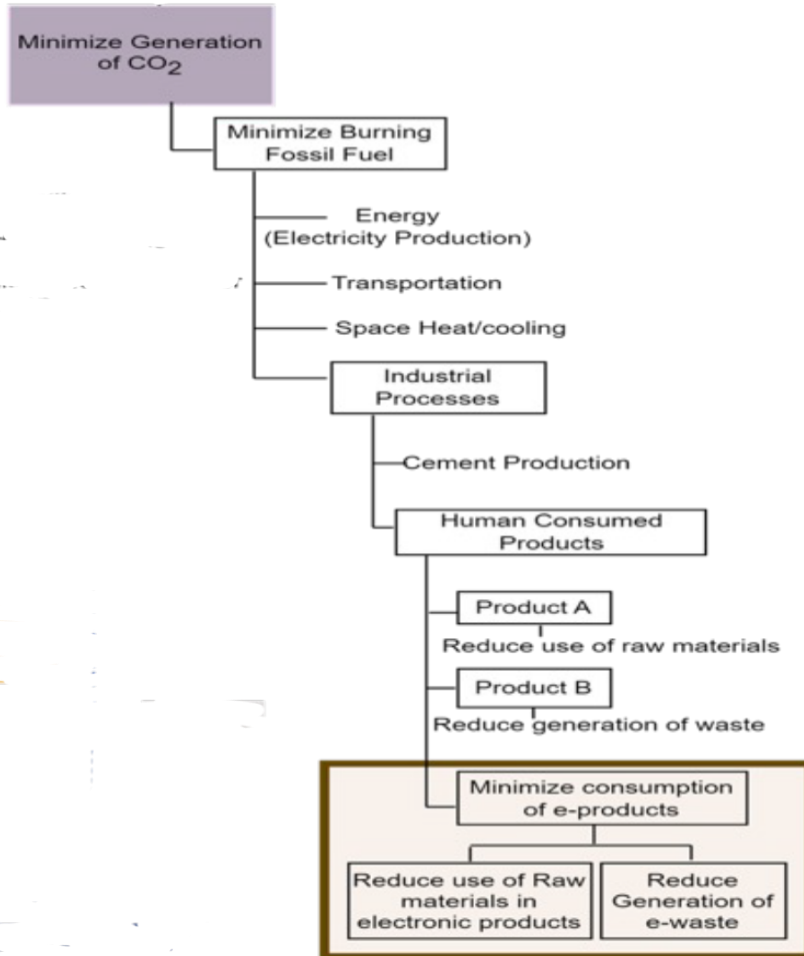
Types of Maintenance and Features

Feature	Corrective Maintenance	Preventive Maintenance	Predictive Maintenance
When it's done	After failure	At scheduled intervals	Based on data/predictions
Cost Efficiency	High long-term cost	Moderate cost	Most cost-effective over time
Downtime Impact	High	Low	Minimal
Technology Need	Low	Low	High (sensors, ML, AI)
Implementation Complexity	Low	Medium	High

Modern Predictive Maintenance Approach



A New Trends in Reliability: Durability



Attribute: Promise of Life

Represents: Ownership risk covering both product's expected lifespan and the manufacturer's assurance for support

Resistance to degradation

Resistance to performance deterioration

Ability to stand overstress

Manufacturer's warranty

Attribute: Functional Readiness

Represents: Ease of keeping a product functional and restoring its functionality after failure

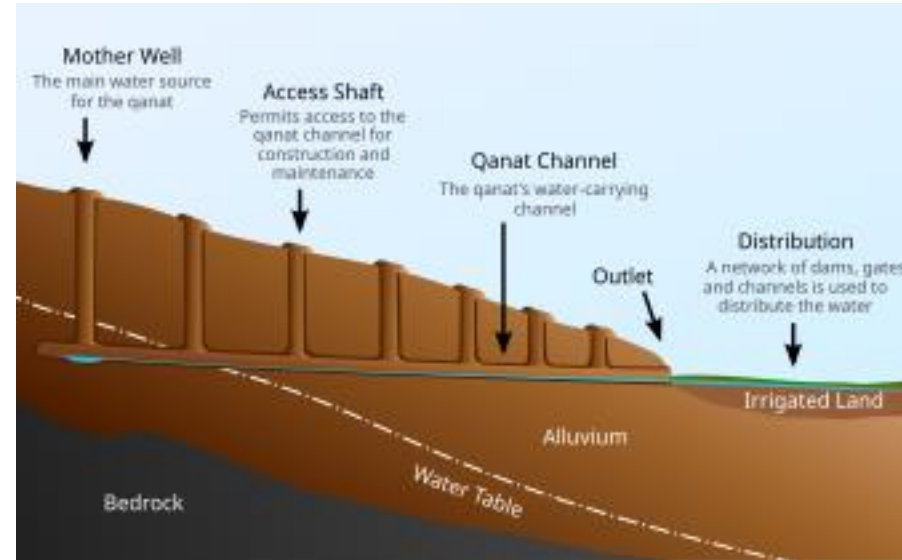
Ease of maintenance

Ease of repair

Ability to upgrade

Why is Durability Important?

- Durability supports the circular economy and sustainability.
- Longevity of components reduces resource use and waste.
- Industries should:
 - Encourages customers buy durable products.
 - Compete to improve product lifespan.
- Laws, standards and methods to measure and index durability are underway.



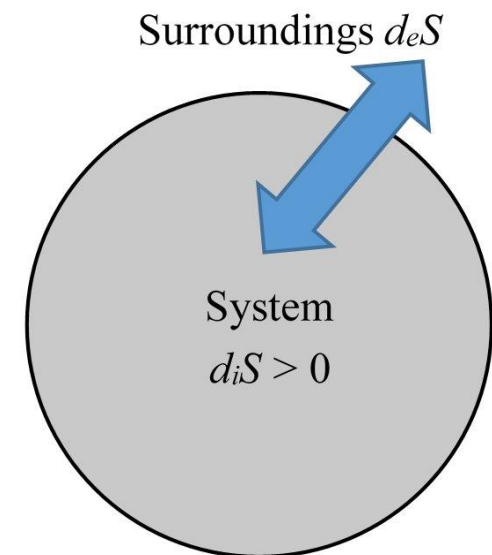
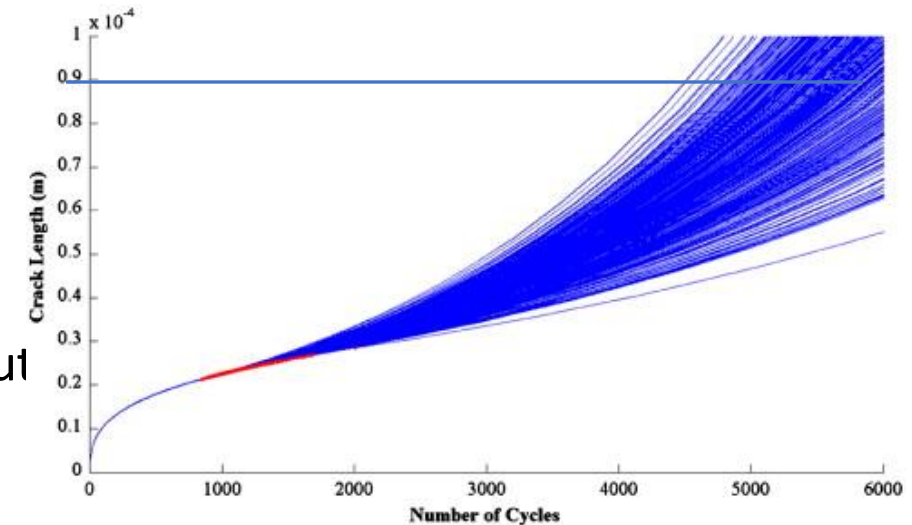
Persian /Iranian
Ghanat:
A UNESCO
Heritage
Engineering
Design that
Symbolizes
Sustainability
and Durability



Reliability Engineering Frontiers

Fundamental sciences underpinning reliability theories and methods

- Reliability Engineering ensures a system works as intended, without failure, for a required time in a specific environment.
- Statistics is the mathematical foundation of reliability engineering. Machine learning and AI are significant tools today.
- Physical Science Basis: Since most failures result from damage, we must identify the science behind material damage.
- Two Key Sciences can describe damage:
 1. Physics-of-Failure (empirical approach)
 2. Thermodynamics (theoretical, especially the 2nd Law)



$$dS = d_e S + d_i S$$

Risk Assessment Frontiers

Infrastructure Safety-Security-Resilience (SSR)

- Highly Connected Infrastructure Networks: Electricity, Gas, and Water Pose Major Societal Risks Through Cyberspace Attacks

Life-Cycle Risks of Advanced Energy Systems

- Renewable and Hydrogen Energy Systems
- Nuclear Energy (Fission and Fusion)
- Risks of Disruptions in Sustained Energy Supply

Health System Risks

- Medical Errors is a leading cause of death in the U.S., Just Behind Cardiovascular Diseases and Cancer!

Dynamic Probabilistic Risk Assessment

- Simulation and AI-based (e.g., Large Language Model) generation of dynamic events

спасибо
danke 謝謝
ngiyabonga
teşekkür ederim
tapadh leat
dank je
gracias
mochchakkeram
go raibh maith agat
arigatō
takk
dakujem
merci
ευχαριστώ
sukriya
kop khun krap
grazie
terima kasih
감사합니다
ممنونم
sagolun
dziękuję
hvala
mauruuru
obrigado
bedankt