Research Frontiers in Probabilistic Risk Assessment

Keynote Talk
23 November 2021
ABRISCO 2021 Congress
Brazilian Association of Risk Analysis, Process Safety and Reliability

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Summary of the Talk

- Risk Assessment Preliminaries
- Critical Elements of Probabilistic Risk Assessment (PRA)
- Strengths of PRA
- Establishment and Uses of Risk Acceptance Levels for Risk Management
- Frontier Areas of Current and Future Research in PRA
- Intelligent Risk Assessment Method Informed by Big Data in Gas and Oil
- Conclusions
- Questions

Risk Assessment Preliminaries: Risk Triplets

- Risk assessment answers three basic questions known as Risk Triplets [Kaplan & Garrick, 1981]:

    1. What can go wrong?
    2. How likely is it?
    3. What are the losses (consequences)?

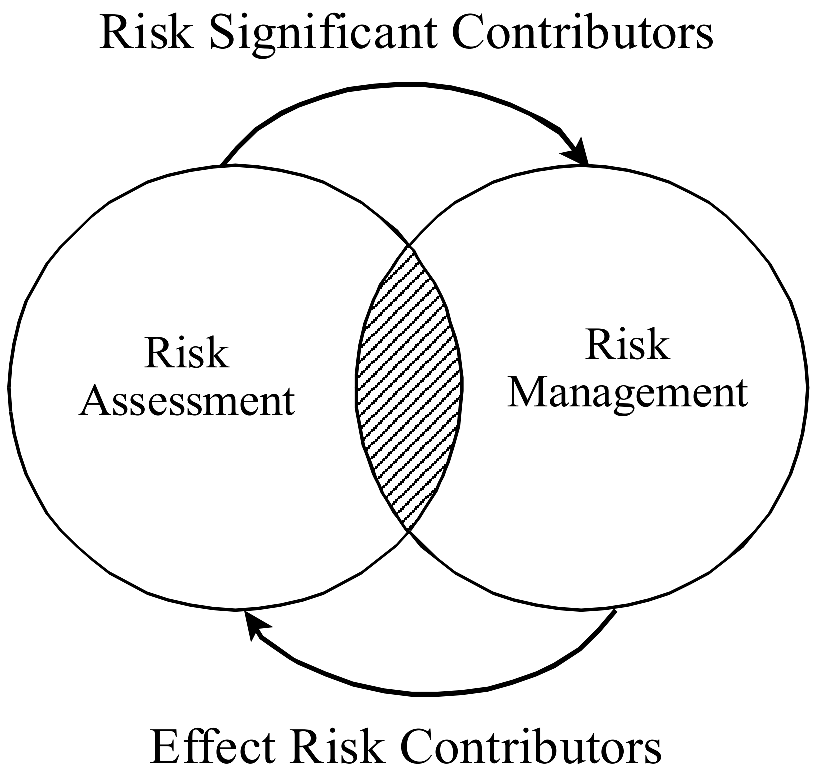
- Answering these questions require significant amount of expertise, analyses and probabilistic modelings.

Risk Assessment Preliminaries: Risk Triplets (Cont.)

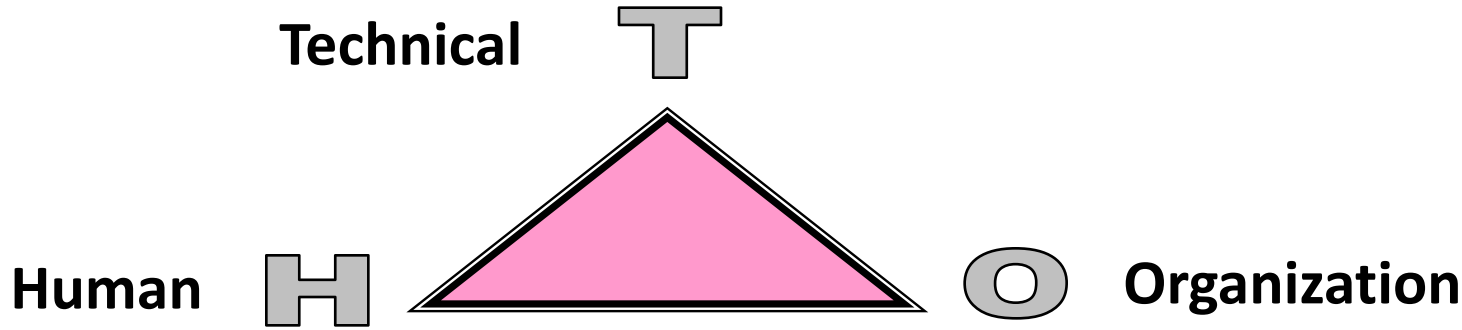
What can go wrong? Develop Scenarios	How likely is it? Determine probability or frequency of scenarios	What are the losses? Estimate losses to humans, environment, other living species and other asset
S_1 S_2 S_3 . . . S_N	l_1 l_2 l_3 . . . l_N	C_1 C_2 C_3 . . . C_N

$$\text{RISK} = \langle S_i, l_i, C_i \rangle$$

Risk Assessment Preliminaries: Risk Assessment vs. Risk Management



Risk Assessment Preliminaries: Complex Systems



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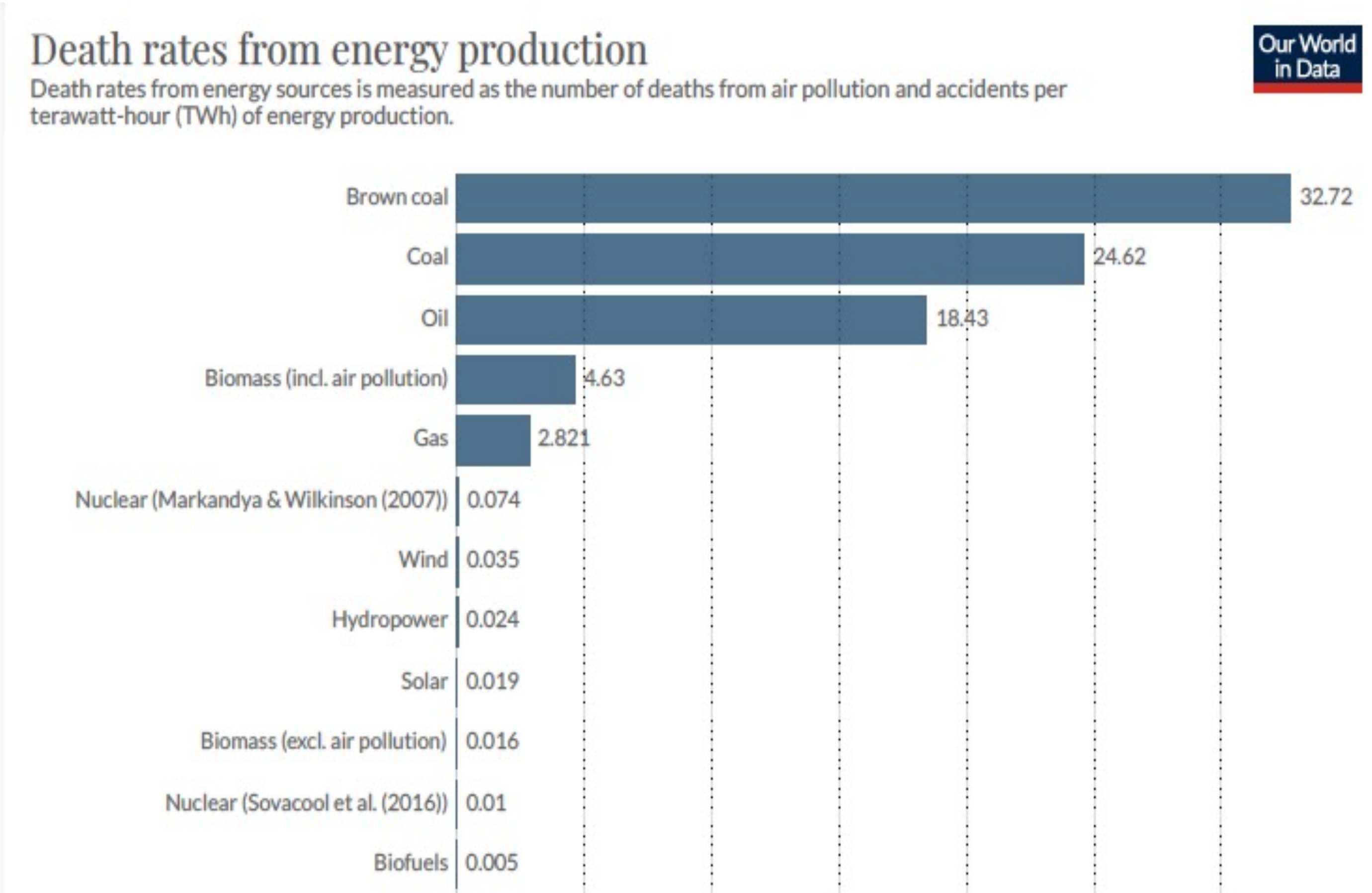
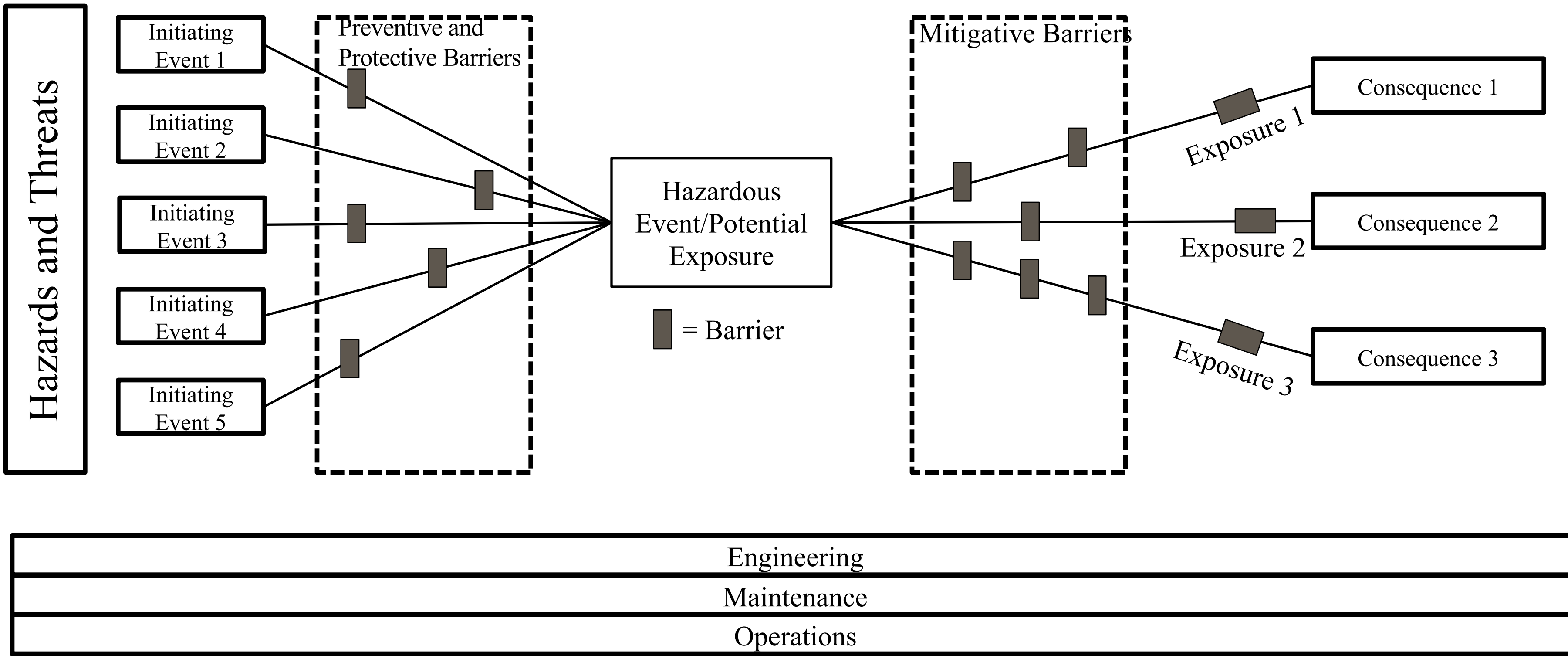
Risks Consequences of Energy Sources



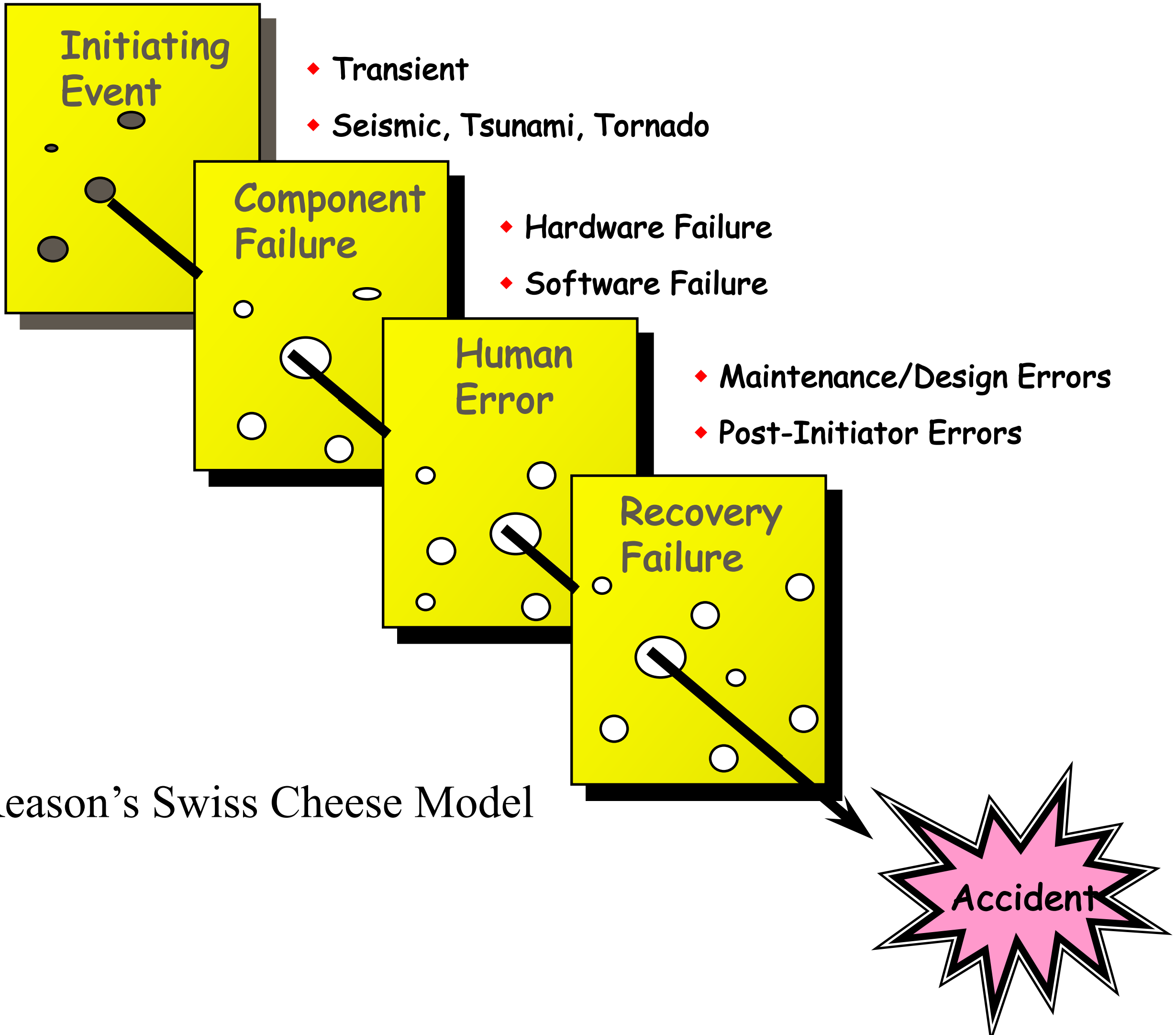
Source: What are the safest sources of energy? by Hannah Ritchie, Feb. 2020, https://ourworldindata.org/safest-sources-of-energy

The Bowtie Construct in Risk



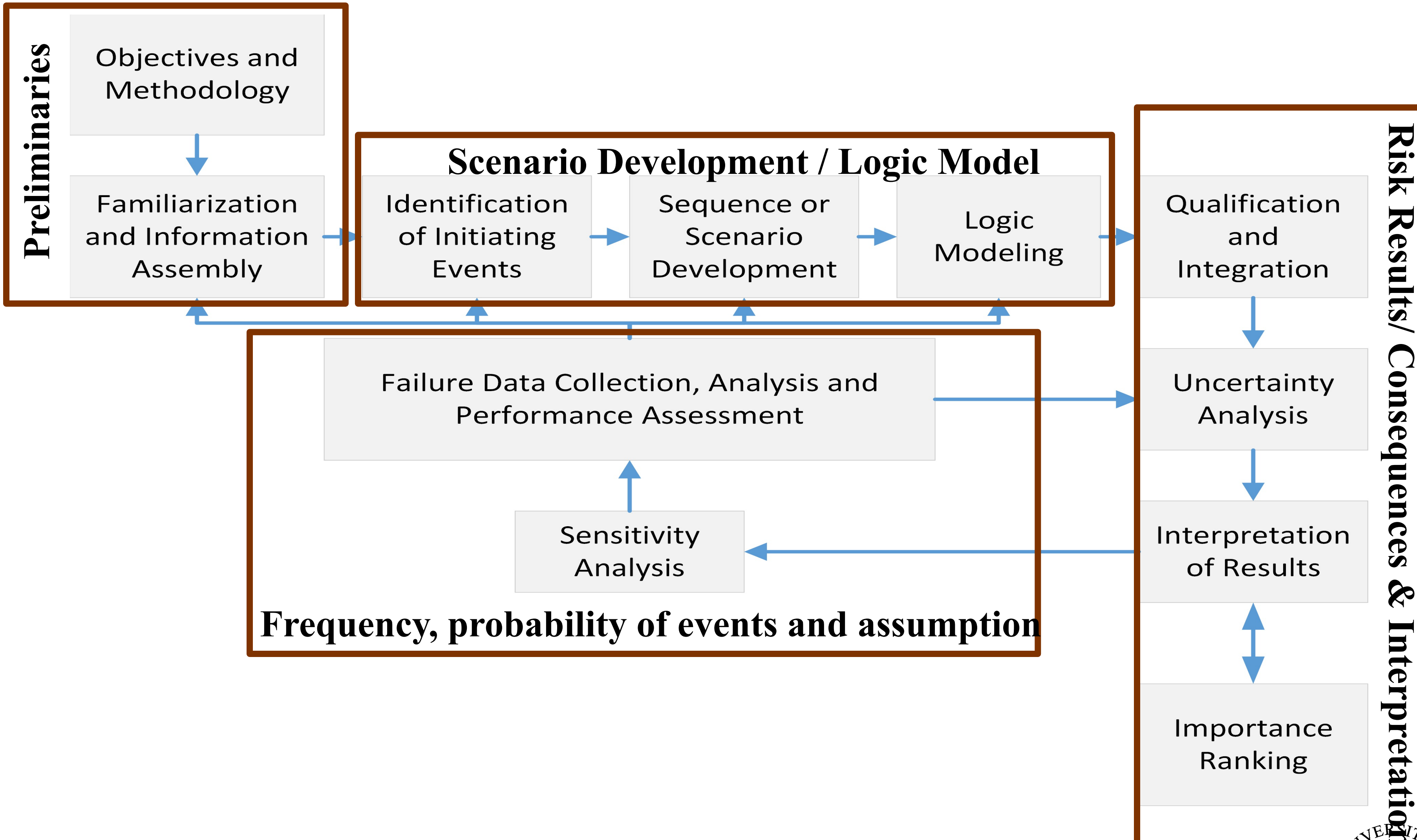
Threat = Intentional Exposure of Hazard or Harm
Hazard = Source of potential harm or loss

Probabilistic Risk Assessment Process

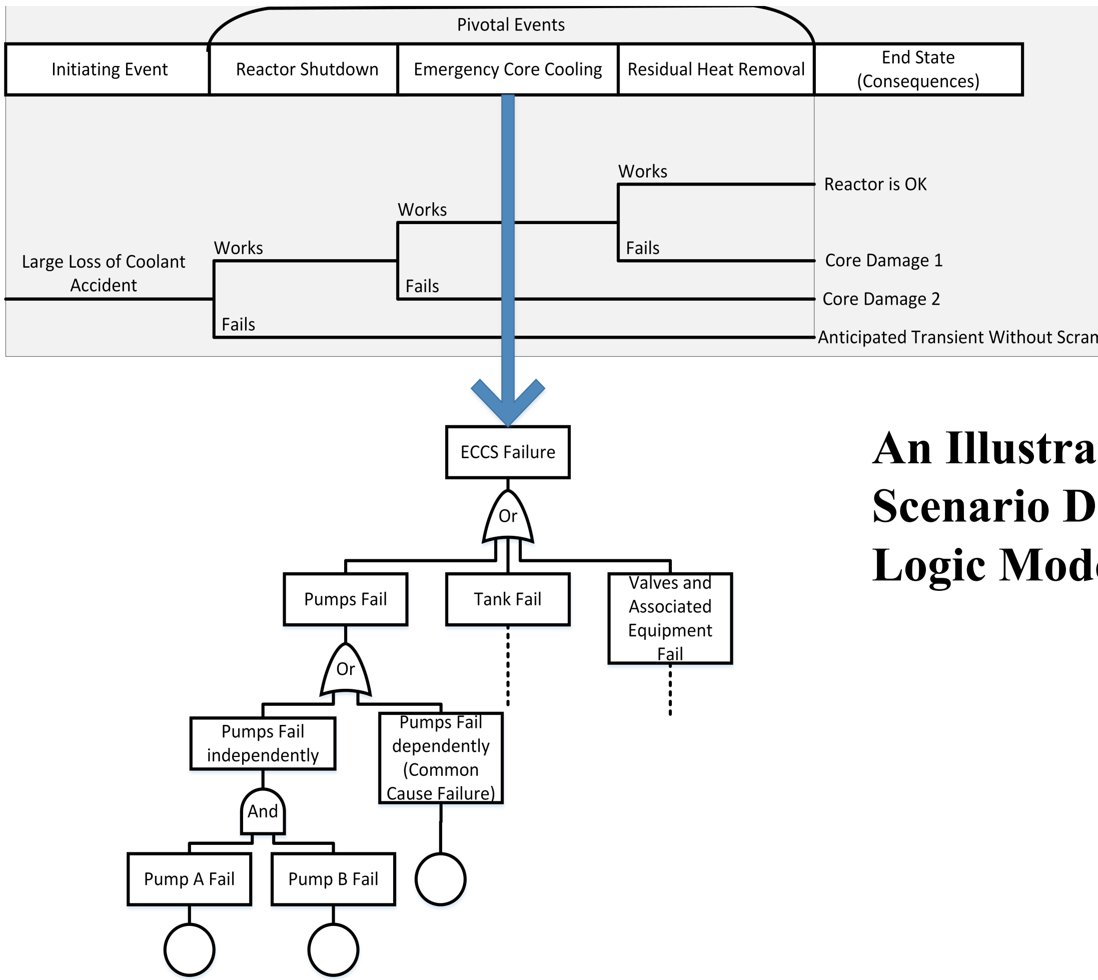


J. Reason's Swiss Cheese Model

Probabilistic Risk Assessment Process (Cont.)



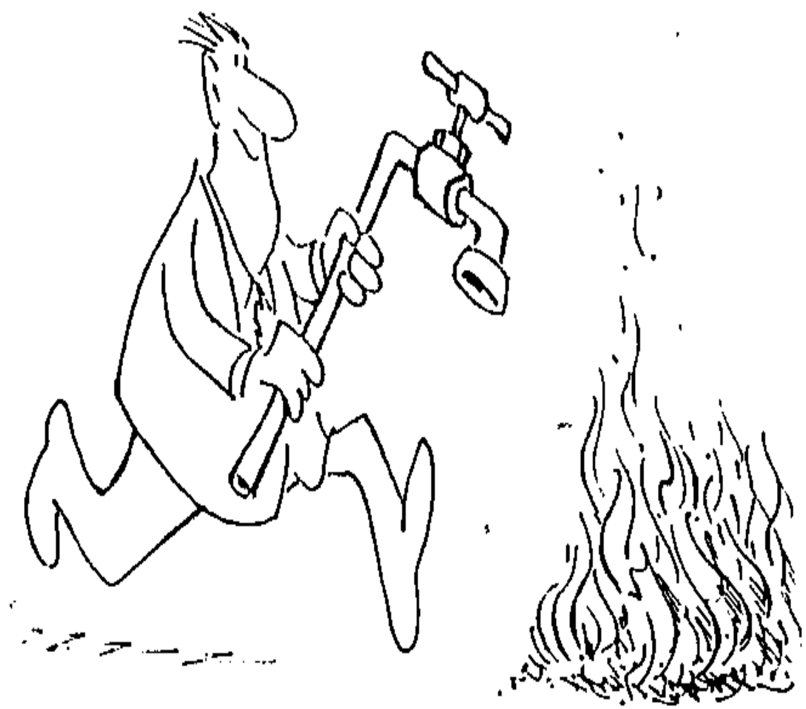
Probabilistic Risk Assessment Process (Cont.)



An Illustration of the Scenario Development / Logic Model Part of the PRA

Critical Element of PRA: Human, A Barrier or Cause of Risk?

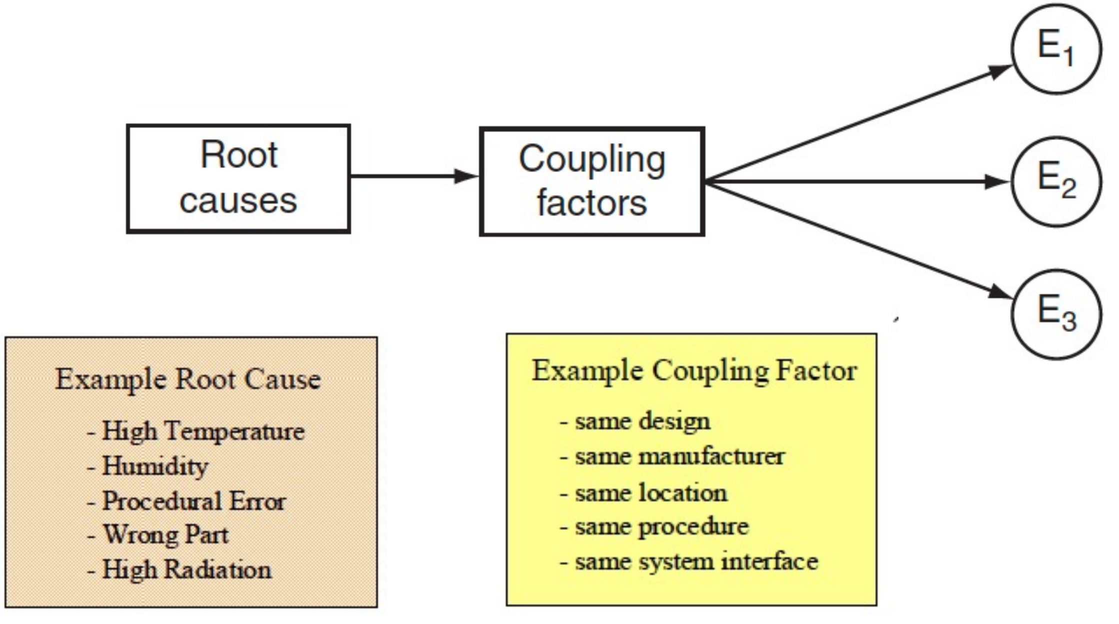
- **Nuclear** (Maintenance Error, Control Room Error)
- **Aviation** (Maintenance Error, Flight Crew Error, Air Traffic Controller Error)
- **Oil & Gas, Chemical and Process** (Operations, Maintenance Errors)
- **Land and Sea Transportation** (Maintenance and Operator Errors)
- **Healthcare** (Procedural Error, Operator Error)
- **Telecommunication** (Procedural Errors)



Critical Element of PRA: Common Cause Failures

A common cause failure (CCF) is a failure where:

1. Two or more items fail within a specified time leading to system failure, loss of redundancy or degradation.
2. Item failures result from a single shared cause and coupling factor (or mechanism)



Critical Element of PRA: Common Cause Failures (Cont.)

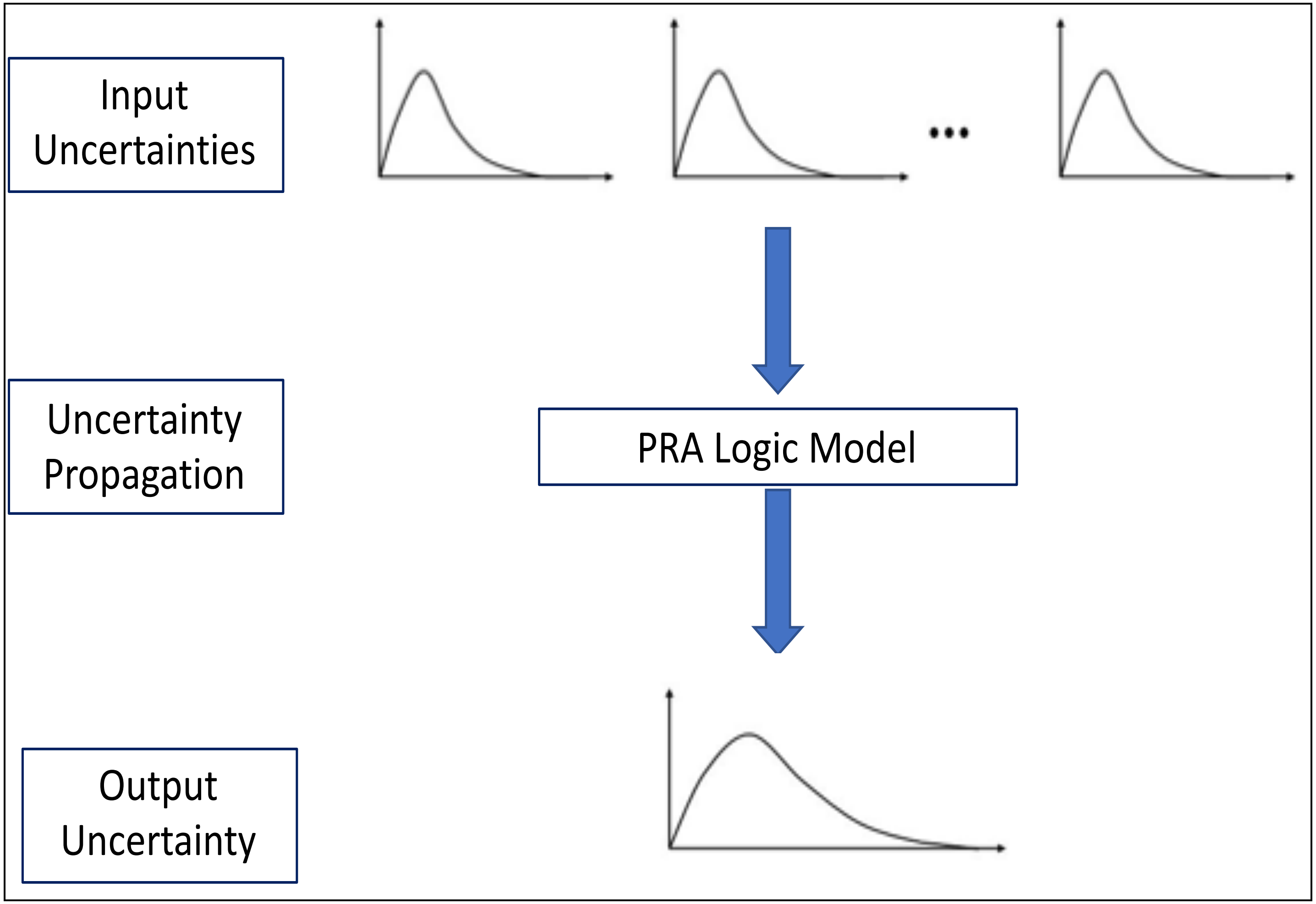
Causes:

- Pre-operational root causes
  - Design, manufacturing, construction, and installation errors.
- Operational root causes
  - *Operation and maintenance related*: Inadequate maintenance and operational procedures, execution, competence and scheduling
  - *Environmental stress related*: Internal and external exposure outside the design envelope or energetic events such as earthquake, fire, flooding.

Couplings:

Same design, Same hardware, Same function, Same software, Same installation staff, Same maintenance and operational staff, Same operating procedures, Same system/item interface, Same environment, Same (physical) location, Same failure mechanism,….

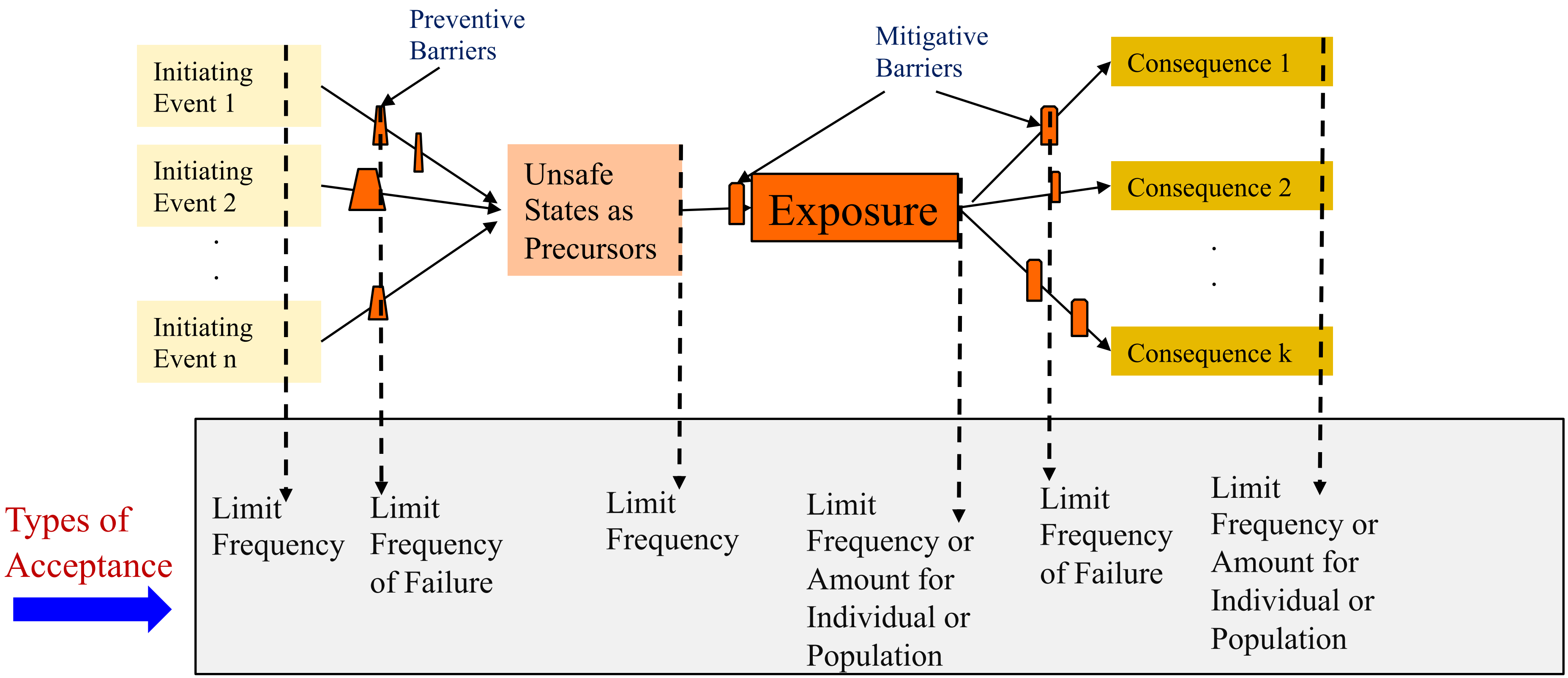
Critical Element of PRA: Uncertainty Analysis (Cont.)



Strength of PRA

1. Integrated and systematic examination of most design and operational features of a complex system.
2. Include influences of interactions and human-system interfaces.
3. A model to formally incorporate operating experiences.
4. Explicit consideration of uncertainties.
5. Analyzes competing risks (e.g., list of risk-significant elements).
6. Analysis of assumptions and data issues via sensitivity studies.
7. Provides a measure of the absolute or relative importance of human, activities, hardware, software components to the calculated risk.
8. Provides a quantitative measure of overall level of health and safety for the engineered system.

Establishment and Uses of Risk Acceptance Levels for Risk Management



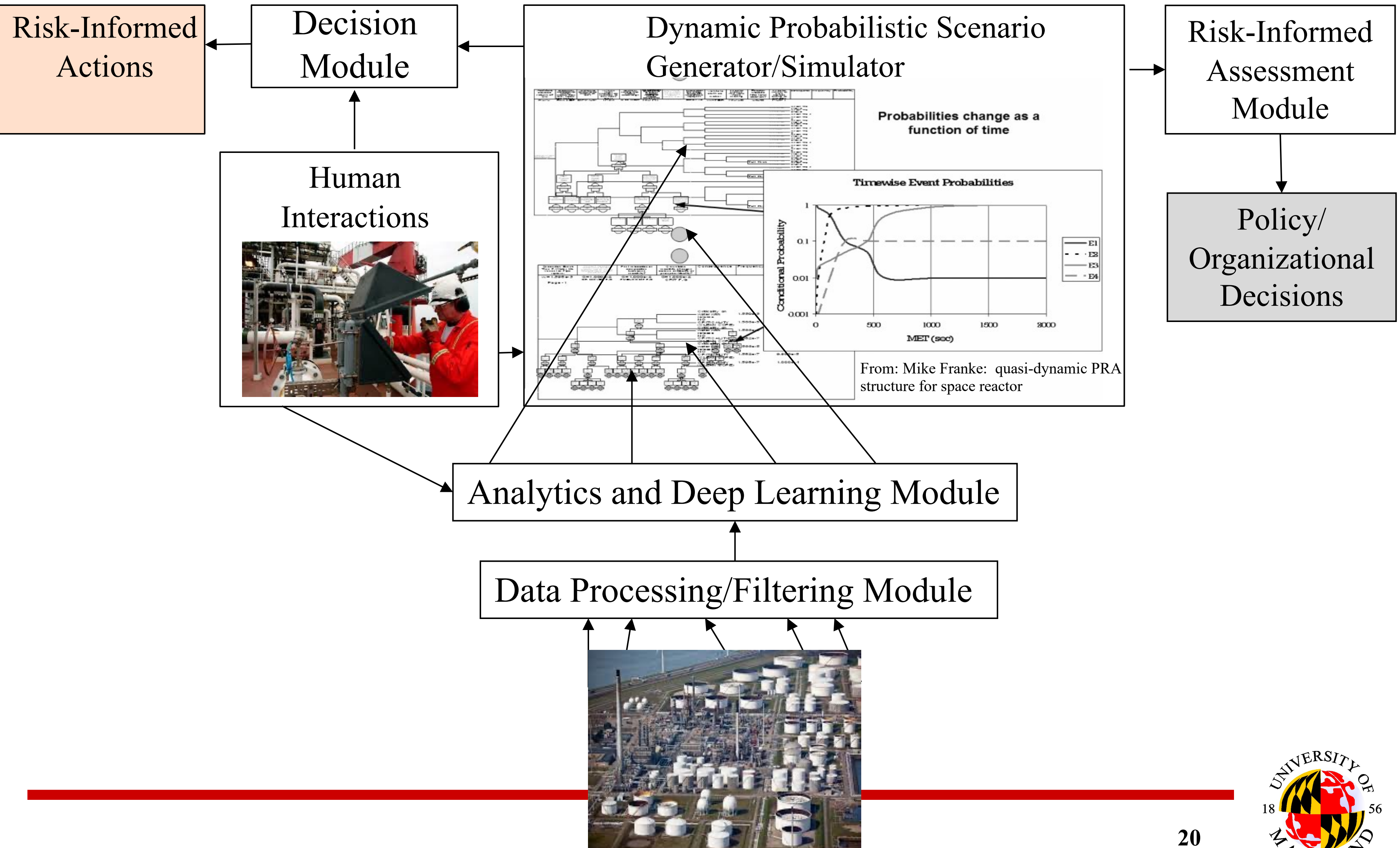
Frontier Areas of Current and Future Research in PRA

- **Facility Safety-Security-Resilience (SSR)**
  - Electronic Information Flow Embedded in Nearly Every Aspect of Facilities
  - Integrity of Complex Systems and Networks: Cyber-Human-Software-Physical (CHSP) Systems
  - Interruption in Connected Infrastructure Networks Through Cyberspace Attacks
  - Societal Disruption, Health, Safety and Resilience Goals
- **Life-Cycle Risks of Complex Facilities**
  - Passive System Risks
  - Organizational Influences in Facility Safety and Risk
  - Climate Risks of Disruptions in Operations
- **Health System Risks**
  - Health System Risks
  - Epidemic, Pandemic and Endemic Risks
- **Simulation-Based Dynamic Probabilistic Risk Assessment**
  - Computer-Assisted Risk Scenario Generation

What to Learn From Past Risk Assessments

- Formal PRA models can provide important realistic static and dynamic scenarios and contributors to operational and accidental risks in design and operation of systems
- The PRA models can be updated through streams of sensor data, sentimental conditions, temporal state of the facility
- PRAs may serve in support of risk management and policy decision making to predict, avoid and mitigate accidents
- PRA can learn by updating its risk models with near-miss events and specialize itself to a specific facility, operator and environment
- Analysis of significant risk scenarios provide an organizational learning resource

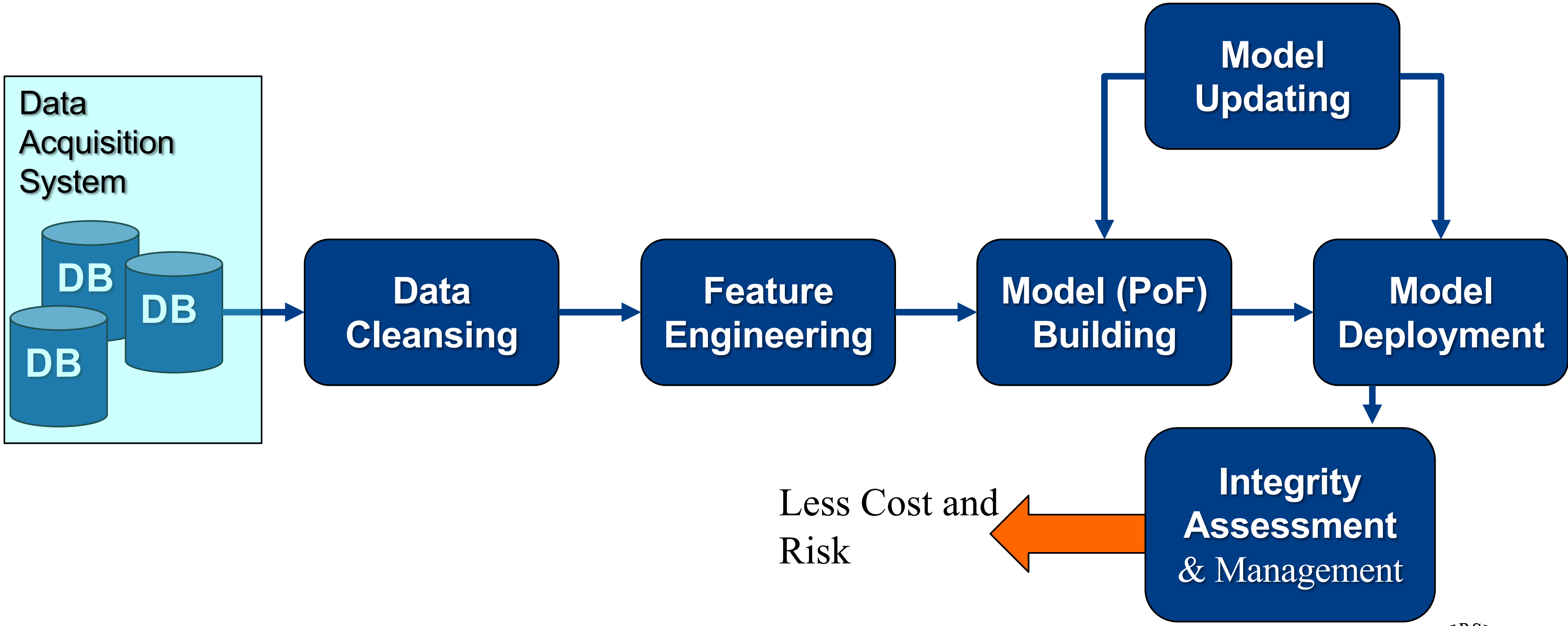
Future Risk Assessments



Future Risk Assessments: Learning

➢ AI-Informed Integrity Assessment

- Transforming raw data into features that better represent the predictive models



Conclusions

- PRA forms the basis for risk-informed decision making
- Supports test and maintenance planning and optimization
- Supports safety upgrades
- Significant development experiences and standards in developing and proper uses of PRA models exist
- Used to develop and show adherence to acceptable risk levels
- Supports compliance to regulatory requirements
- Old methods of safety analysis may be insufficient for complex technologies
- Major accidents could prove disastrous to the vitality of the industry
- Risk-informed approaches characterize uncertainties and risk contributors
- Several exciting research activities are ongoing to mix PRA with modern machine learning methods and technologies

Thank you!

Questions?