Probabilistic Risk Assessment and Management in the Nuclear Industry: An Overview

Mohammad Modarres

Topics Covered

- Definition of Risk and Risk Assessment
- Elements of Probabilistic Risk Assessment (PRA)
- Examples of PRA and Risk Management
- Uses in Operations and Regulations
- Conclusions

Definition of Risk and Risk Assessment

- Risk assessment is the process of providing answer to three basic questions (Kaplan & Garrick, Risk Anal. J. 1981)

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

- Answering these questions forms the basis of the PRA

PRA: A Useful Form of Risk Assessment

- PRA identifies, models and analyzes:
  - Initiating events
    - Disturbances that put a nuclear plant into a transient
  - Safety systems and functions
    - Systems and functions that mitigate the initiating event
  - Accident scenarios
    - Chronological combination of safety system and function successes and failures that lead to release of radiation
    - Chronological combinations that successfully avert any damage
- PRA model estimates the frequency and consequences of core damage and radiation releases

Information Needed for the PRA

- **Information needed include:**
  - Detailed plant design information (core inventory, etc.)
  - Thermal hydraulic and severe accident analyses
  - Safety and other system drawings and success criteria
  - Operating experiences
  - Emergency and operating procedures
  - Maintenance procedures

Examples of Disturbances (IEs)

- Examples of IEs
  - Loss of feedwater
  - Loss of offsite power
  - Loss of coolant accident

- Examples of plant responses
  - Physical
    - Neutronic
    - Reactor vessel and containment pressure, temperature, water level
  - Automatic
    - Reactor trip/turbine trip
    - Safety system actuations
  - Operator
    - Manual reactor trip
    - Manual recovery actions

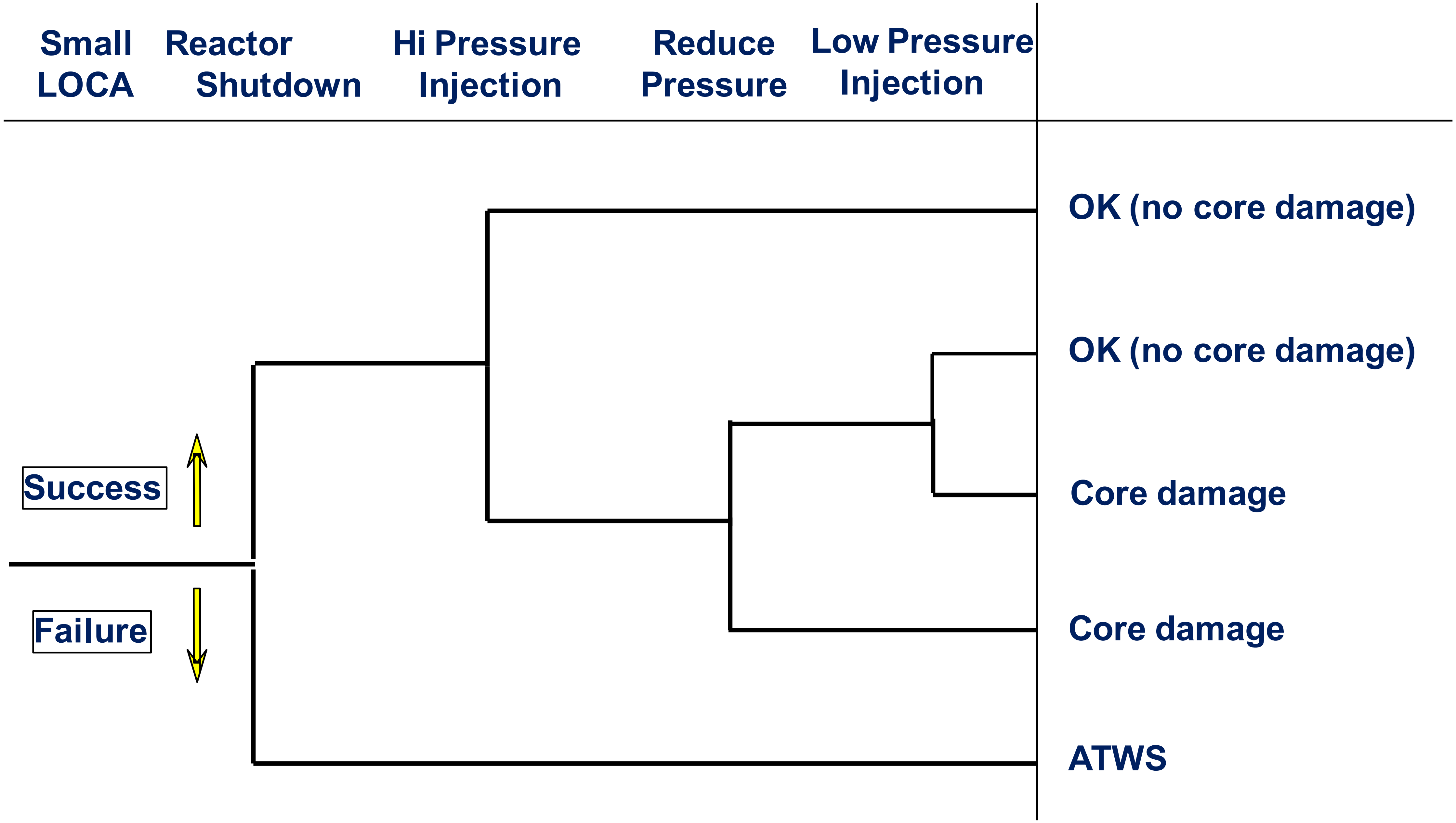
Elements of a PRA

- **Elements**
  - **Event trees** : model scenarios of events from an initiating event to an end-state
  - **Fault trees:** model failure of safety system/ functions that mitigate the accident
  - **Frequency** and **probability:** estimate likehoods of initiating events, component failures, human error

- **PRA Output**
  - Core damage frequency (CDF) (Level-1 PRA)
  - Radioactive Release size and frequencies (Level-2 PRA)
  - Radiological consequences to public and region (Level-3 PRA)

Event tree

Delineates scenario of events after the IE



Adapted From: NRC Tutorial on PRA: http://www.nrc.gov/about-nrc/regulatory/risk-informed/rpp/pra-tutorial.pdf

Event tree (Cont.)

- Top (or pivotal) events represent:
  - Functions or systems that mitigate core damage
  - Important operator actions
  - Systems that mitigate radioactive release

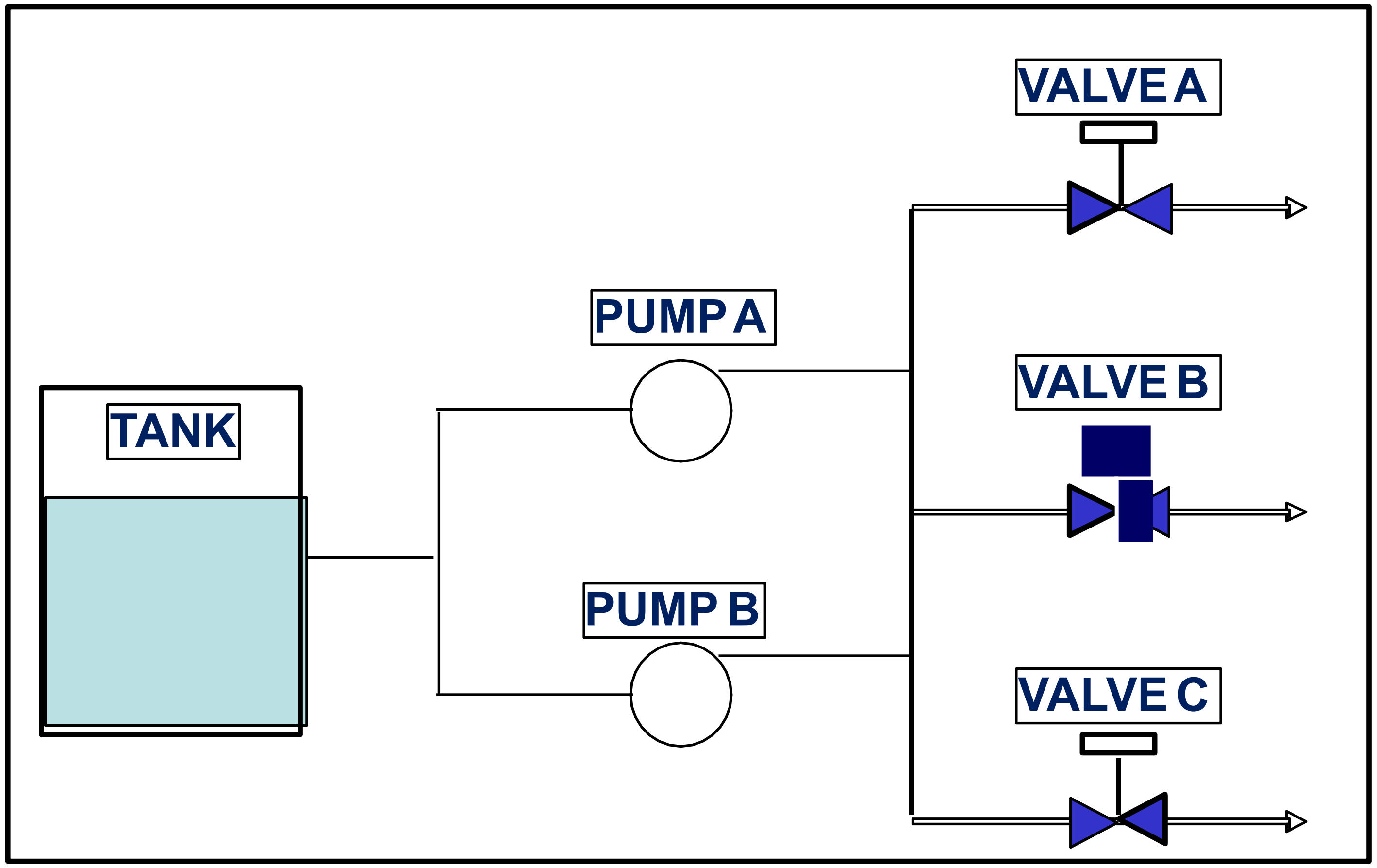
- Event tree also models severe accident phenomenology that challenges containment integrity

Fault tree

- A logical model of how a mitigating safety systems fail

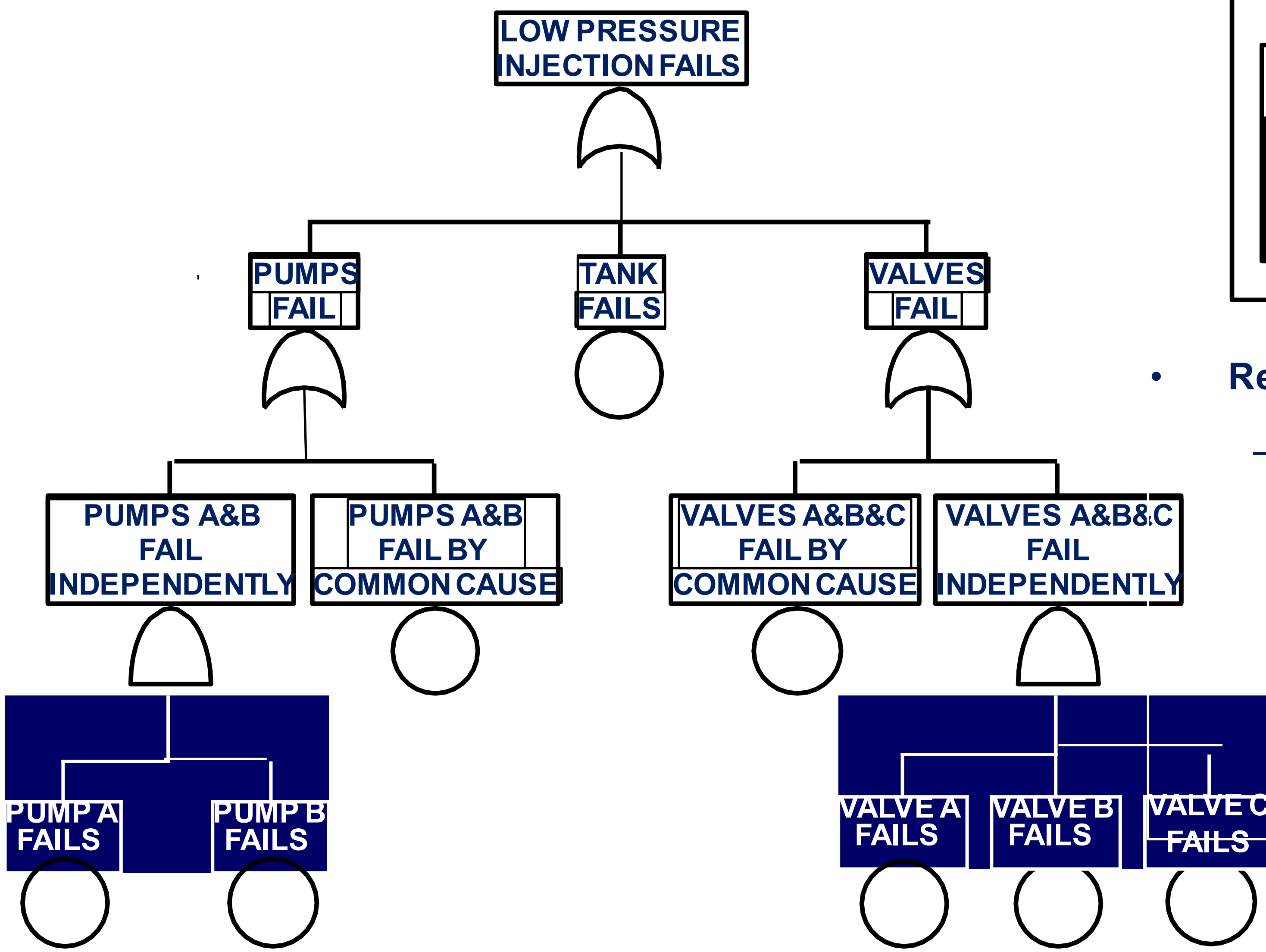
SUCCESS CRITERION:
Flow from tank through 1 of 2 pumps to 1 of 3 injection paths

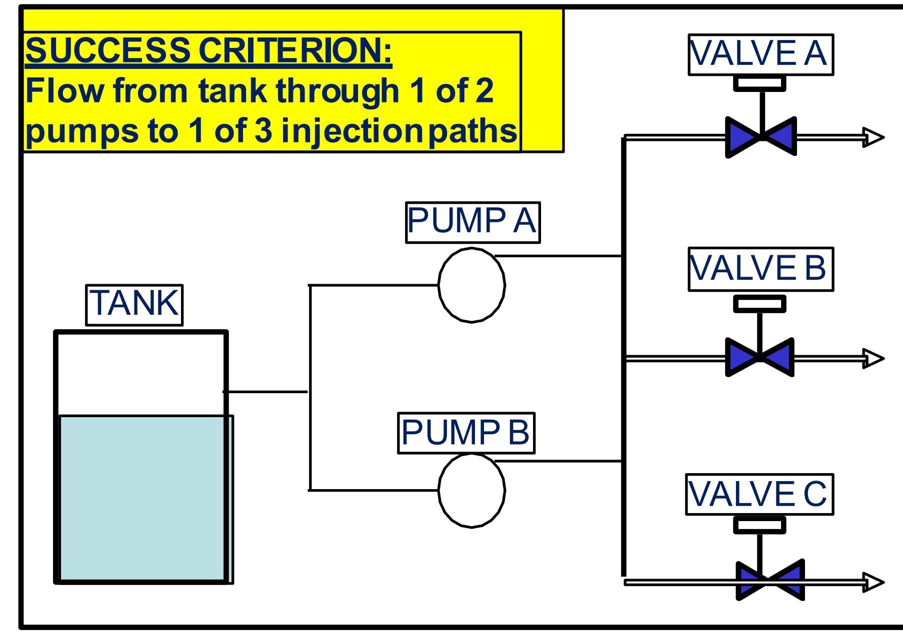
FAILURE OCCURS WHEN:
No flow from tank
OR
No flow from pumps
OR
No flow through injection paths



Adapted From: NRC Tutorial on PRA: http://www.nrc.gov/about-nrc/regulatory/risk-informed/rpp/pra-tutorial.pdf

Fault tree (Cont.)





- **Reducing the logic in a fault tree gives:**
  - <u>**Cut sets**</u>, failures that cause system failure
    - PUMP A FAILS <u>and</u> PUMP B FAILS
      - Independ or by common cause
    - VALVE A FAILS <u>and</u> VALVE B FAILS <u>and</u> VALVE C FAILS (Independent or by common cause)
    - TANK FAILS

Adapted From: NRC Tutorial on PRA: http://www.nrc.gov/about-nrc/regulatory/risk-informed/rpp/pra-tutorial.pdf

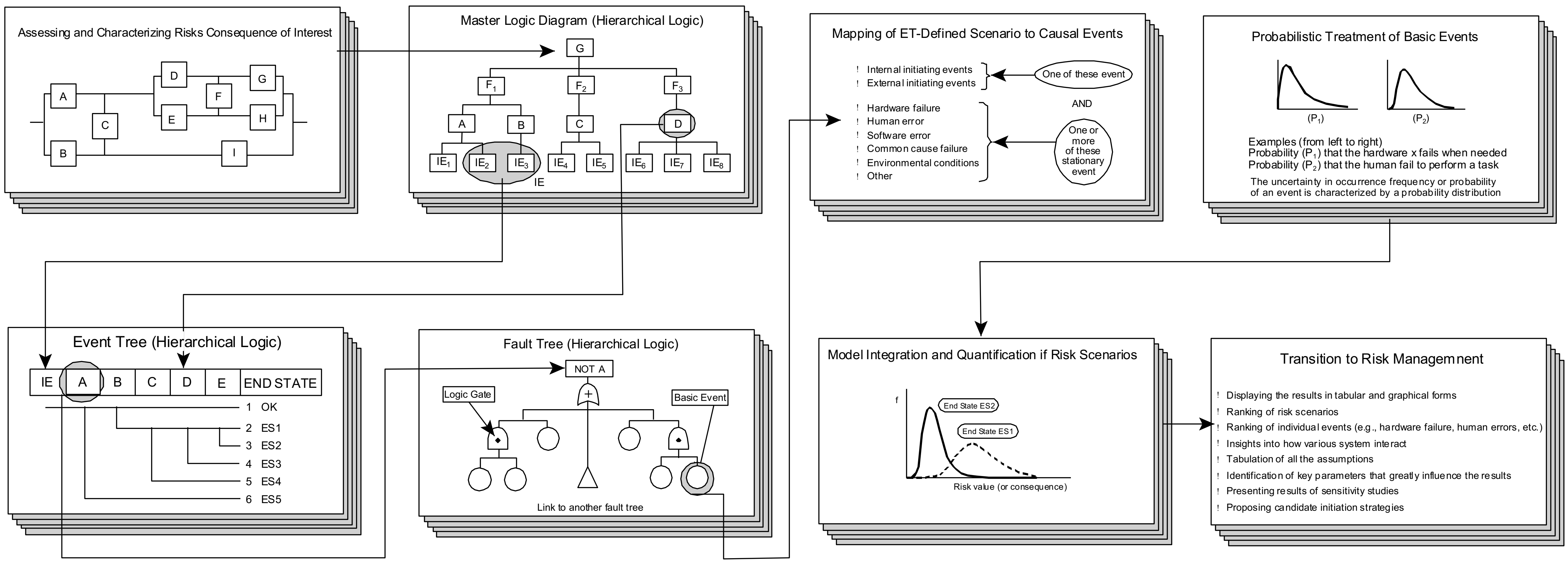
Event Probabilities and Frequencies: Likelihood of Events

Operating experience data for:

- Frequency of initiating events
- Failure rates of harware
- Human reliability and error rates
- Probabilities of repair and operator recovery

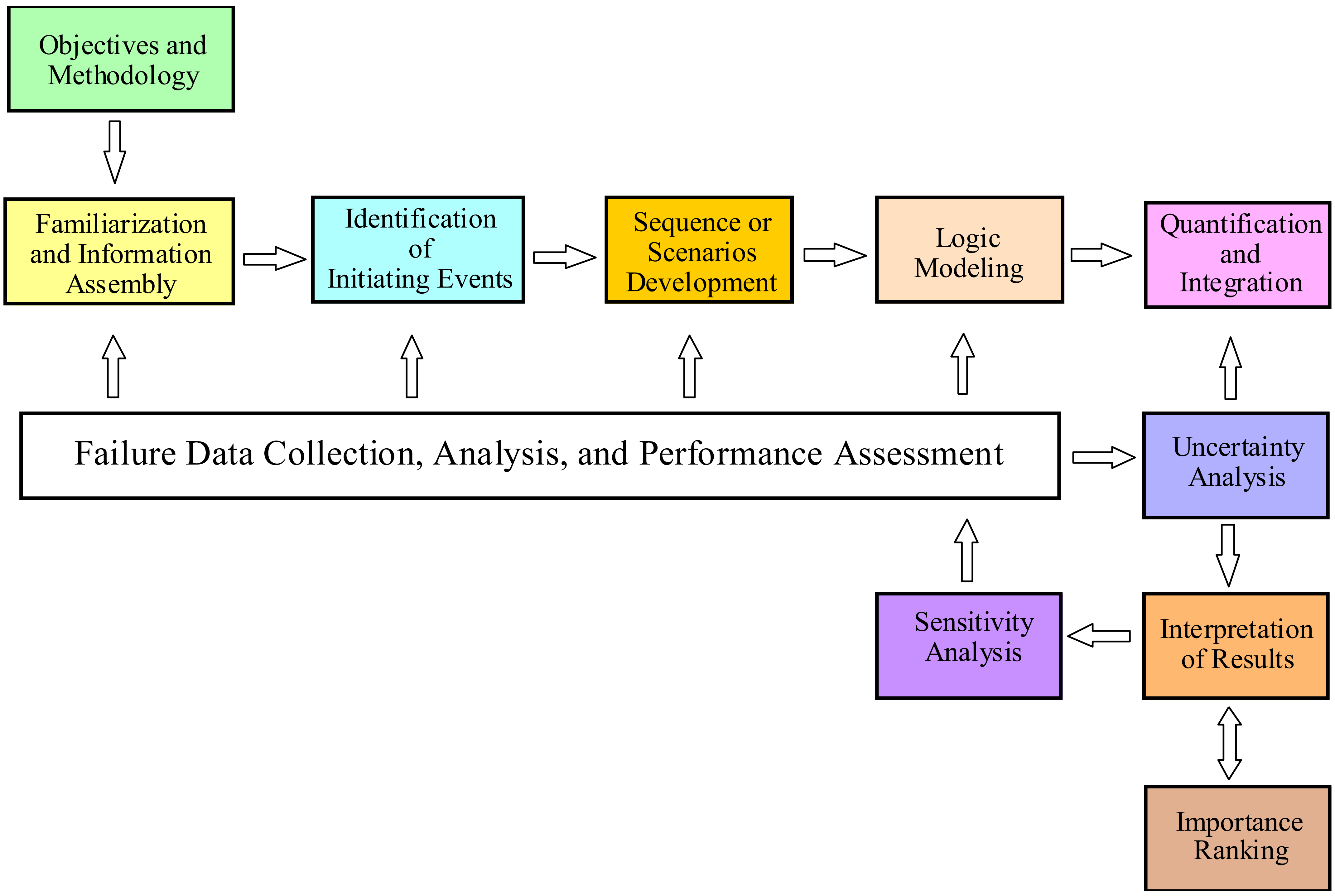
Expert judgement for rare event
Common cause failure modeling

Graphical Depiction of the Overall PRA



PART II: IMPORTANT CONSIDERATIONS IN PRA AND APPLICATIONS

Graphical Depiction of the Overall PRA



Risk Ranking and Importance Analysis

Applications:

1. **(Re)Design:** To support decisions of the system design or redesign by adding or removing equipment
2. **Test and Maintenance:** To Address questions related to the plant performance by changing the test and maintenance strategy
3. **Configuration and Control:** To measure the significance and effect of failure of a component on risk or safety or temporarily taking a component out of service
4. **Key Uncertainties:** identify unknown but important parameters of the PRA

Uncertainty Analysis

Steps in uncertainty analysis include:

1. Identify models and parameters that are important and uncertain
2. Estimate and assign probability distributions depicting PRA models and parameters
3. Propagate uncertainties
4. Present the uncertainties associated with risks and contributors to risk in an easy way to understand

Interpretation of Results

PRA results interpretation include:

1. Determine accuracy of the logic models and scenarios, assumptions, and scope of the PRA
2. Identify system elements for which better information would be needed to reduce uncertainties in failure probabilities and models used to calculate performance
3. Revise the PRA and reinterpret the results until attaining stable and accurate results

Strength of PRA

Important strengths:

1. Provides an integrated and systematic examination of a broad set of design and operational features of the plant
2. Incorporates the influence of system interactions and human-system interfaces
3. Provides a model for incorporating operating experience with the engineered system and updating risk estimates
4. Provides a process for the explicit consideration of uncertainties
5. Permits the analysis of competing risks (e.g., of one system vs. another, or possible modifications to an existing system)
6. Permits the analysis of (assumptions, data) issues via sensitivity studies
7. Provides a measure of the absolute or relative importance of systems, components to the calculated risk value
8. Provides a quantitative measure of the overall level of health and safety for the plant

Applications of PRA in Operations and Regulations

- Safety analysts use PRA for integrated plant evaluations to discover and correct subtle vulnerabilities that resulting in significant safety improvements
- Inspectors use PRA insights to focus on important safety systems, operations and human actions
- Regulators use PRA for Reactor Oversight Program to determine important processes with high safety impact that need to increased inspection and oversight
- Owners use PRA to show compliance to performance-based maintenance and fire protection, and other regulations
- Regulators use PRA to confirm the rigor of any new or revised rules to cover uncertainties and justify new requirements
- Owners and regulators use PRA to assess issues such as emergency planning, evacuations, etc.
- Regulators and designers use PRA to secure license or certification of new reactor designs

Applications of PRA in Operations and Regulations (Cont.)

- Enhance risk-informed technical specifications (e.g., risk-informed in-service inspection programs to focus resources on the most safety-significant systems and components)
- Analyze and enhance new reactor designs
- Develop and use risk monitors in operators

Conclusions

- PRA forms the basis for risk-informed decision making
- Many uses as safety monitors for configuration management
- Supports test and maintenance planning and optimization
- Supports safety upgrades of plants built to earlier standards
- Significant development experiences and standards in developing and proper uses of PRA models
- Can be used to show adherence to formal safety goals (how safe-is-safe enough or deminimis risk) measures
- Supports compliance to many regulatory requirements

Thank you for your attention!

The Center for
Risk and Reliability