# Probabilistic Risk Assessment and Management in the Nuclear Industry: Overview and Applications

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## **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:

- 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

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# 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 radaitation releases

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# Information Needed for the PRA



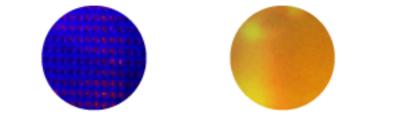
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### Information needed include:

- 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

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### **Elements of a PRA**



### Elements

- <u>Event trees</u>: model scenarios of events from an initiating event to an end-state
- <u>Fault trees:</u> model failure of safety system/ functions that mitigate the accident
- <u>Frequency</u> and <u>probability</u>: 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)

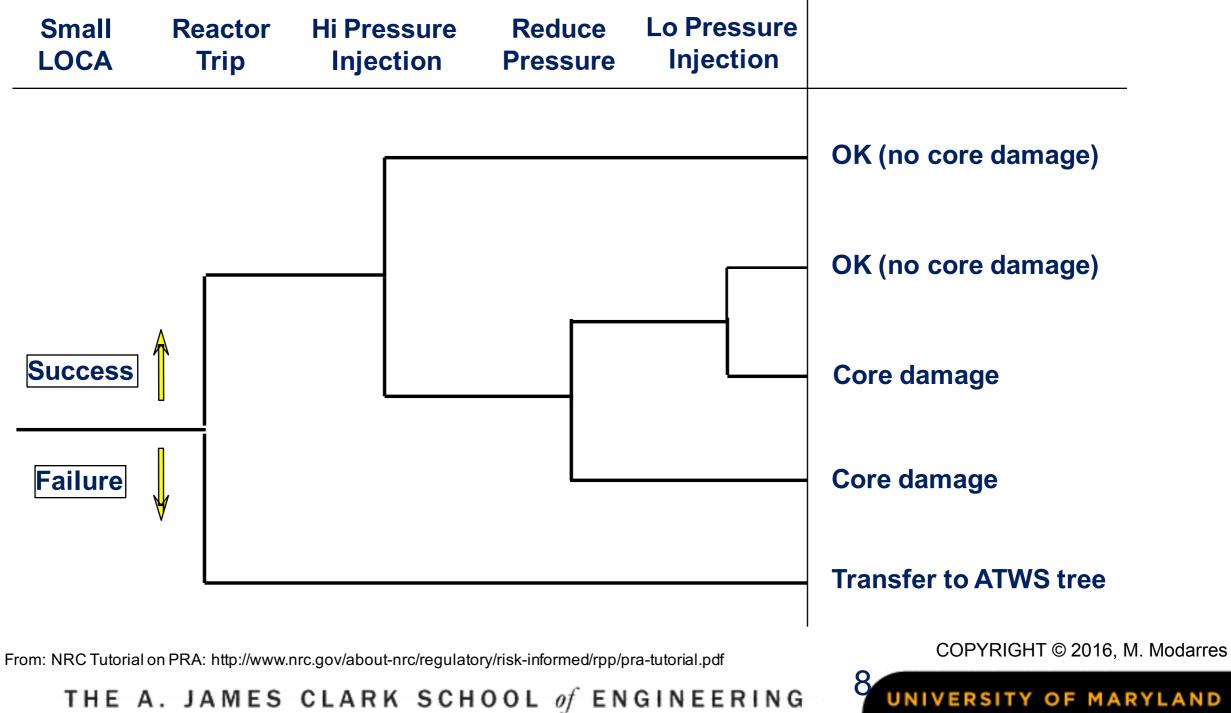
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### **Event tree**



### Delineates scenario of events after the IE



### **Event tree (Cont.)**



- Top 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

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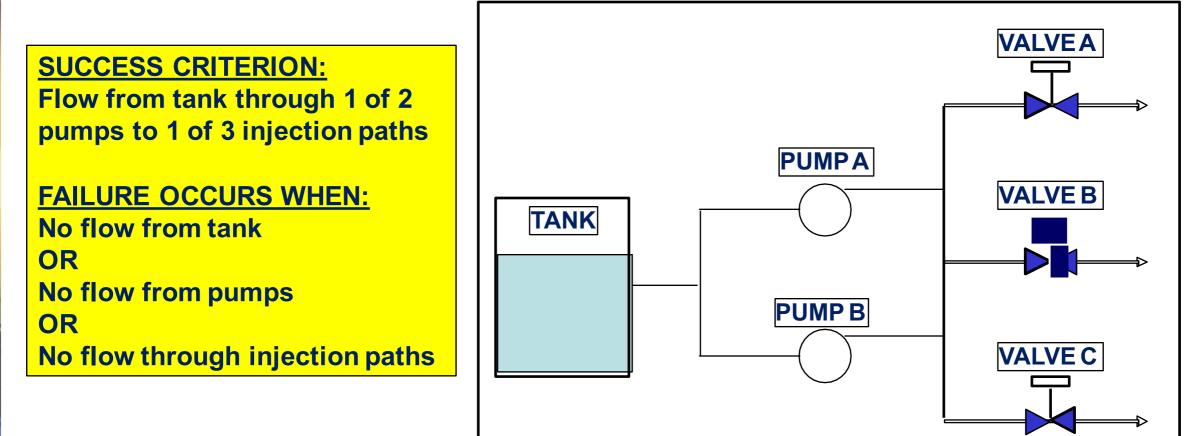
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# Fault tree



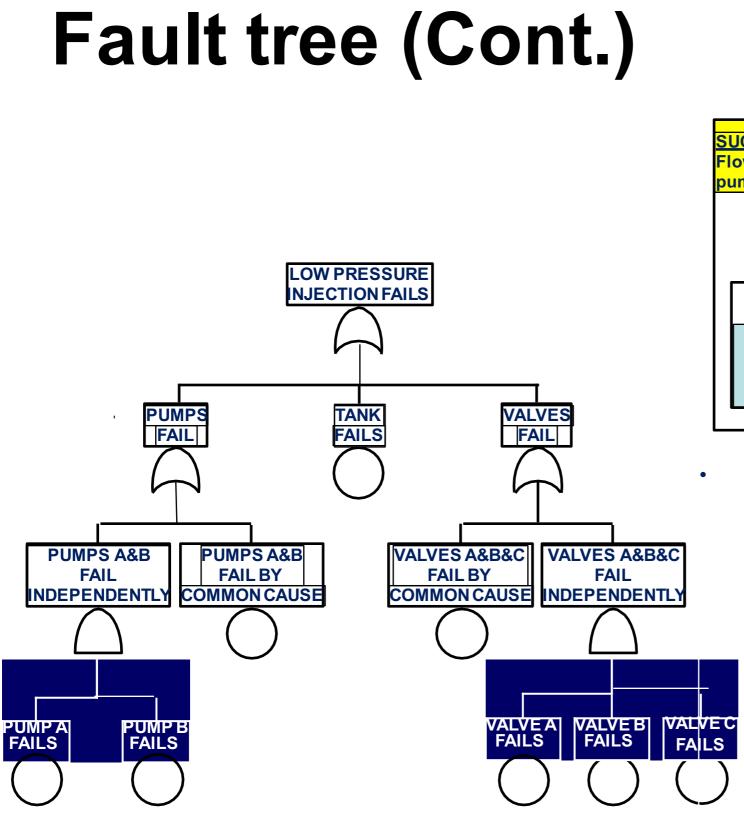
A logical model of how a mitigating system fail

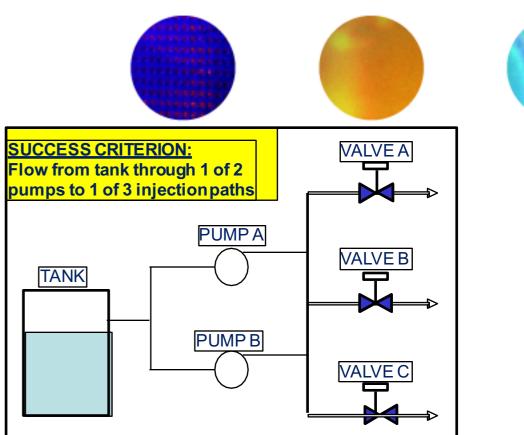


From: NRC Tutorial on PRA: http://www.nrc.gov/about-nrc/regulatory/risk-informed/rpp/pra-tutorial.pdf

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- Reducing the logic in a fault tree gives:
  - <u>Cutsets</u>, failures that cause system failure
    - PUMP A FAILS and 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

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

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# Event Probabilities and Frequencies: Likelihood of Events

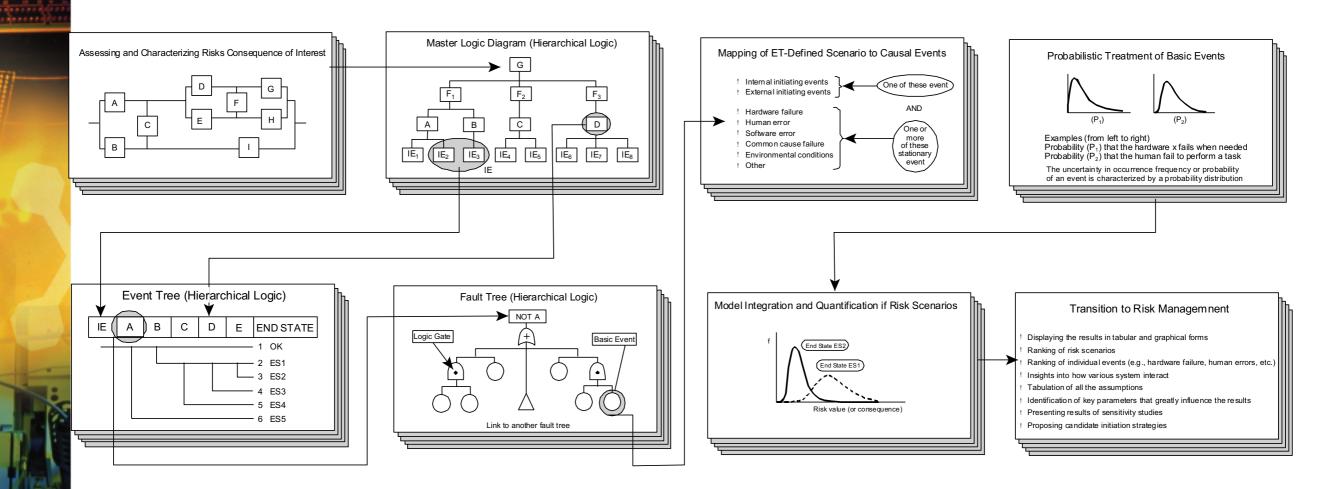


- Frequency initiating events
- Failure rates of harware
- Human reliability and error rates
- Probabilities of repair and recovery

Expert judgement for rare event Common cause failure modeling

# Graphical Depiction of the Overall PRA





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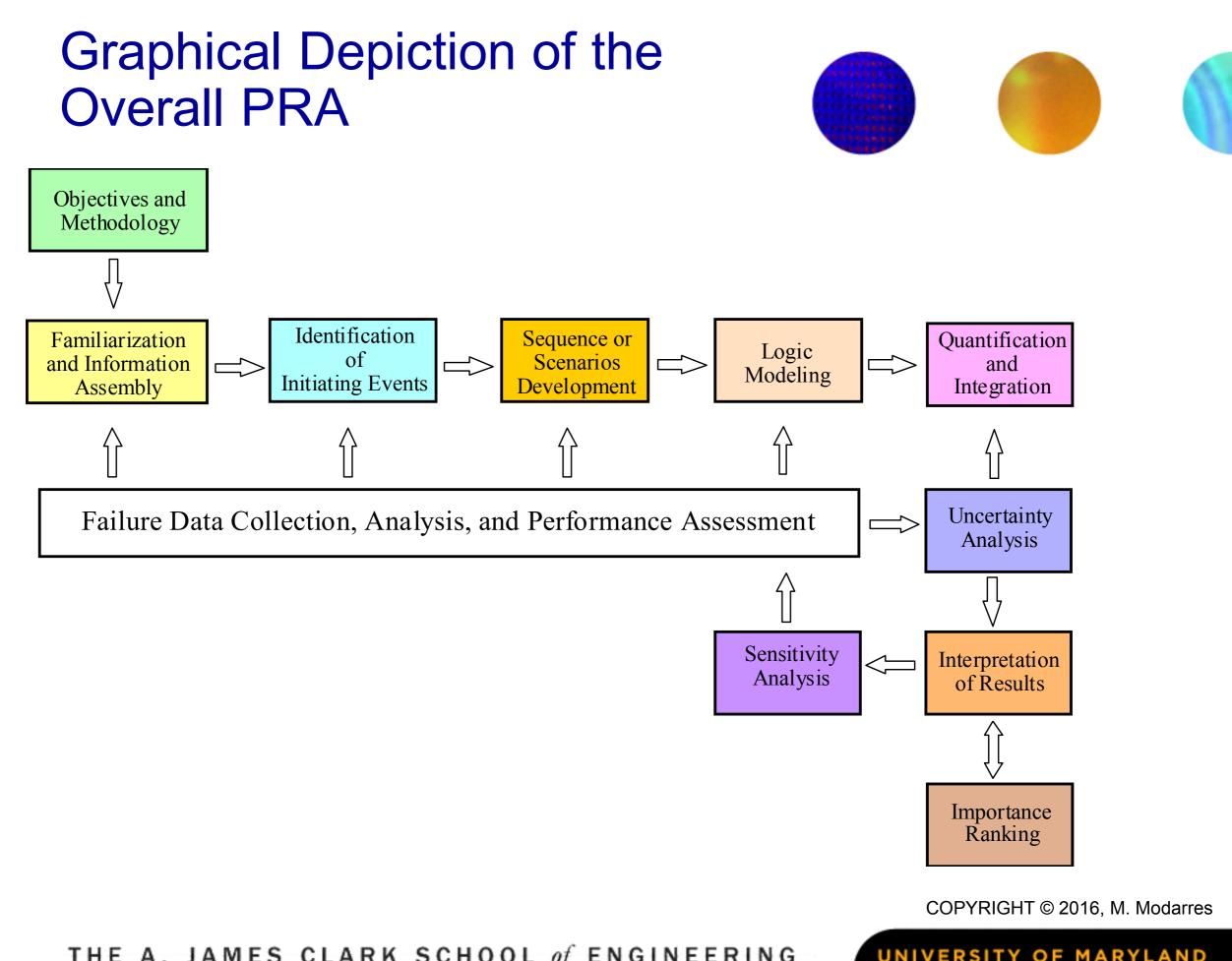
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## PART II: IMPORTANT CONSIDERATIONS IN PRA AND APPLICATIONS

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## **Uncertainty Analysis**



### Steps in uncertainty analysis include:

- 1. Identify models and parameters that are 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

### 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. Reduce Uncertainties: in the unknown parameters of the PRA

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## **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 an engineered system
- 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 of 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 overall level of health and safety for the engineered system

### Applications of PRA in Regulations



- Integrated plant evaluations to discover and correct subtle vulnerabilities that resulting in significant safety improvements
  Inspections use PRA insights to focus on important safety systems, operations and human actions
- •Applications for Reactor Oversight Program to determine important processes with high safety impact that need to increased inspection and oversight
- •Show compliance to performance-based maintenance and fire protection, and other regulations
- PRA uses by the NRC to confirm the rigor of any new or revised rules to cover uncertainties and justify new requirements
  Assess issues such as emergency planning, evacuations, etc.
  License / certify new reactor designs

### Applications of PRA By Plant Operators



Enhance risk-informed technical specifications (riskinformed in-service inspection programs to focus resources on the most safety-significant systems and components)
Analyze and enhance new reactor designs
Risk monitor

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### 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 if safety goals (how safe-is-safe enough) measure are met
- Supports compliance to many regulatory requirements



# Thank you for your attention!



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