Risk-Informed Decision Making and Nuclear Power

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Outline

This lecture will cover the following topics:

- What is risk assessment?
- Concept of residual risk
- What is risk-informed decision making?
- History of RIDM in the USA
- Examples of RIDM and their impact
- Related NRRC activities

The Concept of Risk

- **The possibility that something bad or unpleasant (such as an injury or a loss) will happen (Merriam-Webster dictionary)**

- **For technological systems, risk assessment answers the questions (Kaplan and Garrick, 1981)**
  - **What can go wrong? (accident scenarios)**
  - **How likely is it?**
  - **What are the consequences?**

- **This risk triplet has been implemented in nuclear power plant and space shuttle risk assessments**

Residual Risk

- **All activities and technological systems pose a residual risk after all protective measures are taken**

- **Examples of U.S. Annual Residual Risks**
  - ➢ **Occupational: 40 deaths per 100,000 people (firefighters)**
  - ➢ **Public**
    - ✓ **Heart Disease: 271 deaths per 100,000 people**
    - ✓ **All cancers: 200 deaths per 100,000 people**
    - ✓ **Motor vehicles: 15 deaths per 100,000 people**

From: Wilson & Crouch, *Risk/Benefit Analysis,* Harvard University Press, 2001.

- **The Challenge: To manage residual risk and reduce it to "acceptable" or "tolerable" levels**

“Acceptable” vs. “Tolerable” Risks
U.K. Health and Safety Executive

Increasing individual risks and societal concerns

UNACCEPTABLE REGION

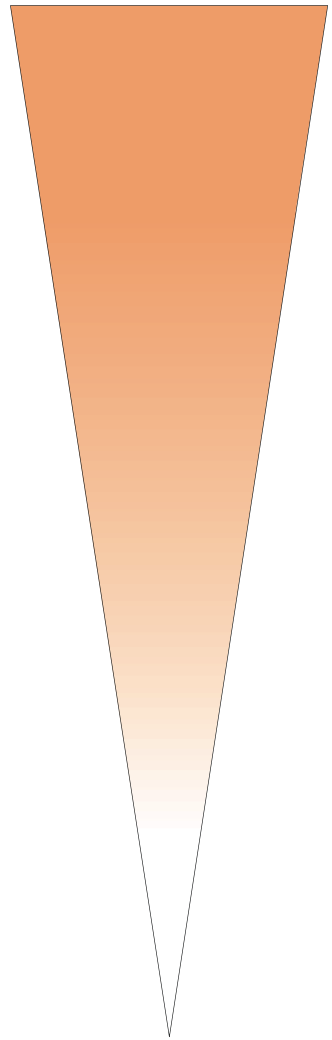
Risk cannot be justified save in extraordinary circumstances

TOLERABLE REGION

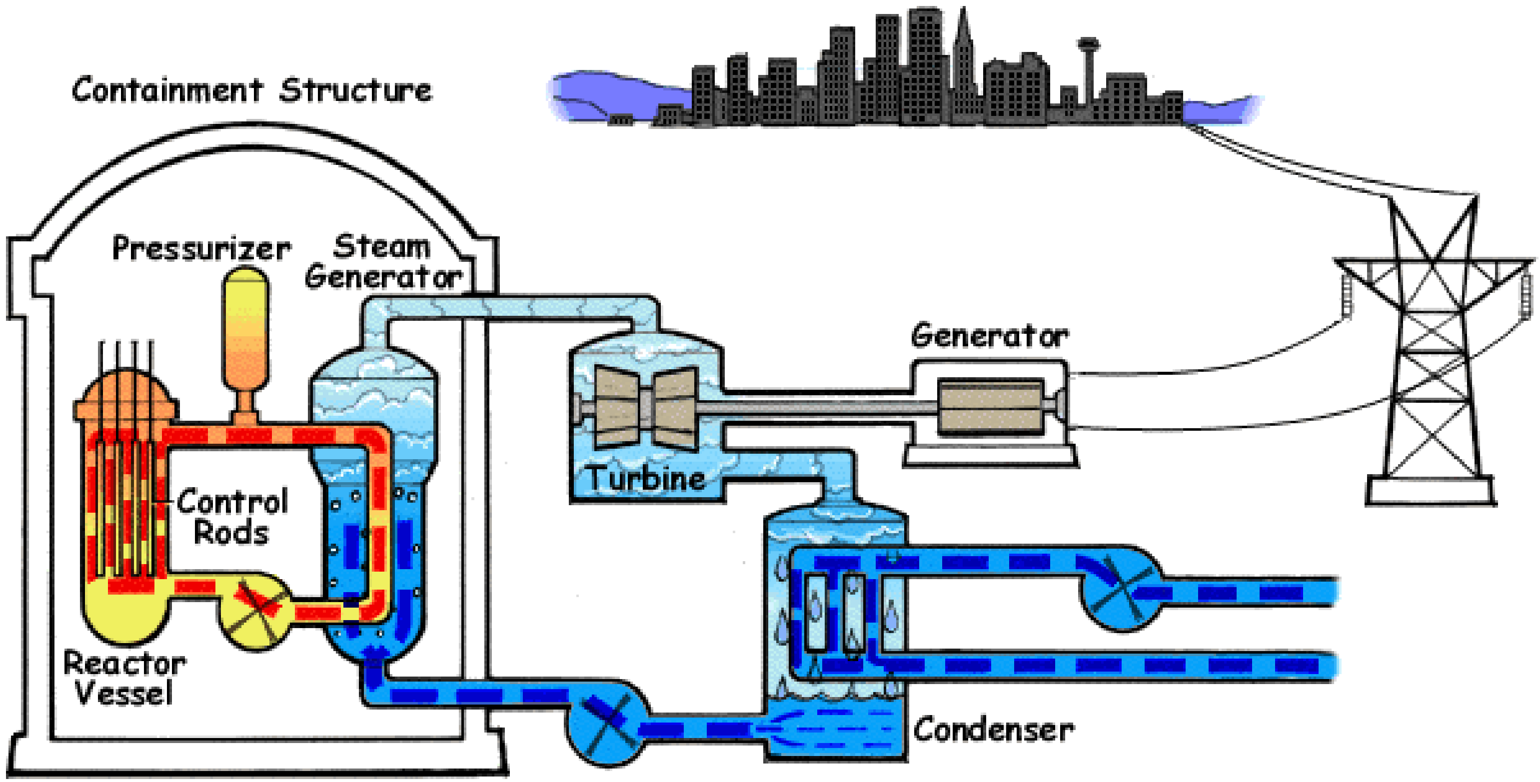
Control measures must be introduced for risk in this region to drive residual risk towards the broadly acceptable region

BROADLY ACCEPTABLE REGION

Level of residual risk regarded as insignificant -- further effort to reduce risk not likely to be required



Pressurized Water Reactor

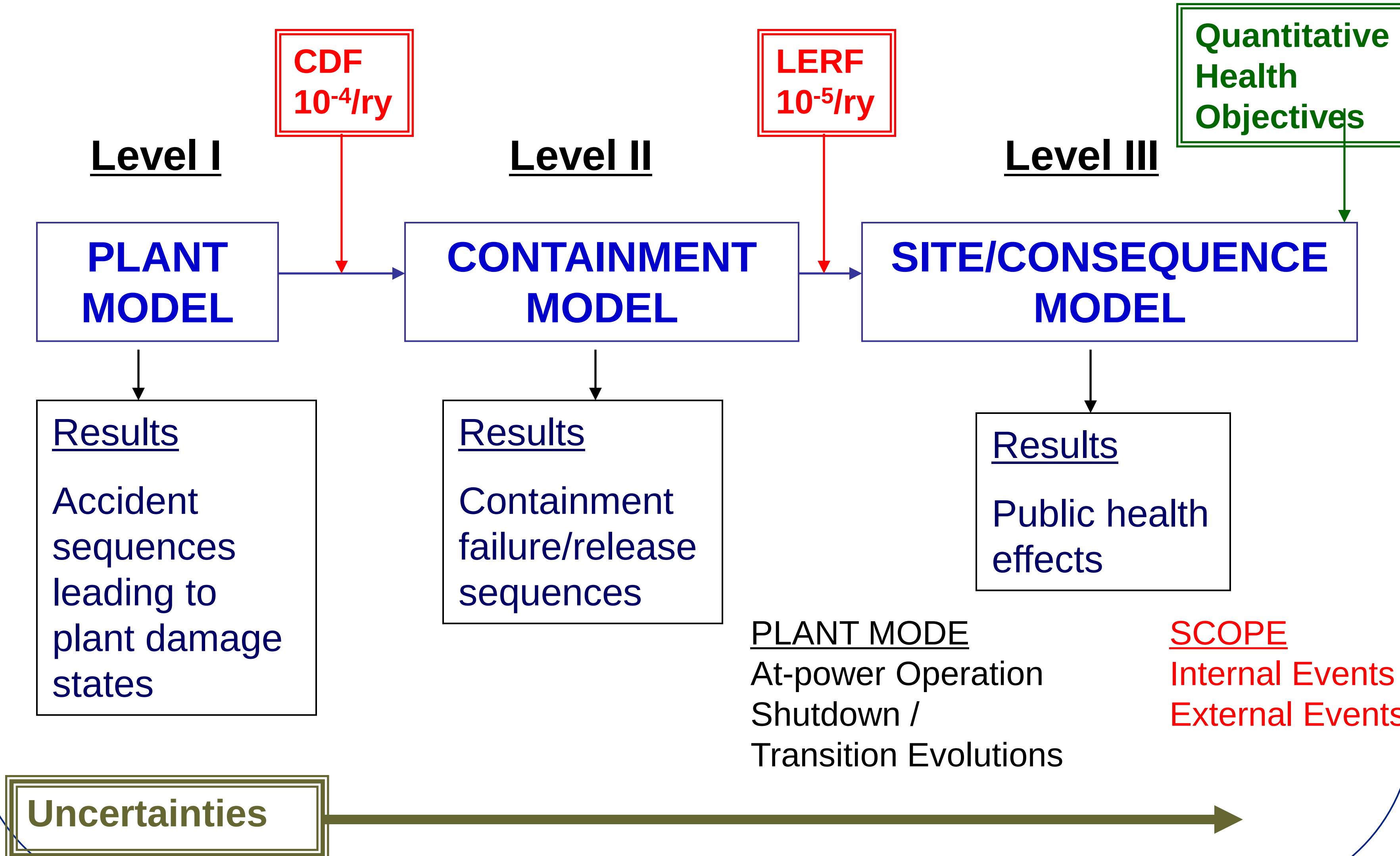


Risk Metrics for Nuclear Power Plants

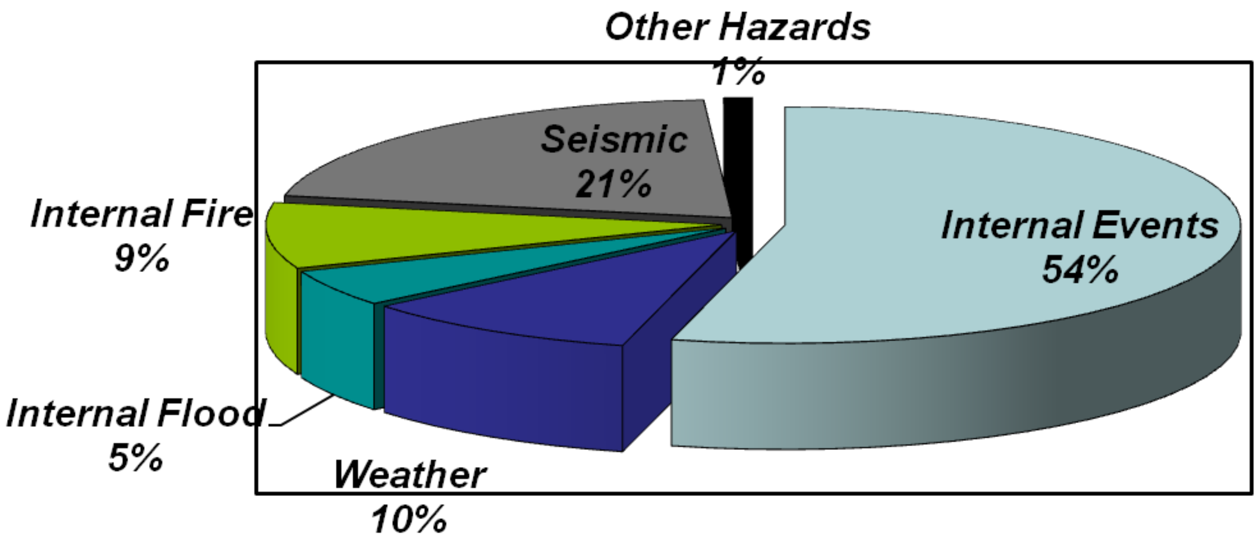
- **Core damage frequency (CDF): The frequency per reactor year of accidents that cause severe fuel damage. CDF is the surrogate risk measure for individual latent cancer fatality risk.**

- **Large early release frequency (LERF) : The frequency per reactor year of a rapid, unmitigated release of airborne fission products from the containment to the environment that occurs before effective implementation of offsite emergency response and protective actions, such that there is a potential for early health effects. LERF is the surrogate risk measure for individual prompt fatality risk.**

PRA Model Overview and Objectives



Contribution of Initiators to Core Damage Frequency (CDF) for a U.S. Plant



CDF = 1.45E-5 / yr (mean value)

R. Turcotte presentation, MIT, 2008

The Traditional Approach to Regulation
Prior to Risk Assessment (1975)

- **Management of (unquantified at the time) uncertainty was always a concern.**
- **Defense-in-depth and safety margins became embedded in the regulations.**
- **"*Defense-in-Depth* is an element of the NRC's safety philosophy that employs successive compensatory measures to prevent accidents or mitigate damage if a malfunction, accident, or naturally caused event occurs at a nuclear facility." [USNRC White Paper, February, 1999]**

Major Elements of Defense in Depth

Accident Prevention

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Safety Systems

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Containment

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Accident Management

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Siting & Emergency Plans

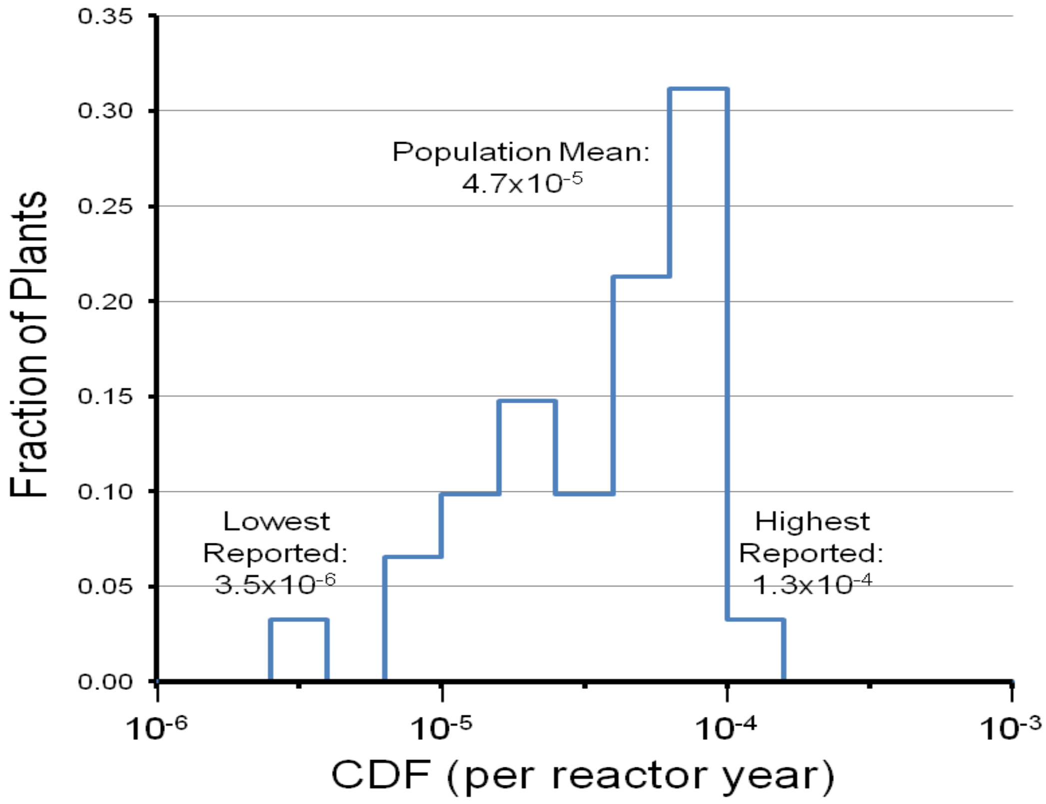
Design Basis Accidents (Adequate Protection)

- **A DBA is a postulated accident that a facility is designed and built to withstand without exceeding the offsite exposure guidelines of the NRC's siting regulation.**
- **They are stylized and very unlikely events.**
- **They protect against "unknown unknowns".**

Problems with the Traditional Approach

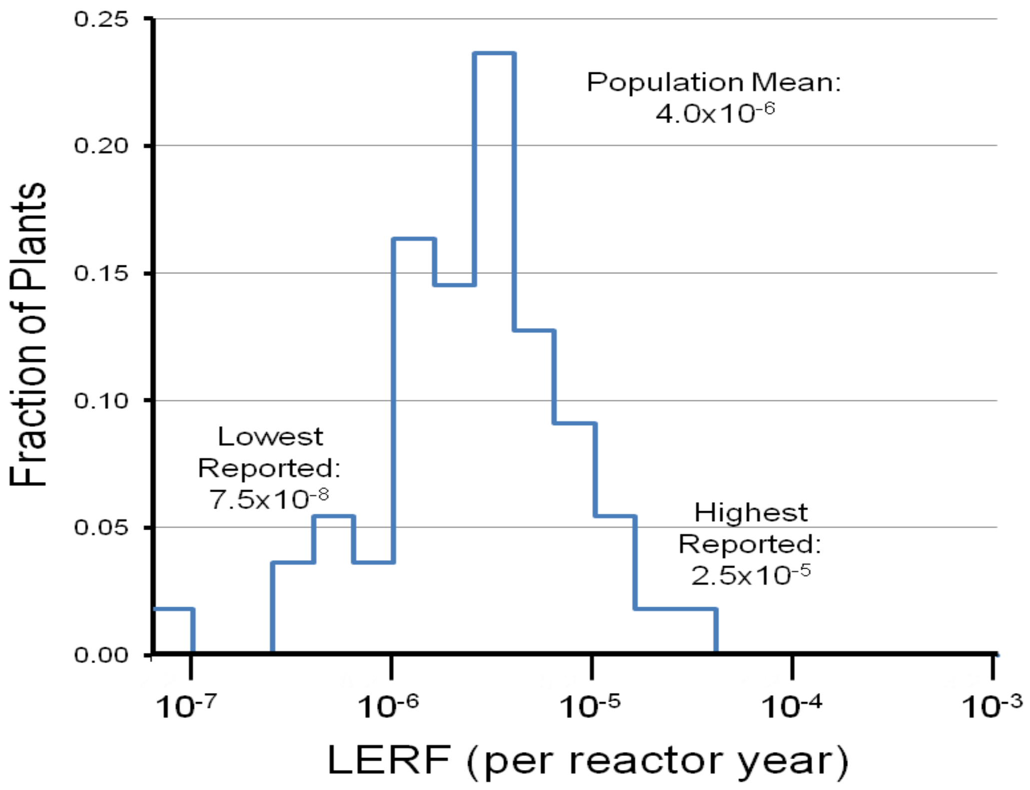
- There is no guidance as to how much defense in depth is sufficient
- DBAs use qualitative approaches for ensuring system reliability (the single-failure criterion) when more modern quantitative approaches exist
- DBAs use stylized considerations of human performance (e.g., operators are assumed to take no action within, for example, 30 minutes of an accident's initiation)
- DBAs do not reflect operating experience and modern understanding
- Industry-sponsored PRAs showed a variability in risk of plants that were licensed under the same regulations.

Point Estimates of CDF for U.S. Plants



From: NUREG-2201

Point Estimates of LERF for U.S. Plants



From: NUREG-2201

Reactor Safety Study Insights
(WASH-1400; 1975)

Prior Beliefs:

1. Protect against large loss-of-coolant accident (LOCA)
2. Core damage frequency (CDF) is low (about once every 100 million years, 10^{-8} per reactor year)
3. Consequences of accidents would be disastrous

Major Findings

1. Dominant contributors: Small LOCAs and Transients
2. CDF higher than earlier believed (best estimate: 5×10^{-5}, once every 20,000 years; upper bound: 3×10^{-4} per reactor year, once every 3,333 years)
3. Consequences significantly smaller
4. Support systems and operator actions very important

Regulatory Decision Making

- **Regulatory decision making (like any decision) should be based on the current state of knowledge and should be documented (clear and reliable regulations)**
  - **The current state of knowledge regarding design, operation, and regulation is key.**
  - **PRAs do not "predict" the future; they evaluate and assess future possibilities to inform the decision makers' current state of knowledge.**
  - **Ignoring the results and insights from PRAs results in decisions not utilizing the complete state of knowledge.**

Evolution of the USNRC's Risk-Informed Regulatory System

- **1980s:** New or revised regulatory requirements based on PRA insights introduced
- **1990s:** Risk-informed changes to a plant's licensing basis allowed
- **2000s:**
  - Change to a risk-informed reactor oversight process
  - Risk-informed alternative to comply with fire protection requirements
  - Regulation requiring PRAs for licensing new reactors

NRC Policy Statement on the USE of PRA in Regulations (1995)

- **Deterministic approaches to regulation consider a limited set of challenges to safety and determine how those challenges should be mitigated.**

- **A probabilistic approach to regulation enhances and extends this traditional, deterministic approach, by:**

  (1) Allowing consideration of a broader set of potential challenges to safety,

  (2) Providing a logical means for prioritizing these challenges based on risk significance, and

  (3) Allowing consideration of a broader set of resources to defend against these challenges.

Risk-informed Regulation

"A risk-informed approach to regulatory decision-making represents a philosophy whereby risk insights are considered together with other factors to establish requirements that better focus licensee and regulatory attention on design and operational issues commensurate with their importance to public health and safety."

[Commission's White Paper, USNRC, 1999]

The Deliberation (NUREG-2150)

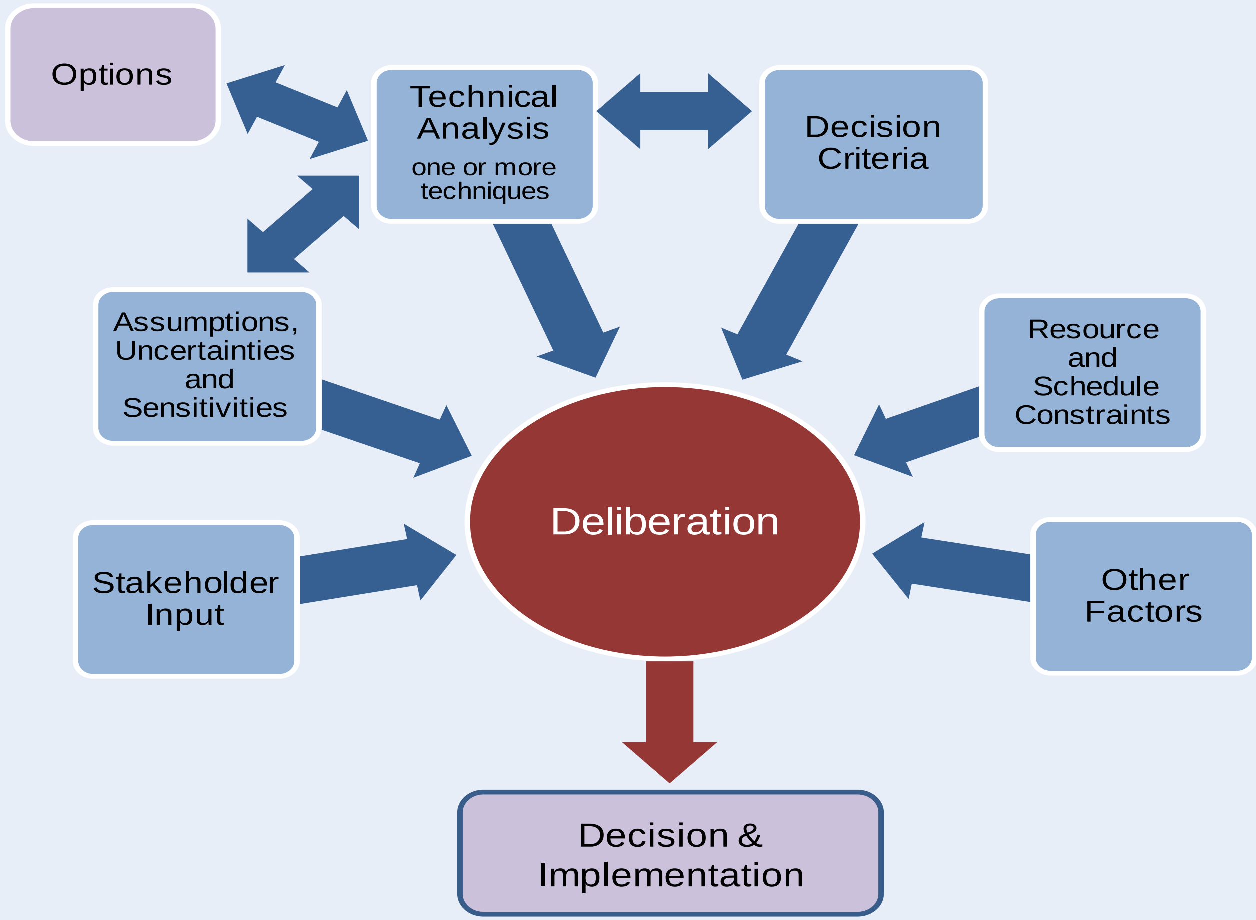


Figure 3-2 Deliberations

Risk-Informed Framework

Traditional "Deterministic" Approach

- **Unquantified probabilities**
- **Design-basis accidents**
- **Defense in depth**
- **Can impose unnecessary regulatory burden**
- **Incomplete**

Risk-Informed Approach

- **Combination of traditional and risk-based approaches through a deliberative process**

Risk-Based Approach

- **Quantified probabilities**
- **Thousands of accident sequences**
- **Realistic**
- **Incomplete**

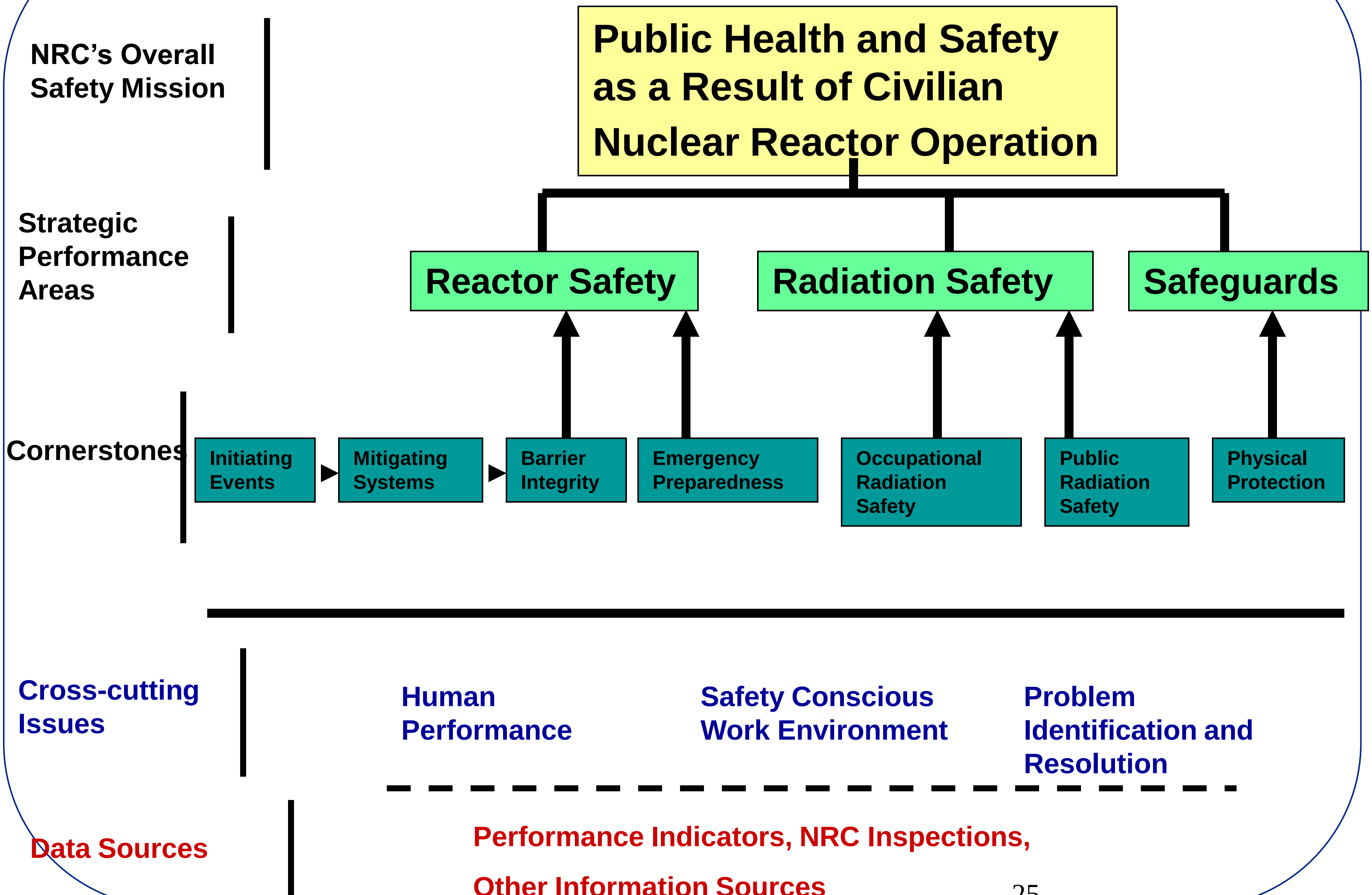
A Success: Reactor Oversight Process

- **Motivation**
  - ➢ **The previous inspection, assessment and enforcement processes**
    - a. **Were not clearly focused on the most safety important issues**
    - b. **Consisted of redundant actions and outputs**
    - c. **Were overly subjective with NRC action taken in a manner that was at times neither scrutable nor predictable.**
  - ➢ **Commission's motivation**
    - a. **Improve the objectivity of the oversight processes so that subjective decisions and judgment were not central process features**
    - b. **Improve the scrutability of these processes so that NRC actions have a clear tie to licensee performance**
    - c. **Risk-inform the processes so that NRC and licensee resources are focused on those aspects of performance having the greatest impact on safe plant operation.**

ROP: Challenges and Context

- **Challenges**
  - The large size of the program, in terms of both the number of USNRC staff (e.g., hundreds of affected staff) and the number of licensed facilities affected (i.e., all licensed power reactors).
  - The development of performance indicators using plant data (e.g., results of equipment tests translated into quantitative estimates of system reliability) required the development of methods to collect the data, techniques for consistently and clearly displaying the results, and determining action “thresholds” (e.g., what action should be taken in response to decreasing performance).
  - The quality of the licensee PRAs varied considerably across the set of plants
  - This variability presented a significant challenge to USNRC as it attempted to develop realistic and objective assessment tools that were not sensitive to this variability.

ROP: Regulatory Framework



ROP: Implementation

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- Establishment of new training programs within USNRC to provide information on PRA to inspectors and their management.
- Creation of a new category of inspector, the “senior reactor analyst,” with expertise in both inspection processes and risk assessment.
- Development of a set of “standardized” plant analysis risk (SPAR) models. This was judged to be necessary to compensate for the variability of PRAs that had been developed and were being used by plant licensees.
- Inclusion of provisions (alternative approaches) for considering the risks from hazards not modeled realistically in the SPAR models, such as fires. In some cases, the results of using these alternative approaches can become the focus of considerable discussion between USNRC and licensees.

ROP: Outcomes

- Very successful
- Improves the consistency and objectivity of the previous process by using more objective measures of plant performance
- Focuses NRC and licensee resources on those aspects of performance that have the greatest impact on safe plant operation
- Provides explicit guidance on the regulatory response to inspection findings
- Full implementation required considerable resources, including data collection and evaluation, training, and agency risk expertise and models
- The benefits of the program, including the objectivity and public availability of plant evaluations, justified the costs incurred.

ROP: Take-Away

- Implementation of a risk-informed reactor oversight process requires considerable development, testing, and communication among stakeholders early in the process, and an extensive infrastructure during use. The objectivity and clarity of outcomes more than justifies the investment.
- Implementation of RIDM requires “Good” plant-specific PRAs.
- The NRRC is aiding Japanese utilities in developing “Good” PRAs.

NRRC Mission and Vision

Mission Statement

To assist nuclear operators and nuclear industry to continually improve the safety of nuclear facilities by developing and employing modern methods of Probabilistic Risk Assessment (PRA), risk-informed decision making and risk communication.

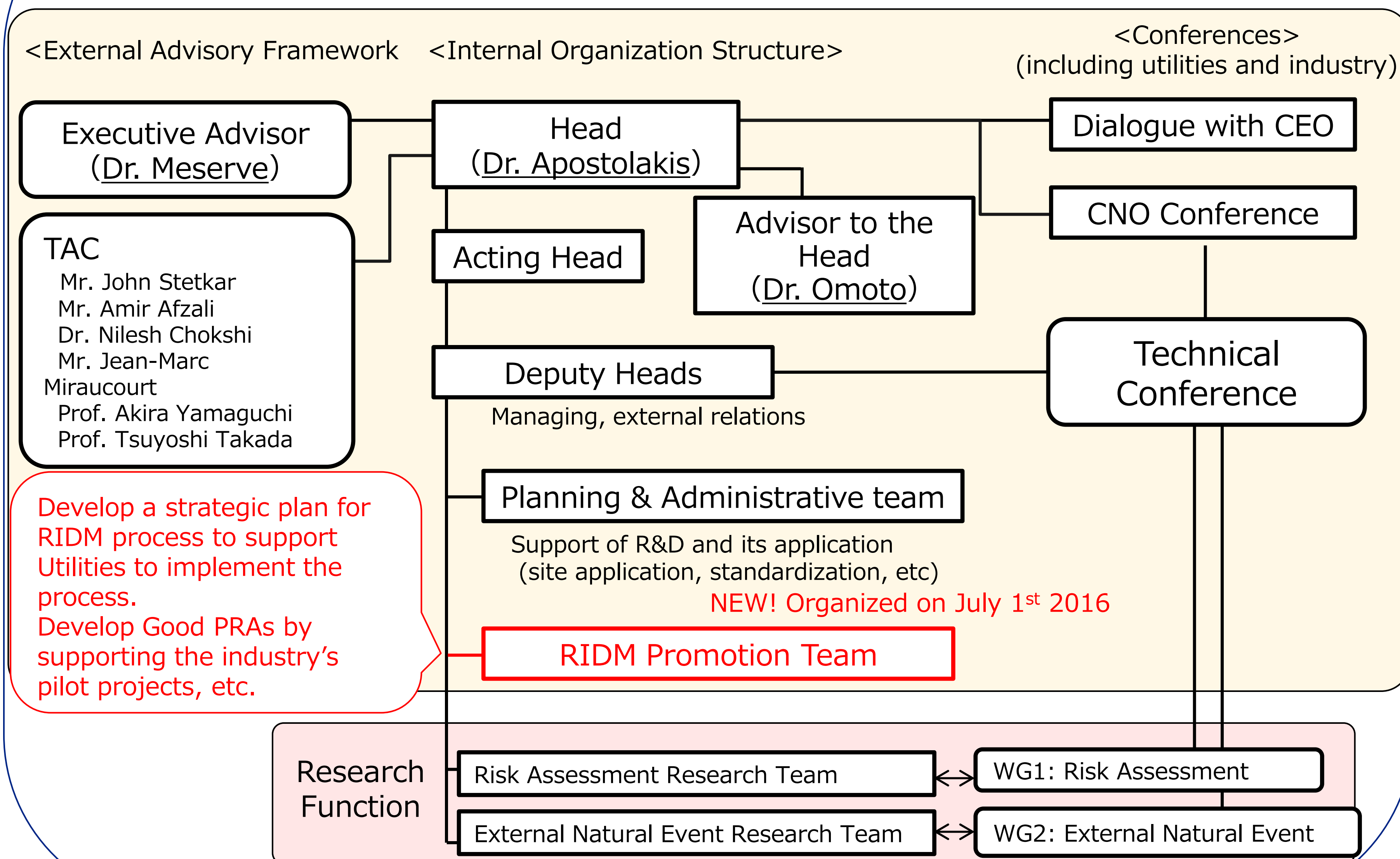
Vision Statement

To become an international center of excellence in PRA methodology and risk management methods, thereby gaining the trust of all the stakeholders.

NRRC Activities

- Position paper for proper application of RIDM in Japan
  - Establishment of RIDM Promotion Team
  - Pilot projects for establishing "Good" PRAs: Ikata Unit 3, Kashiwazaki-Kariwa Units 6 and 7
- White paper on RIDM applications in the U.S.A.
  - What was the motivation?
  - How can Japan benefit from the U.S. experience?
- Research projects
  - Human Reliability Analysis
  - Seismic PRA
    - ✓ SSHAC process for Ikata Unit 3 (Senior Seismic Hazard Analysis Committee)
  - Fire PRA
  - Volcano PRA

NRRC Organization



Summary

- **Decision making should be based on the current state of knowledge**
  - **PRA results are an essential part of this knowledge**
- **PRAs provide metrics that facilitate communication with the public**
- **PRAs consider a broader set of potential challenges to safety and prioritize these challenges based on risk significance (we can't do everything)**
  - **Challenge: Would the NRA be willing to relax requirements that are of low risk significance?**
- **RIDM allows more effective and efficient use of resources, thus improving safety indirectly**
- **NRRC is supporting the utilities to develop "Good" PRAs**