Safety Goals and Risk-Informed Regulation at the U.S. NRC

Commissioner George Apostolakis
U.S. Nuclear Regulatory Commission
CmrApostolakis@nrc.gov

Canadian Nuclear Safety Commission
Ottawa, Ontario, Canada
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Outline

- Early regulation at the U.S. NRC
- Introduction of probabilistic risk assessment (PRA)
- Development of safety goals
- Evolution of risk-informed regulation
- Examples of risk-informed regulation
- Current risk-informed initiatives
- Whole-site risk
- U.S. industry proposal

The Pre-PRA Era

- **Management of uncertainty (unquantified at the time) was always a concern.**
- **Defense in depth and safety margins became embedded in the regulations.**
- ***Design Basis Accidents* (DBAs) are postulated accidents that a nuclear facility must be designed and built to withstand without loss to the systems, structures, and components necessary to assure public health and safety.**

Some Problems

- 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

Technological Risk Assessment (Reactors)

- Probabilistic Risk Assessment (PRA) supports Risk Management by answering these questions
  - What can go wrong? (thousands of accident scenarios are investigated, as opposed to the limited number of DBAs)
  - How likely are these scenarios?
  - What are their consequences?
  - Which systems and components contribute the most to risk?

At Power Level I PRA Results

CDF = $4.5x10^{-5}$ / yr

Initiator Contribution to CDF Total:

- Internal Events…………………..56%
- External Events …………………..44%
  - Seismic Events 24%
  - Fires 18%
  - Other 2%

Reactor Safety Study (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: $5x10^{-5}$, once every 20,000 years; upper bound: $3x10^{-4}$ per reactor year, once every 3,333 years)
3. Consequences significantly smaller
4. Support systems and operator actions very important

History of NRC Safety Goals

- **1979: President's Commission on TMI Accident and NRC's special inquiry group recommended the Commission articulate its safety objectives**
- **1980: The Advisory Committee on Reactor Safeguards issued a report on Safety Goals**
- **1983: Commission published a draft safety goal policy statement to be evaluated for two years**
  - **The Commission was divided and the Chairman held one-on-one meetings to get the safety goals approved with two of the Commissioners abstaining**
- **1986: The NRC Safety Goals were published**
  - **For the first time, the NRC defined "How safe is safe enough"**

Qualitative Safety Goals

- Individual members of the public should be provided protection from the consequences of nuclear power plant operation such that individual bear no signification additional risk to life or health

- Societal risks to life and health from nuclear power plant operation should be comparable to or less than the risks of generating electricity by viable competing technologies and should not be a significant addition to other societal risks

Quantitative Health Objectives

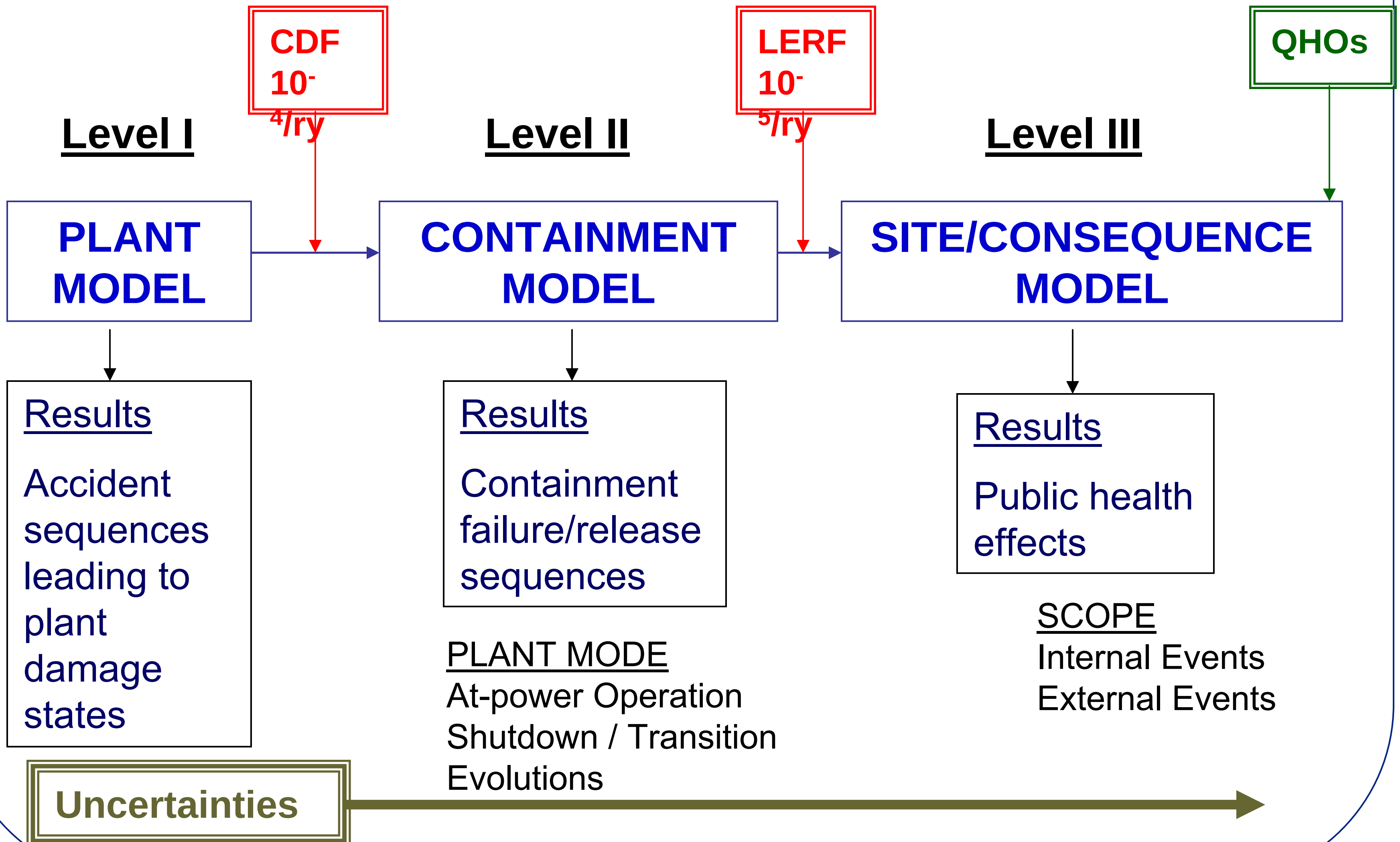
- **The risk to an average individual in the vicinity of a nuclear power plant of prompt fatalities that might result from reactor accidents should not exceed 0.1 percent of the sum of prompt fatality risks resulting from other accidents to which members of the U.S. population are generally exposed (approximately 5×10^{-7}/year)**

- **The risk to the population in the area of a nuclear power plant of cancer fatalities that might result from nuclear power plant operation should not exceed 0.1 percent of the sum of cancer fatality risks resulting from all other causes (approximately 2×10^{-6}/year)**

•The prompt fatality goal applies to an average individual living in the region between the site boundary and 1 mile beyond this boundary.

•The latent cancer fatality goal applies to an average individual living in the region between the site boundary and 10 miles beyond this boundary.

PRA Model Overview and Subsidiary Objectives



PRA Policy Statement (1995)

- The use of PRA should be increased to the extent supported by the state of the art and data and in a manner that complements the defense-in-depth philosophy

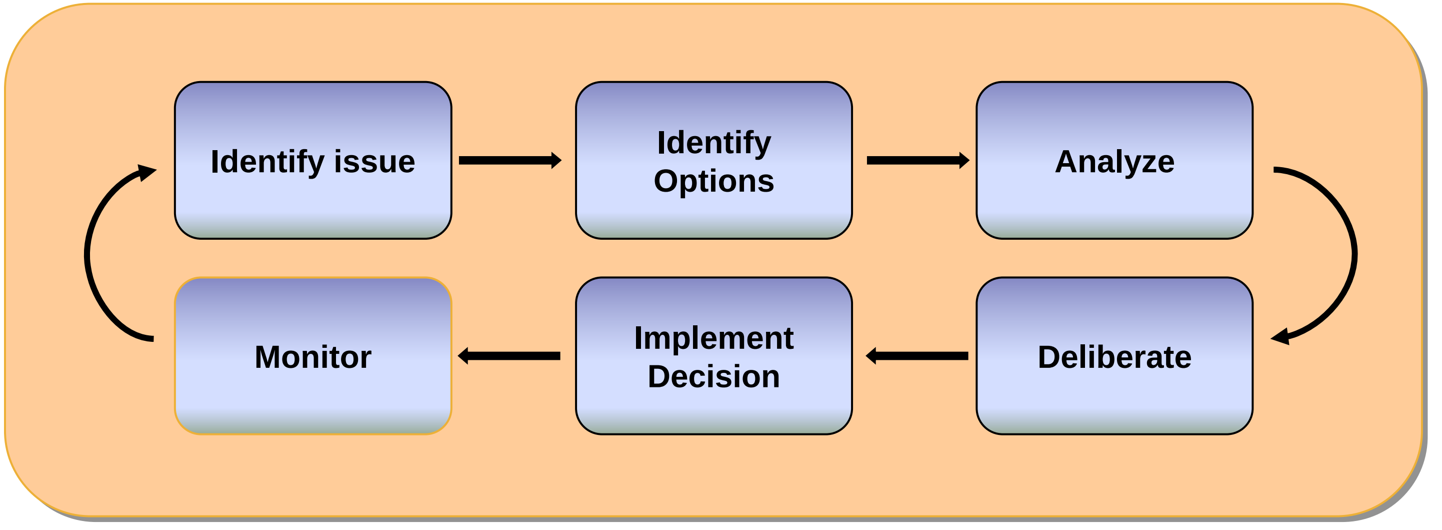
- PRA should be used to reduce unnecessary conservatisms associated with current regulatory requirements

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 Decision-Making Process



NUREG-2150

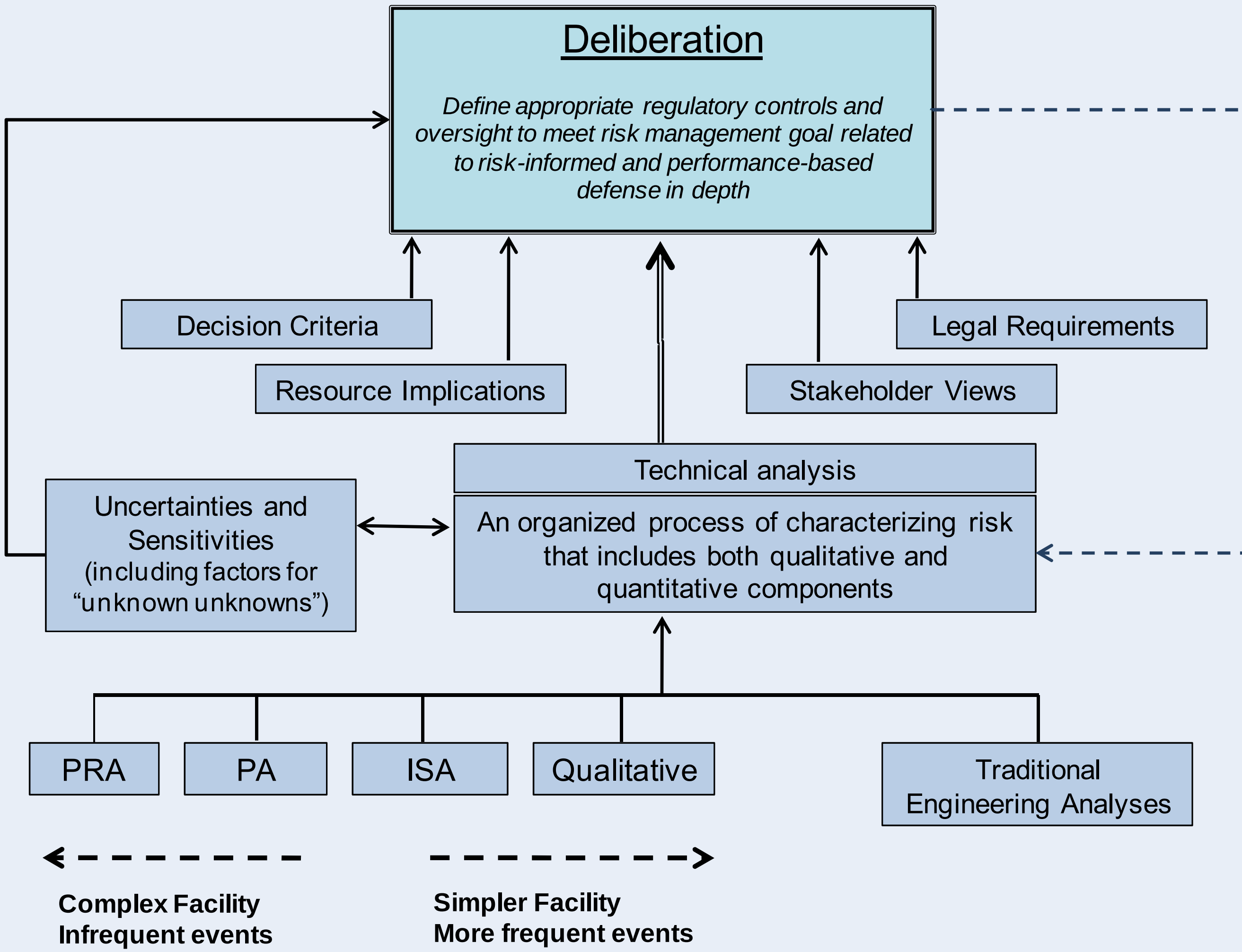
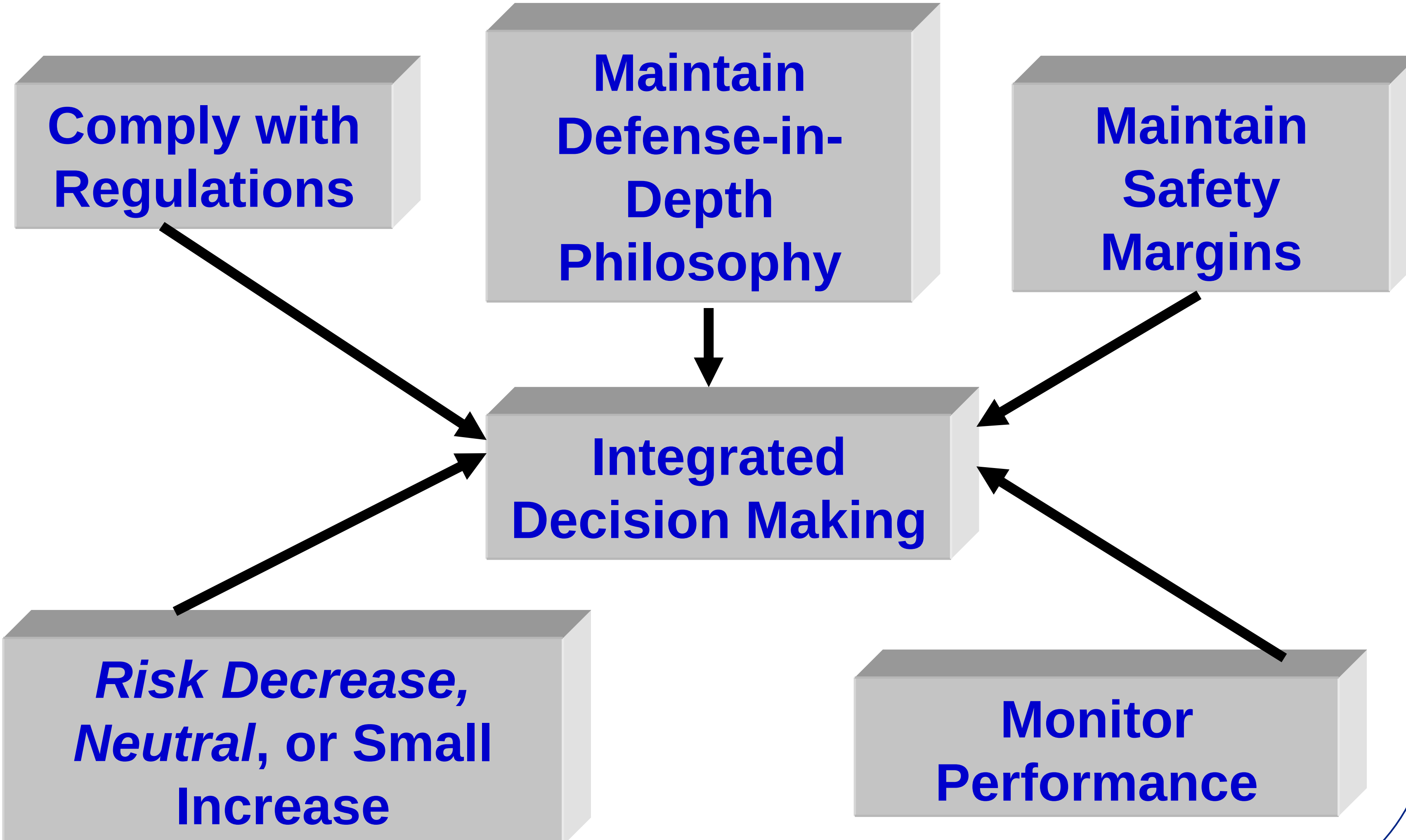


Figure B-4 Technical Analysis Techniques & Deliberation

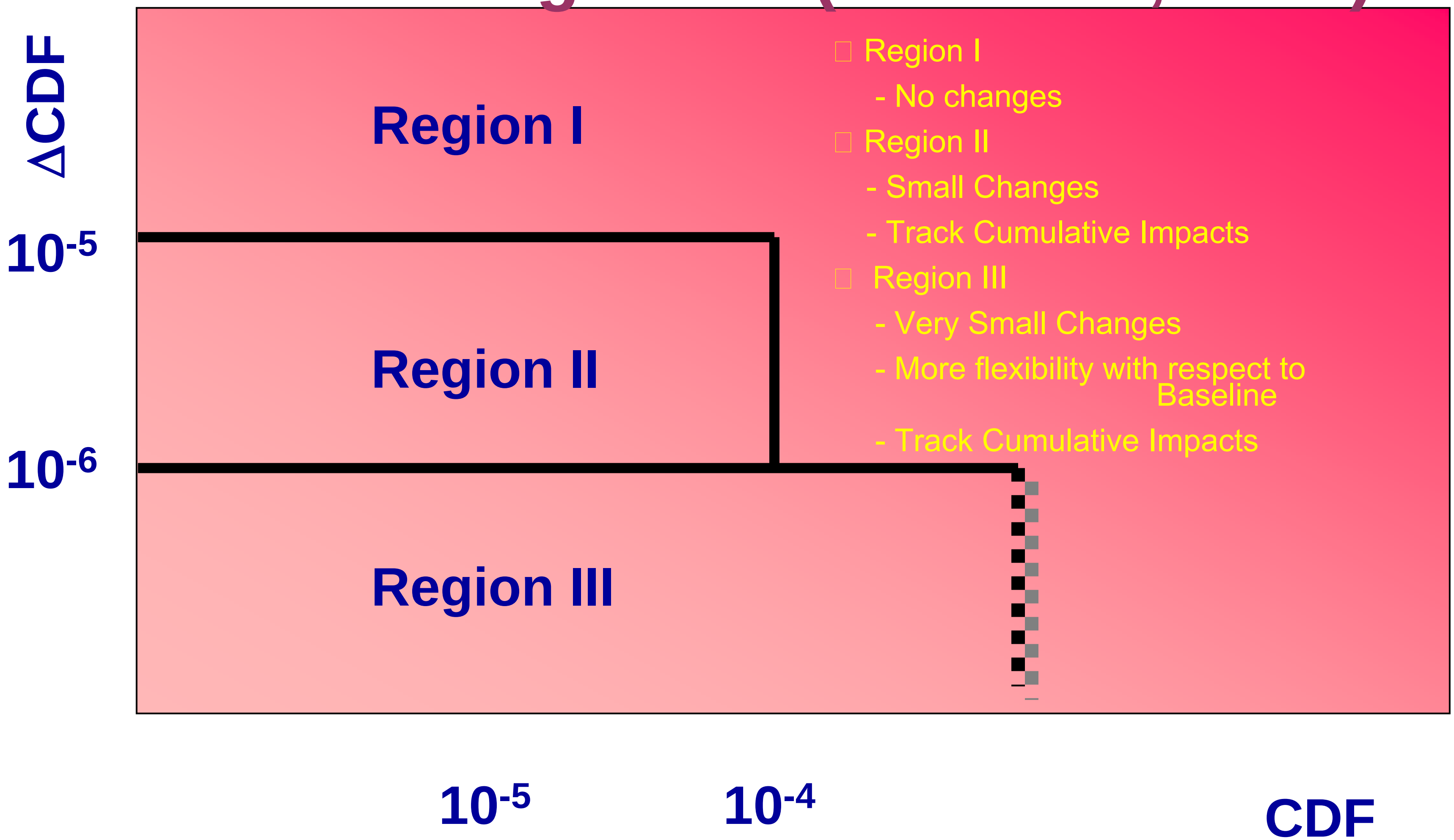
Evolution of the Risk-Informed Regulatory System

- Regulatory Requirements
  - ATWS Rule (1984)
  - Station Blackout Rule (1988)
  - Maintenance Rule (1991)
- Risk-Informed Changes to the Licensing Basis
  - Regulatory Guide (RG) 1.174 (1998)
  - Technical Specification Improvement Initiatives
  - Risk-Informed Inservice Inspection
  - Special Treatment/Categorization (“Graded QA”)
- Reactor Oversight Process (2000)
- Fire Protection (2004)
- New Reactor Licensing (2007)

Risk-Informed Changes to the Licensing Basis (RG 1.174; 1998)



Risk-Informed Changes to the Licensing Basis (RG 1.174; 1998)



Acceptance Guidelines for Core Damage Frequency

ASME BPVC Section XI Requirements

- Class 1 piping systems: 25% welds examined every 10-year interval
- Class 2 piping systems: 7.5% welds examined every 10-year interval
- Class 3 piping systems: Only pressure test for leakage every 10-year interval

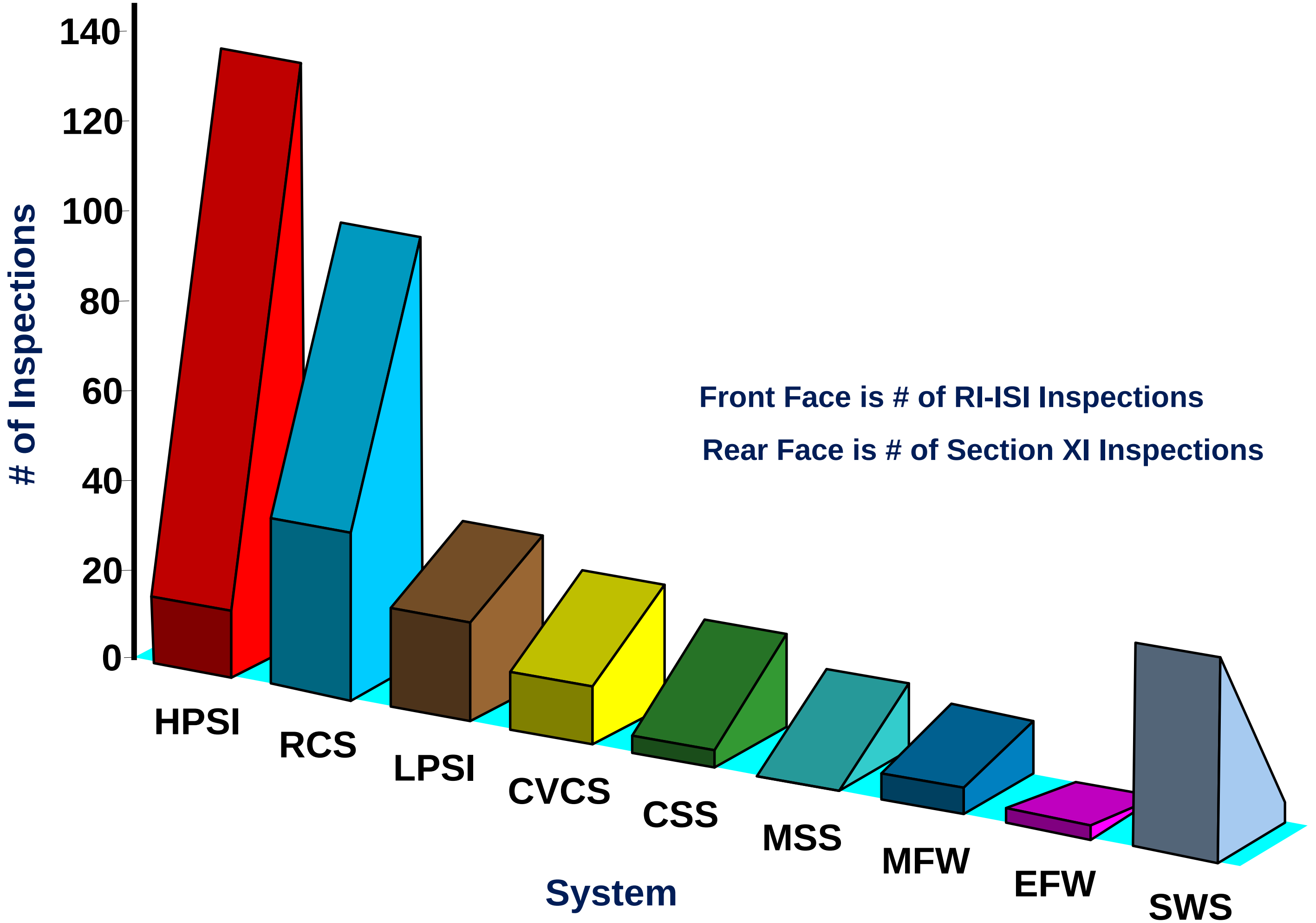
Risk Evaluation Matrix

CONSEQUENCE CATEGORY
(Safety Significance)

DEGRADATION CATEGORY (Pipe Rupture Potential)

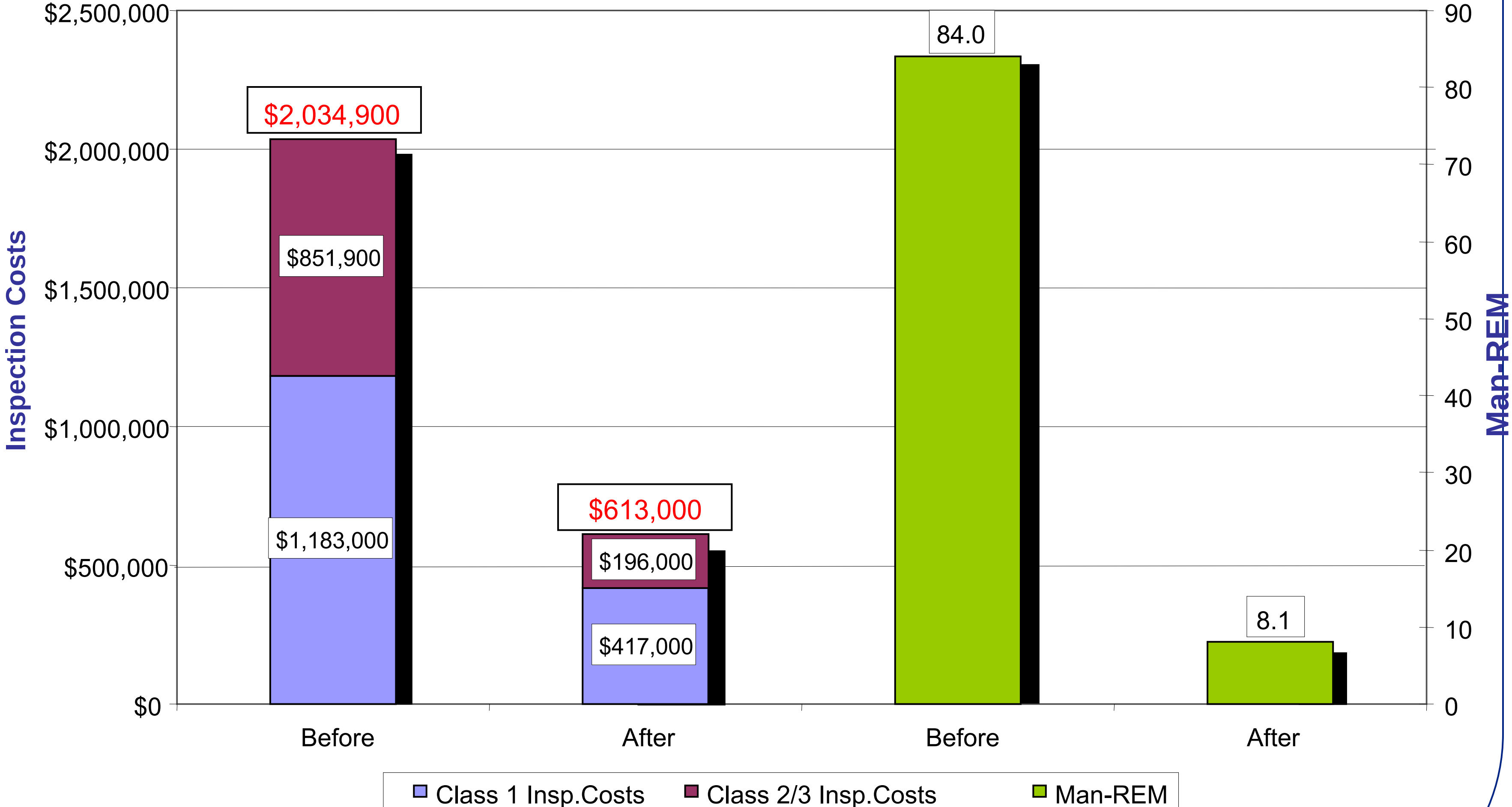
	NONE	LOW	MEDIUM	HIGH
HIGH	LOW (Cat. 7)	MEDIUM (Cat. 5)	HIGH (Cat. 3)	HIGH (Cat. 1)
MEDIUM	LOW (Cat. 7)	LOW (Cat. 6)	MEDIUM (Cat. 5)	HIGH (Cat. 2)
LOW	LOW (Cat. 7)	LOW (Cat. 7)	LOW (Cat. 6)	MEDIUM (Cat. 4)

Plant X: Number of Inspections Before and After



V. Dimitrijevic, MIT Lecture, 2008

Cost and Man-Rem Savings



V. Dimitrijevic, MIT Lecture, 2008

Benefits of Risk-Informed Regulation

- **Improves Safety**
  - New requirements (SBO, ATWS)
  - Design of new reactors
  - Focus on important systems and locations
- **Makes regulatory system more rational**
  - Reduction of unnecessary burden
  - Operating experience accounted for in regulations
  - Consistency in regulations
- **Encourages performance-based regulation**
  - Maintenance rule
  - Fire protection
  - Determination of seismic design basis motion

Role of Safety Goals in Regulatory Analysis (1)

- **Safety Goal Screening**
  - Intended to eliminate some proposed requirements from further consideration because the residual risk is already acceptably low
  - Compare reduction in CDF to Subsidiary Goal for CDF of 10^{-4} per reactor-year

Estimated Reduction in CDF	Staff Action
> 10^{-4} per reactor-year	Proceed with the regulatory analysis on a high-priority basis
10^{-4} – 10^{-5} per reactor-year	The decision whether to proceed with the regulatory analysis is to be made by the responsible division director*
< 10^{-5} per reactor-year	Terminate further analysis unless the office director decides otherwise based upon strong engineering or qualitative justification*

*Decision to proceed affected by probability of containment failure

Role of Safety Goals in Regulatory Analysis (2)

- Commission is considering a policy issue related to spent fuel storage in pools vs. dry casks
- NRC staff compared results to the QHO for latent cancer fatality risk
  - Cancer fatality QHO represents a $2x10^{-6}$ per year objective for an average individual within 16 km (10 mi) of the plant
    - NRC staff assessed the criterion based on recent cancer rate data and developed an updated safety goal of $1.84x10^{-6}$ per year
  - NRC staff developed a conservative high estimate of individual latent cancer fatality risk from a SFP accident of $1.52x10^{-8}$ cancer fatalities per year
  - This is less than one percent of the $1.84x10^{-6}$ per year societal risk goal value
- It is unclear whether the Commission explicitly considered risk from a spent fuel pool accident when it established the safety goals

Risk Management Task Force (RMTF)

- **Task Force formed in February 2011**
- **Charter**

> ***"To develop a strategic vision and options for adopting a more comprehensive and holistic risk-informed, performance-based regulatory approach for reactors, materials, waste, fuel cycle, and transportation that would continue to ensure the safe and secure use of nuclear material."***

Fukushima Near-Term Task Force Recommendation 1

- **Establish a logical, systematic, and coherent regulatory framework for adequate protection that appropriately balances defense in depth and risk considerations**

- **NRC staff made its recommendations to the Commission in December 2013**

A Proposed Risk Management Regulatory Framework

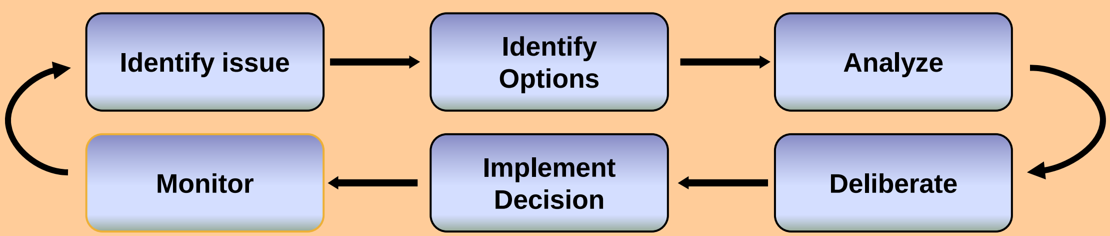
Mission
Ensure adequate protection of public health and safety, promote the common defense and security, and protect the environment

Objective
Manage the risks from the use of byproduct, source and special nuclear materials through appropriate performance-based regulatory controls and oversight

Risk Management Goal
Provide risk-informed and performance-based defense-in-depth protections to:

- Ensure appropriate barriers, controls, and personnel to prevent, contain, and mitigate exposure to radioactive material according to the hazard present, the relevant scenarios, and the associated uncertainties; and
- Ensure that the risks resulting from the failure of some or all of the established barriers and controls, including human errors, are maintained acceptably low

Decision-Making Process
Use a disciplined process to achieve the risk management goal:



Initiative to Improve Nuclear Safety and Regulatory Efficiency

- In early 2013, the Commission directed NRC staff to develop approaches for allowing licensees to propose prioritization of the implementation of regulatory actions as an integrated set and in a way that reflects their risk significance on a plant-specific basis

- Proposal would require licensees to have site-specific Level 1 and 2 PRAs addressing all initiating events (including natural hazards) and plant modes as supported by NRC endorsed consensus standards

- Prioritization would be done in a risk-informed manner, including considerations such as defense-in-depth, particularly for issues where probabilistic methods have not been sufficiently developed (e.g., external flooding hazards)

Whole-Site Risk: Early Consideration

- In the early 1980s, staff proposed that Safety Goals be applied on a per-site basis
- Commission decided not to impose a bias against multi-unit sites
- Quantitative Health Objectives are now interpreted on a per-reactor basis

Whole-Site Risk Today: NRC's Level 3 PRA Project

- In September 2011, the Commission directed NRC staff to perform a full-scope site Level 3 PRA
- Why perform a full-scope site Level 3 PRA?
  - NRC last sponsored a Level 3 PRA in late 1980s (NUREG-1150)
  - NUREG-1150 only focused on single reactor unit risk
  - Numerous technical advances have occurred since completion of NUREG-1150
  - New full-scope site Level 3 PRA could yield new and improved risk insights and re-baseline NRC's understanding of nuclear power plant risk

Level 3 PRA Project Scope

- **Full-Scope Site Level 3 PRA**
  - All site radiological sources (all reactor cores, spent fuel pools, and dry storage casks on site)
  - All internal and external hazards
  - All modes of reactor operation
  - Excludes radiological sources involving fresh nuclear fuel, radiological waste, and minor radiological sources (e.g., calibration devices) and initiating events involving malevolent acts
- **Excludes some aspects for which there is no current state of practice (e.g., software failure and aging)**
- **Study will be for a single multi-unit site**

Nuclear Energy Institute letter dated December 19, 2013: “Industry Support and Use of PRA and Risk-Informed Regulation”

Stage	Timeframe	Objectives
Stage 1 – Resolve problems with fire PRAs and NFPA 805	2014	1. Provide for use of more realistic fire PRA methods and a more efficient and predicable regulatory process.
Stage 2 – Characterization of Site Risk Drivers	2014 - 2015	1. Provide foundation for reactor safety prioritization 2. Identify fleet-wide risk drivers to support generic prioritization and decision-making 3. Document (best understanding of) important risk contributors for each reactor site
Stage 3 – Identification of Site-specific Risk Insights	2014 - 2016	1. Identify site-specific risk insights for consideration in prioritization 2. Provide a consistent basis for decision-making on the need for more detailed quantification of dominant risk contributors
Stage 4 – Characterization of Dominant Risk Contributors	2015 - 2019	1. Obtain detailed, site-specific understanding of dominant risk contributors

Lord Kelvin

"I often say that when you can measure what you are speaking about, and express it in numbers, you know something about it; but when you cannot measure it, when you cannot express it in numbers, your knowledge is of a meager and unsatisfactory kind."