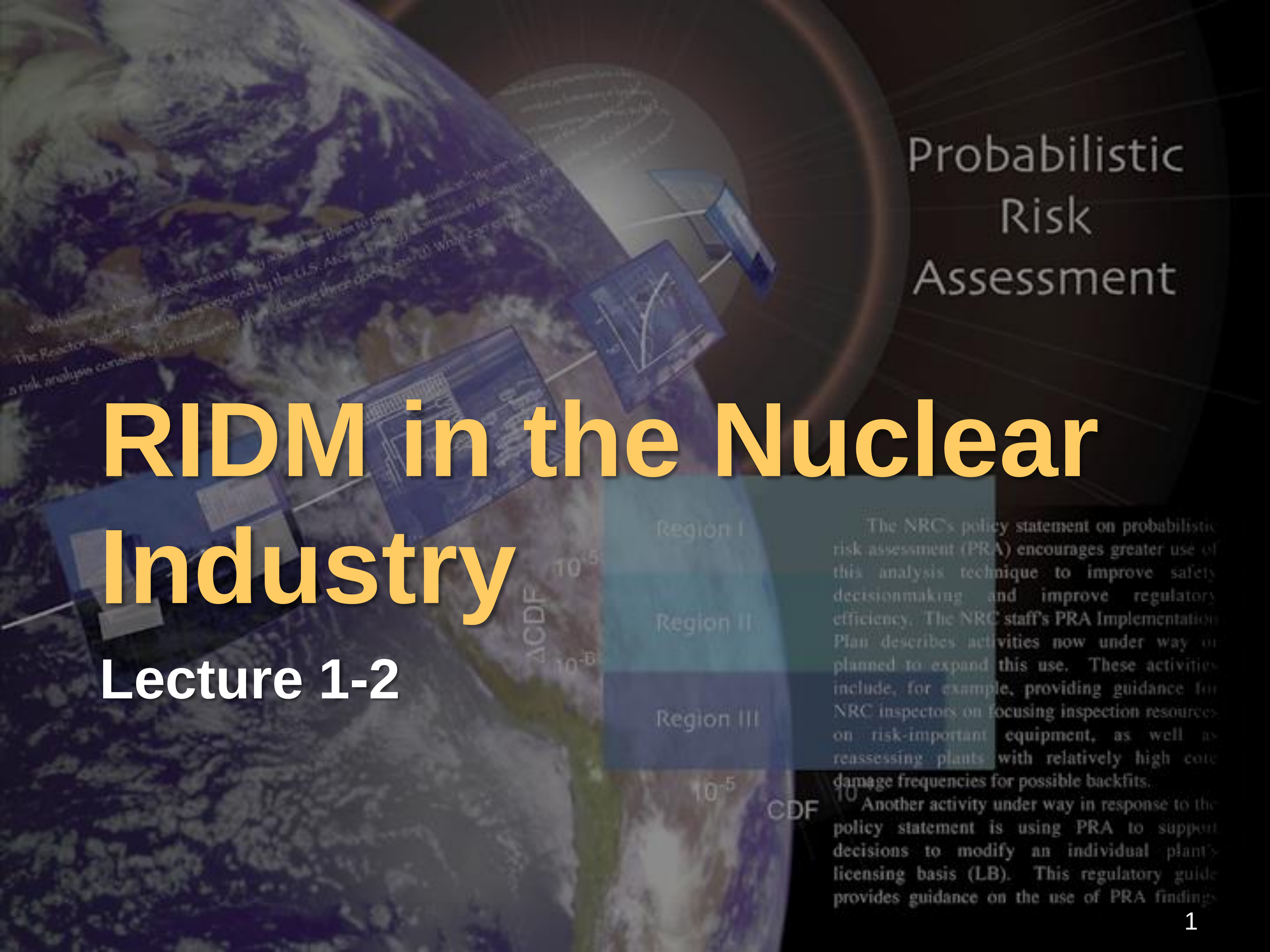

RIDM in the Nuclear Industry

Lecture 1-2

Key Topics

- Range of stakeholders and perspectives
- Key policy drivers for risk-informed regulation
- Range and types of risk-informed applications
- General characteristics of nuclear power plant (NPP) risk-informed decision making (RIDM)
- General characteristics of NPP probabilistic risk assessment (PRA) and role in RIDM

Resources

- U.S. Nuclear Regulatory Commission, “Use of Probabilistic Risk Assessment Methods in Nuclear Activities; Final Policy Statement,” *Federal Register, Vol. 60*, p. 42622 (60 FR 42622), August 16, 1995.
- N. Siu, et al., “Probabilistic Risk Assessment and Regulatory Decisionmaking: Some Frequently Asked Questions,” *NUREG-2201*, U.S. Nuclear Regulatory Commission, September 2016.
- Organisation for Economic Co-operation and Development, “Use and Development of Probabilistic Safety Assessment: An Overview of the Situation at the End of 2010”, *NEA/CSNI/R (2012)11*, Nuclear Energy Agency, Paris, France, 2012, (Available from: http://www.oecd-nea.org/nsd/docs/indexcsni.html)
- U.S. Nuclear Regulatory Commission, “An Approach for Using Probabilistic Risk Assessment in Risk-Informed Decisions on Plant-Specific Changes to the Licensing Basis,” *Regulatory Guide 1.174, Revision 3*, January 2018. (ADAMS ML17317A256)

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Other References

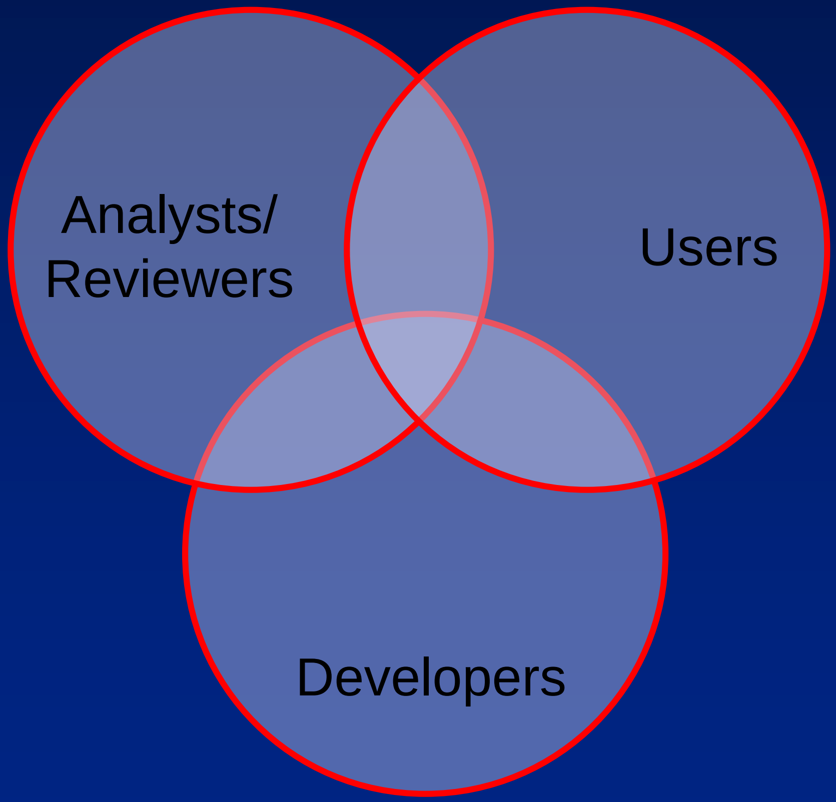
- U.S. Nuclear Regulatory Commission, “Safety Goals for the Operation of Nuclear Power Plants; Policy Statement; Correction and Republication,” *Federal Register, Vol. 51*, p. 30028 (51 FR 30028), August 21, 1986.
- U.S. Nuclear Regulatory Commission, “Risk-Informed Activities” https://www.nrc.gov/about-nrc/regulatory/risk-informed/rpp.html
- K. A. Coyne, “Risk-Informed Regulation at the U.S. Nuclear Regulatory Commission,” April 14, 2016. (ADAMS ML16105A427)
- U.S. Nuclear Regulatory Commission, “Integrated Risk-Informed Decision-Making Process for Emergent Issues,” Office of Nuclear Reactor Regulation Office Instruction *LIC-504, Revision 4*, June 2, 2014. (ADAMS ML14035A143)
- F.E. Haskin, A.L. Camp, S.A. Hodge, and D.A. Powers, “Perspectives on Reactor Safety,” *NUREG/CR-6042, Revision 2*, March 2002.

Stakeholders in NPP RIDM - Organizational

- Stakeholders can:
  - have a role (including support) in decision making process
  - be affected by decisions
- Stakeholder roles, beliefs, and backgrounds, can affect views on risk assessment as well as views on the appropriate use of risk information in support of decision making

- Industry
- Regulators
- Other Government Agencies
- Technical Support Organizations
- Consensus Standards Organizations
- International Organizations
- Academia
- Non-Governmental Organizations
- General Public

Stakeholders in NPP RIDM - Functional



External Flooding : A Really Big Picture

- Sparse data and concerns with extrapolation => mechanistic analysis
- Daunting scale
  - Regional analysis
  - Human actions
  - Besides flooding level: duration, debris, dynamic forces, warning time
  - Multi-site impacts
- “Good enough” can vary across organizations

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Policy Driver: Safety Goal Policy Statement (1986)

- "How safe is safe enough?"
- Qualitative health objectives
  - Individuals should bear no significant additional risk
  - Societal risks should be ≤ risks from other generating technologies, should not be a significant addition to other societal risks
- Quantitative health objectives (QHOs)
  - Prompt fatality risk for an average, nearby individual < 0.1% risks from all other accidents
  - Cancer fatality risk for population in area) < 0.1% cancer fatality risks from all other causes
- Surrogate risk measures
  - Prompt fatality: LERF < 10^{-5}/ry
  - Latent cancer: CDF < 10^{-4}/ry

Policy Driver: PRA Policy Statement (1995)

- Policies:
  - Increase use of PRA technology to the extent supported by the state of the art and data.
  - Complement deterministic approach, support defense-in-depth philosophy
  - Reduce unnecessary conservatism, support additional requirements as appropriate
  - Analyses should be as realistic as practicable; data should be publicly available for review
  - Consider uncertainties when using the Commission's Safety Goals and subsidiary objectives
- Expected Benefits:
  - (1) Considers broader set of potential challenges
  - (2) Helps prioritize challenges
  - (3) Considers broader set of defenses

RIDM – NRC Examples

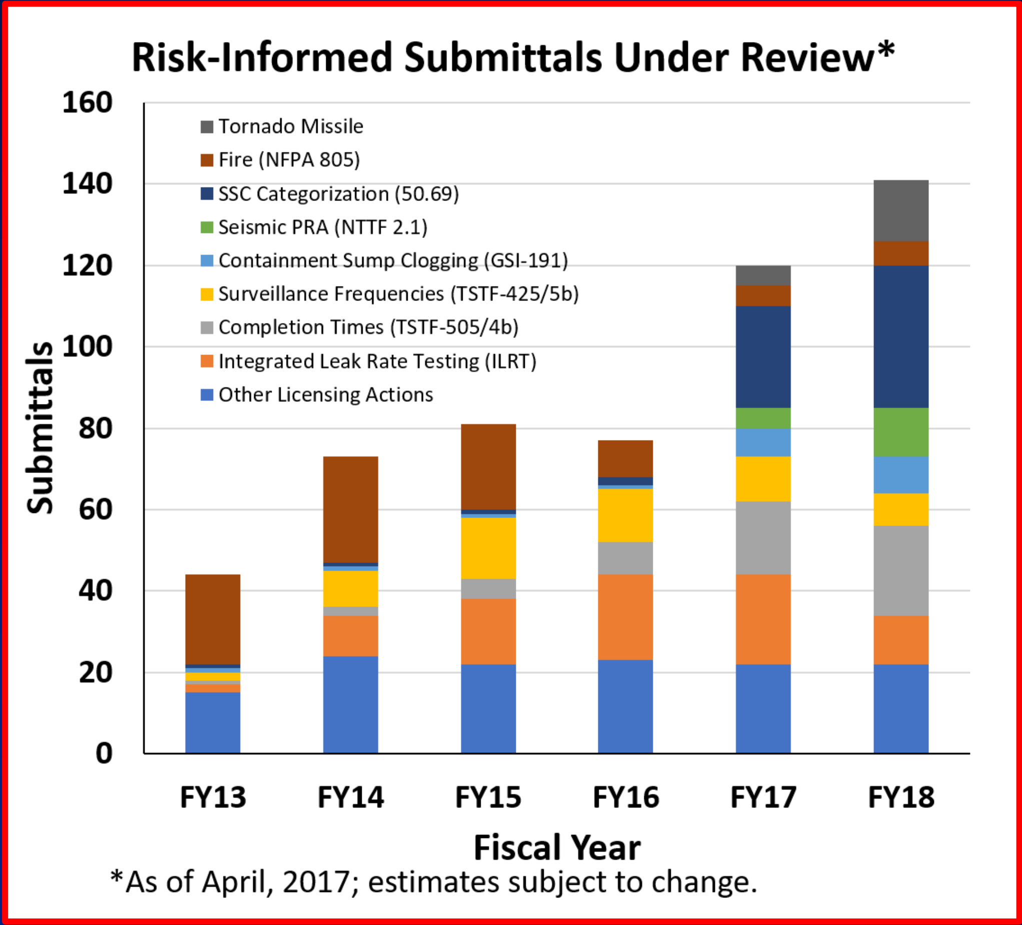
10 CFR 50.65, "Maintenance Rule" (1991)

- Rule
  - Requires monitoring of in-scope SSC performance to identify and address maintenance related issues
  - **Paragraph "(a)(4)" requires licensees to assess and manage the increase in risk that may result from the proposed maintenance activities**
- Risk-informed and performance-based
- Outcome: widely viewed as a success
  - NEI: Improved equipment reliability and plat performance
  - UCS: "focus necessary resources on today's problems so as to prevent them from becoming tomorrow's disaster"*

*See https://allthingsnuclear.org/dlochbaum/nrcs-nuclear-maintenance-rule

Changes in Plant Licensing Basis (RG 1.174)

- Voluntary changes: licensee requests, NRC reviews
- Small risk increases may be acceptable
- Change requests may be combined
- Decisions are risk-informed



Reactor Oversight Program

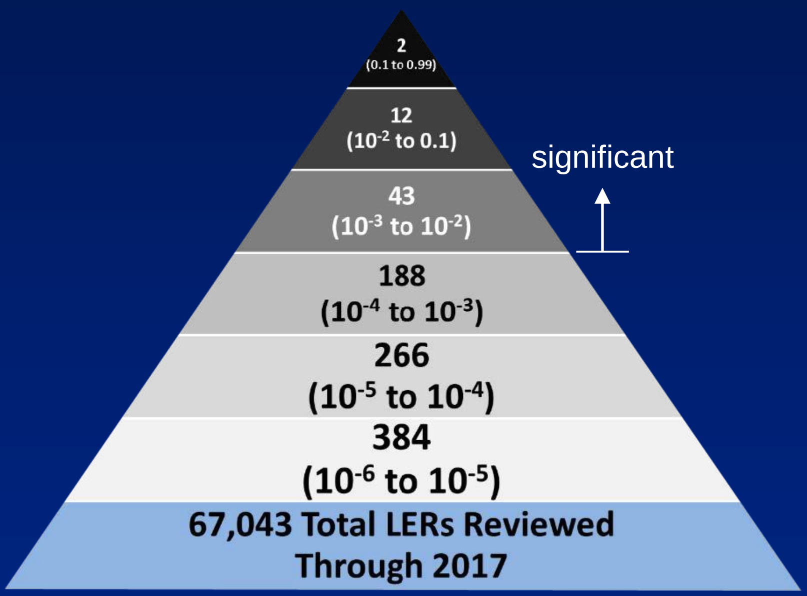
- Inspection planning
- Determining significance of findings
  - Characterize performance deficiency
  - Use review panel (if required)
  - Obtain licensee perspective
  - Finalize
- Performance indicators

ΔCDF < 1E-6 **ΔLERF < 1E-7**
1E-6 < ΔCDF < 1E-5 **1E-7 < ΔLERF < 1E-6**
1E-5 < ΔCDF < 1E-4 **1E-6 < ΔLERF < 1E-5**
ΔCDF > 1E-4 **ΔLERF > 1E-5**

CDF = Core damage frequency
LERF = Large early release frequency

Accident Sequence Precursor Program

- Program recommended by WASH-1400 review group (1978)
- Provides risk-informed view of nuclear plant operating experience
  - Conditional core damage probability (events)
  - Increase in core damage probability (conditions)
- Supported by plant-specific Standardized Plant Analysis Risk models



Licensee Event Reports 1969-2017
(No significant precursors since 2002)

I. Gifford, C. Hunter, and A. Gilbertson, "U.S. Nuclear Regulatory Commission Accident Sequence Precursor Program: 2017 Annual Report," May 2018. (ADAMS ML18130A856)

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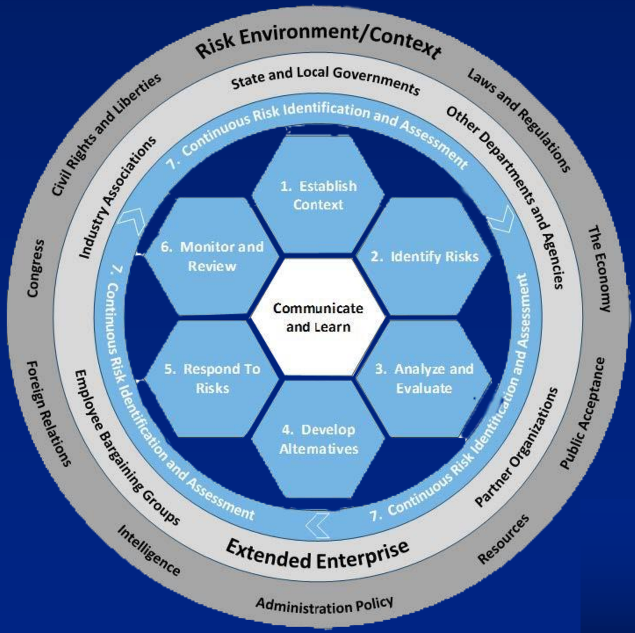
NPP RIDM – Industry Examples

- Risk-informed Licensing Amendment Requests (LARs)
- Severe Accident Mitigation Alternatives (SAMA)
- Outage planning
- Enterprise Risk Management
- Advanced reactor designs



OMB Circular A-123, 2016

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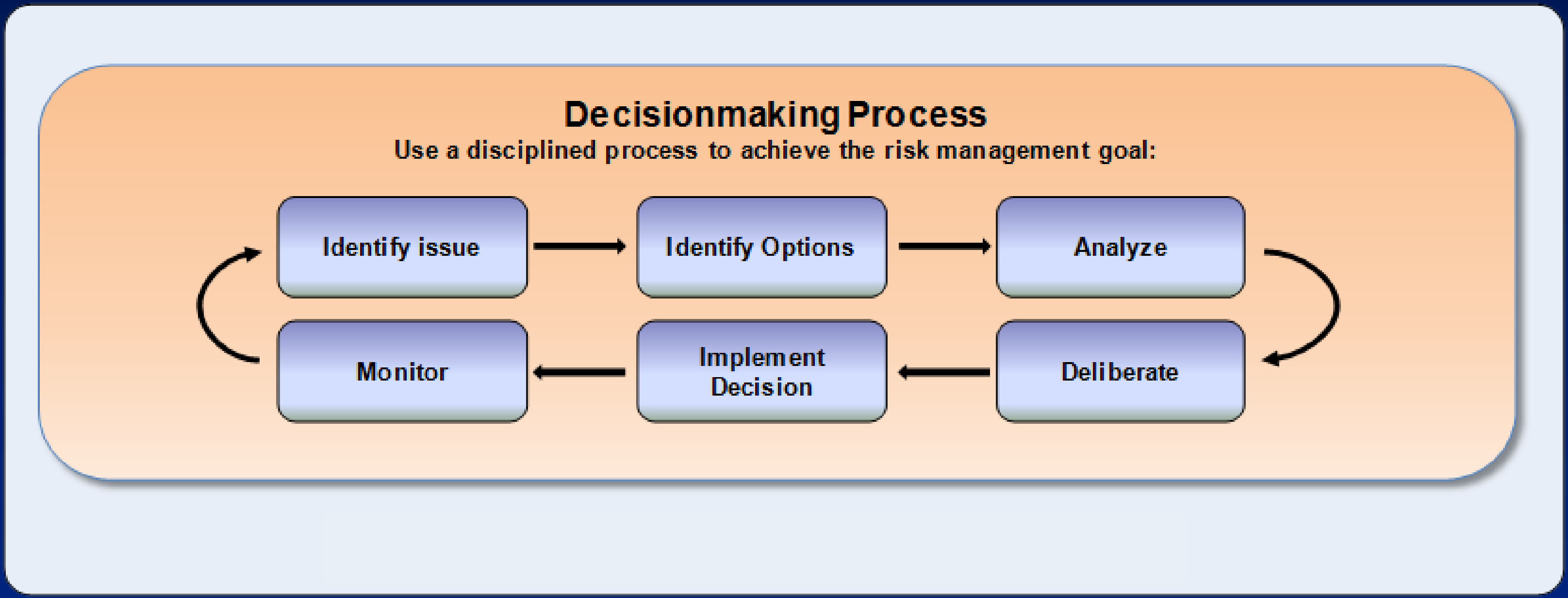
NPP RIDM – International Examples

- Periodic Safety Reviews
- Plant improvements
- Demonstrating acceptable safety levels

RIDM Process



NUREG-2150

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Licensing Basis Changes – RG 1.174

Change meets current regulations unless it is specifically related to a requested exemption

Change is consistent with defense-in-depth philosophy

Maintain sufficient safety margins

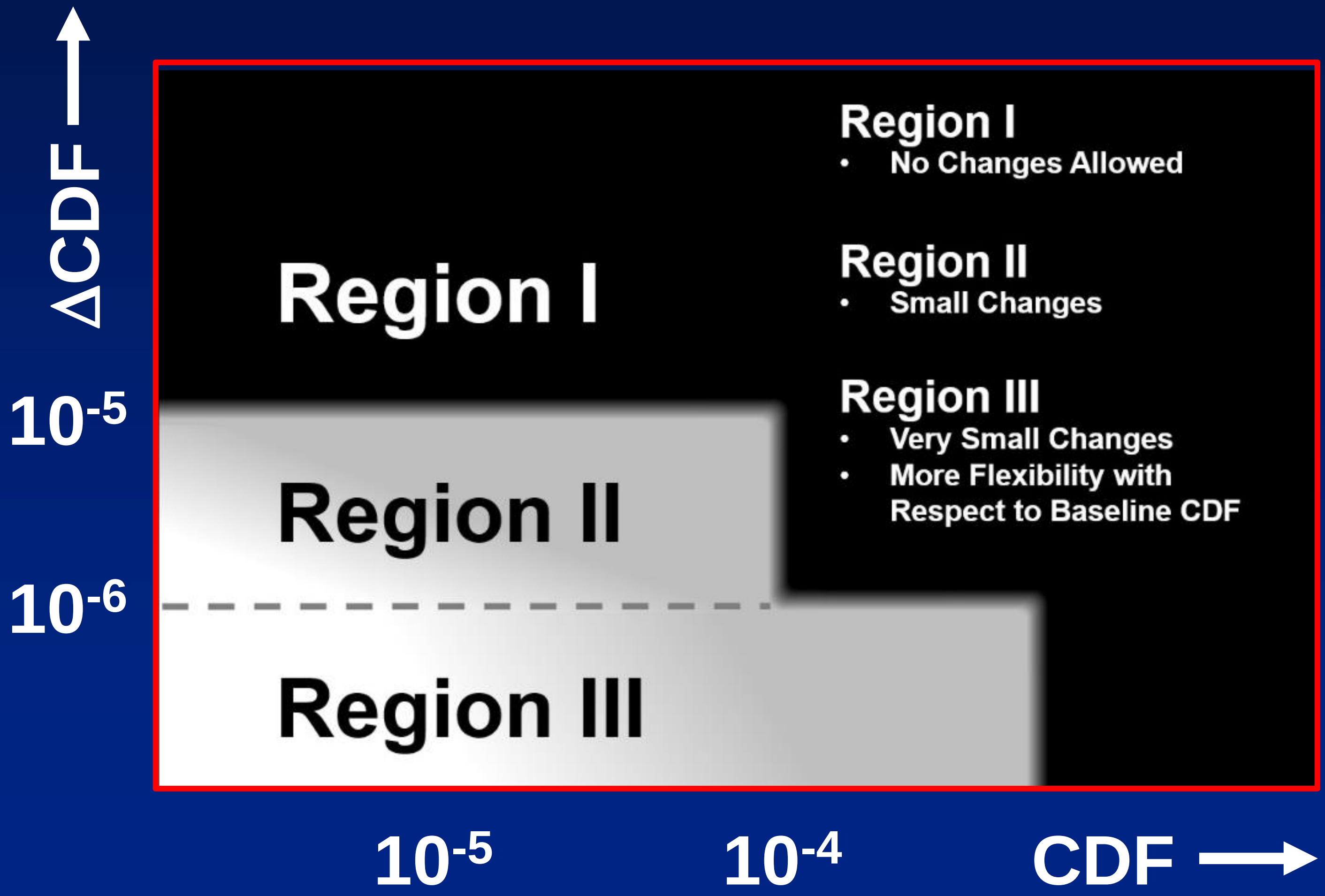
Integrated Decision Making

Use performance measurement strategies to monitor change

Proposed changes in risk are small and are consistent with the Commission's Safety Goal Policy Statement

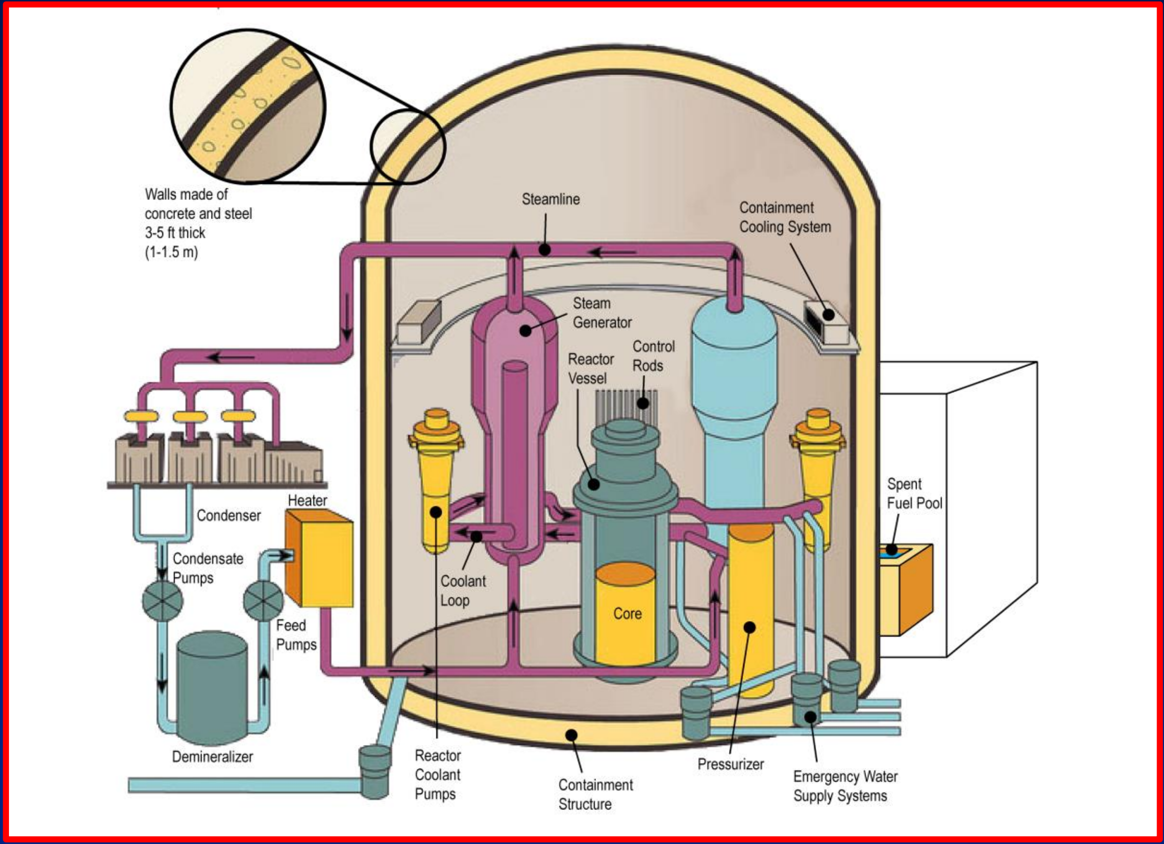
U.S. Nuclear Regulatory Commission, "An Approach for Using Probabilistic Risk Assessment in Risk-Informed Decisions on Plant Specific Changes to the Licensing Basis," Regulatory Guide 1.174, Revision 3, 2018.

CDF Acceptance Guidelines – RG 1.174



Nuclear Design 101: How Things Work

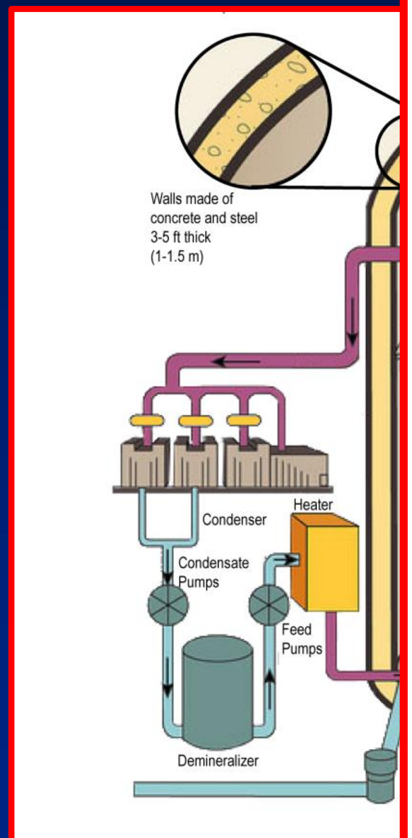
- Nuclear fission → heat → steam → electricity
- Chain reaction controlled/stopped by control rods
- Heat generation continues after chain reaction is stopped ("decay heat")

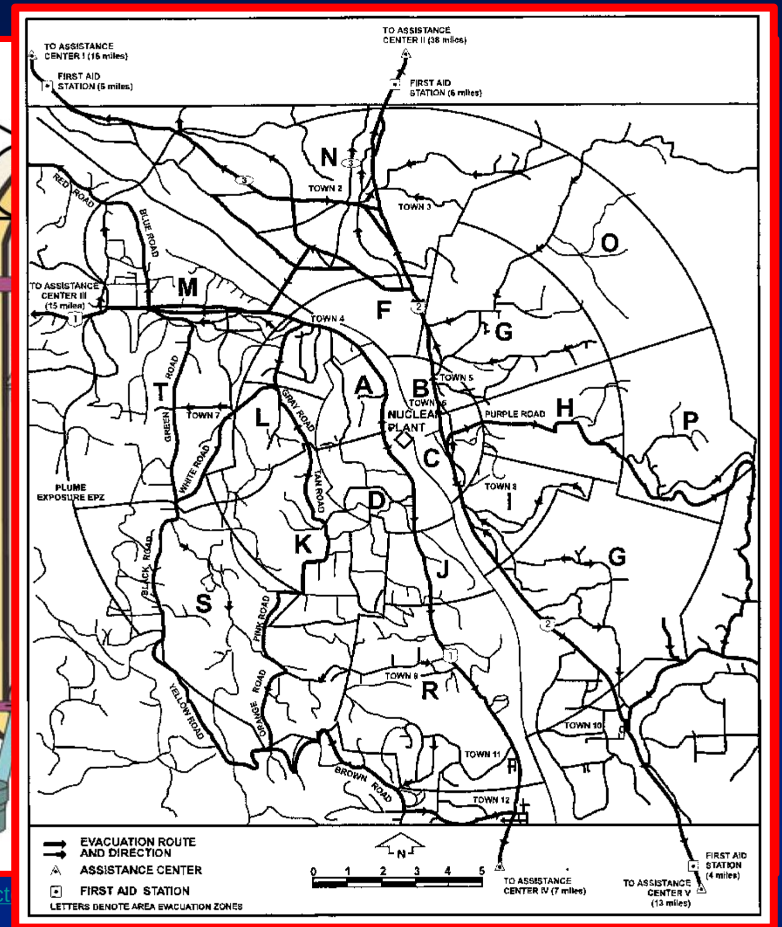


Adapted from: https://www.nrc.gov/reactors/pwrs.html

Nuclear Power Plant Design Features

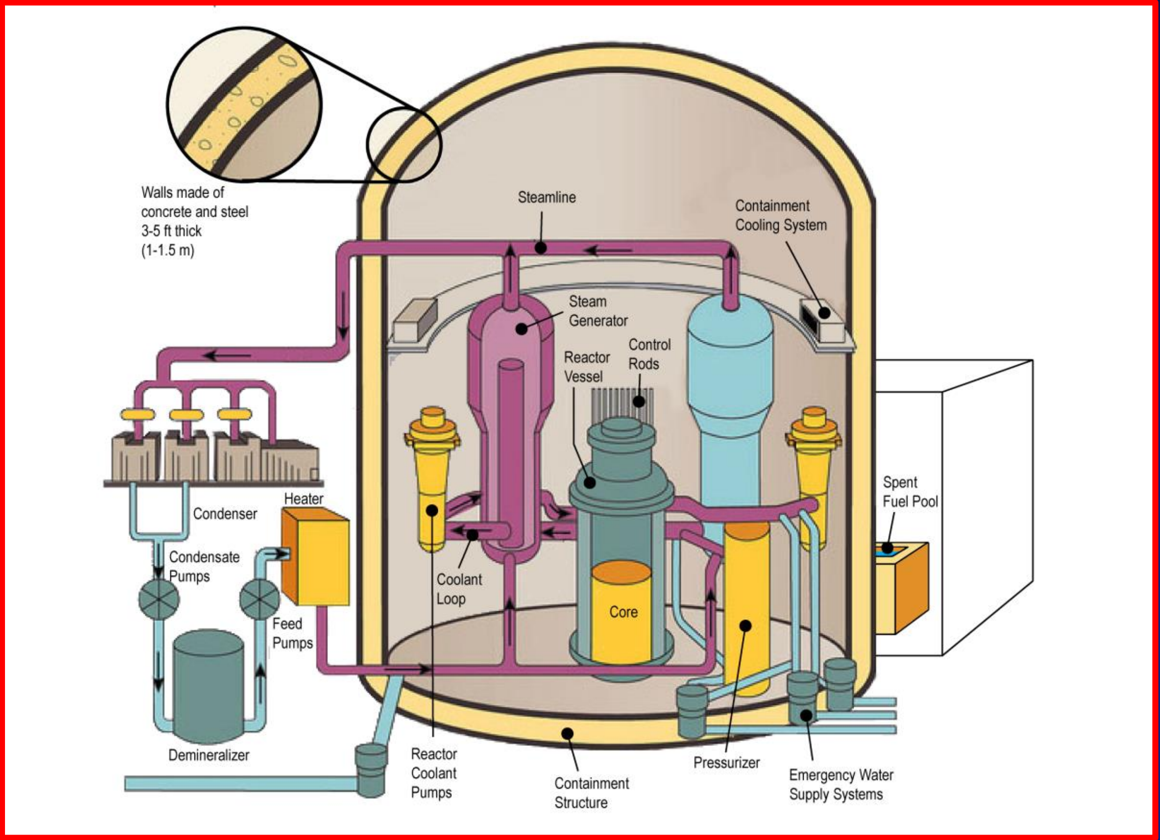
- General Design Criteria (10 CFR Part 50, Appendix A)
- Key safety principles
  - Defense-in-depth
  - Single failure criterion and redundancy
  - Diversity
- Robust structures, separation





Adapted from: https://www.nrc.gov/react

Core Damage Frequency (CDF)



Adapted from https://www.nrc.gov/reactors/pwrs.html

From NUREG-2122:

Core Damage: Sufficient damage that could lead to a release of radioactive material from the core that could affect public health.

Frequency: The expected number of occurrences of an event or accident condition expressed per unit of time.*

*Lecture 3-1 will provide a more precise mathematical definition.

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Analysis Challenges and Implications

- Multiple safety systems and barriers (physical and operational) => multiple failures required to cause core damage => need to treat large numbers of possible combinations of events
- Empirical data are sparse => need to bring in other forms of evidence (e.g., model predictions, expert judgments)
- Accidents generally involve multiple phenomena => need to integrate multiple technical disciplines

⇒ Need systematic, scrutable approach to handle these complexities with appropriate treatment of uncertainties

Probabilistic Risk Assessment (PRA)

- Process/model(s) to answer the risk triplet questions
  - A form of systems analysis
  - Expresses uncertainties in terms of probabilities
- Current practices for NPPs tailored to address
  - Rare events
  - Sparse data
  - Combinations of failures (including dependencies)
  - Multiple phenomena
  - Difference between aleatory (“random,” “stochastic”) uncertainties and epistemic (“state of knowledge”) uncertainties*

*The distinction can be arguable on philosophical grounds but has proven useful in practice. See Lecture 3-1 for further discussion.

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NPP PRA Distinguishing Characteristics

- Levels
  - Level 1 (core/fuel damage)
  - Level 2 (radioactive release)
  - Level 3 (offsite consequences)
- Hazards
  - Internal events (hardware, human, LOOP)
  - Internal hazards (flood, fire, heavy load drops, …)
  - External hazards (seismic, flood, wind, …)
- Operating Mode
  - At power
  - Low power/shutdown
- Sources
  - Core
  - Spent fuel pool
  - Other (e.g., dry cask storage)