PRA and Risk-Informed Decision Making at the NRC: Some Trends and Challenges*

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*The views expressed in this presentation are not necessarily those of the U.S. Nuclear Regulatory Commission
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“It is of the highest importance in the art of decision making to be able to recognize, out of a number of facts, which are incidental and which vital. Otherwise your energy and attention must be dissipated instead of concentrated.”

- With apologies to Sherlock Holmes
  (The Hound of the Baskervilles)

NRC USE OF RISK INFORMATION
Triplet Definition of Risk (Kaplan and Garrick, 1981)*

Risk \equiv \{s_i, C_i, p_i\}

- What can go wrong?
- What are the consequences?
- How likely is it?

Features
- Vector, not scalar
- Qualitative and quantitative
- Differences across accident spectrum

*See:
- “White Paper on Risk-Informed and Performance-Based Regulation (Revised),” SRM to SECY-98-144, March 1, 1999
A PRA/RIDM Timeline

Use of risk information

Atomic Energy Act “No undue risk”

Price-Anderson (non-zero risk)

Indian Point

ASME/ANS PRA Standard

Revised Reactor Oversight

RG 1.174

Modern Applications

Safety Goal Policy

PRA Policy

Windscale

EU Stress Tests

AEC created

Fukushima

WASH-1400

Hanford to WASH-1400

Early PRAs

Expansion

Farmer Curve

German Risk Study

TMI

WASH-740

WASH-1400

Russian NRC created

German NRC created

Germany

Farmer Curve

Use of risk information
NRC Uses of Risk Information


- Increase use of PRA technology in all regulatory matters
  - Consistent with PRA state-of-the-art
  - Complement deterministic approach, support defense-in-depth philosophy

- Benefits:
  1. Considers broader set of potential challenges
  2. Helps prioritize challenges
  3. Considers broader set of defenses

Recent Application (2019)
In any licensing review or other regulatory decision, the staff should apply risk-informed principles when strict, prescriptive application of deterministic criteria such as the single failure criterion is unnecessary to provide for reasonable assurance of adequate protection of public health and safety.


“…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.” [Emphases added]

Use of risk information

Risk-Informed Decisionmaking (RIDM)

Current regulations

Defense-in-depth

Safety margins

Integrated Decision Making

Monitoring

Risk

Adapted from RG 1.174
Use of risk information

In Addition to Immediate Decision Support...

Risk Information

- Results
- Insights
- Explanations
- Uncertainties
- Qualifications

Foundational Knowledge

Analyses

Methods, Models, Tools, Databases, Standards, Guidance, ...

Adapted from NUREG-2150
“It’s tough to make predictions, especially about the future.”
- Yogi Berra

SOME TRENDS AND CHALLENGES
Drive to RIDM: Transformation

Evolving situation: market forces, new nuclear technologies, new analytical methods and data, new professionals

• Vision: make safe use of nuclear technology possible
• Continuing standard: reasonable assurance of adequate protection
• Attitude: recognize potentially different ways of achievement – embrace change

“Applying the Principles of Good Regulation as a Risk-Informed Regulator,” October 15, 2019 (ADAMS ML19260E683)
**Market Forces**

**Operating Rx – More use of PRA models**

**New Rx – Early use of PRA in design**

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**Risk-Informed Submittals Under Review***

<table>
<thead>
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<th>Fiscal Year</th>
<th>Submittals</th>
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<tbody>
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*As of April, 2017; estimates subject to change.

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New Technologies

- New designs
- New operational concepts

Smart reactor systems
- Improved analysis tools

Photo courtesy of NEA Halden Reactor Project

Trends and challenges
New Professionals

Changing

- Experiences, knowledge
- Information content and delivery preferences
- Comfort with analytics, risk, probability
- Mobility

NRC Technical Staff Age Distribution (FY 2019 Q2)

**Trends and Impacts: A Two-Way Street**

**Trends**
- Increasing # RI-applications
- New licensing approaches
- New designs
- New operational concepts
- New technologies
- New analytical methods
- New professionals
- ...

**Decision Making**
- Issue Identification
- Option Identification
- Analysis
- Deliberation
- Implementation
- Monitoring

**PRA Technology**
- Methods
- Models
- Tools
- Data
SOME RISK-ORIENTED THOUGHTS ON MeV

“Many calculations bring success; few calculations bring failure. No calculations at all spell disaster!”
- Sun-Tzu (The Art of War)
Thoughts on MeV

A PRA Perspective on MeV

What: “System of Systems”

Why: Decision Support

model, n. a representation of reality created with a specific objective in mind.

Thoughts on MeV

Potential Benefits of Improved MeV

• Improved realism
  – Finer resolution
  – Fewer simplifications
  – Address sources of completeness/model uncertainty

• Improved decision support
  – Improved insights (not just “the numbers”)
  – Better use of available information

• Broader stakeholder acceptance
  – Facilitated integration of disciplines
  – Consistency with current engineering trends
Thoughts on MeV

Some General Challenges*

- Trustworthiness
  - breadth/completeness
  - integration and balance
  - uncertainty characterization**
  - “good enough”
- Transparency
- Explainability
  - complexity
  - uncertainties**

* Building on framework of Artificial Intelligence/Machine Learning (AI/ML) community: see Idaho National Engineering Laboratory AI/ML Symposium 2.0, July 9, 2020.

**See ML20080N774 for additional thoughts on the characterization and communication of uncertainties.

https://earthquake.usgs.gov/earthquakes/eventpage/official20110311054624120_30/shakemap/intensity
Thoughts on MeV

A Matter of Perspective

Developer
• Method/model/tool
• Validity
• Best-Estimate [Plus Uncertainty]

Decision Maker
• Results (including user effect)
• Acceptability (for intended use)
• Community state-of-knowledge

Adapted from University of Wisconsin-Milwaukee
(https://web.uwm.edu/hurricane-models/models/archive/)

Adapted from NUREG-2156
Closing Remarks

- NRC has long used risk information to support decision making
- Ongoing trends are shaping current use
- Improvements in MeV developments and applications are welcome and inevitable
- MeV challenges
  - Are amenable to technical solutions
  - Depend on perspective
Knowledge Checks

• What is the triplet definition of risk?
• What are some of the NRC regulatory functions supported by risk information?
• What are some of the current trends affecting NRC’s use of risk information?
• What are some of the ways in which a decision maker’s views on MeV development needs can differ from a developer’s?
Essay Questions

• Is airplane flight less risky than automobile travel?
• How do advances in MeV support NRC’s “risk-informed” approach to regulatory decision making?
• In your field of interest, should there be more support for the development of diverse modeling approaches? Why or why not?


“Will somebody find me a one-handed scientist?!”
- Senator Edmund Muskie
(Concorde hearings, 1976)
ADDITIONAL SLIDES
NRC Overview

NRC Organization

- Headquarters + 4 Regional Offices
- 5 Commissioners
- ~3100 staff (FY 2019)
- Annual budget ~$930M
- Website: www.nrc.gov
- Information Digest: NUREG-1350 V31
Regulated Facilities At A Glance*

- Operating Reactors
  - 97 plants (58 sites)
  - 65 PWR, 32 BWR
  - Shutting down: 12
  - License Renewal: 89
  - Subsequent License Renewal: 8 (in process)
- New Reactors
  - Early Site Permits: 5 approved, 1 under review
  - Combined Licenses: 18 received, 8 issued and active
  - Design Certifications: 6 issued, 3 under review
- Research and Test Reactors
  - 31 operating (21 States)
  - 2 medical isotope production facilities authorized for construction
- Nuclear Materials
  - 19,300 licensees
  - 3 Uranium recovery facilities
  - 10 fuel cycle facilities

*As of early 2019, from NUREG-1350 V31
NRC Mission

“The U.S. Nuclear Regulatory Commission licenses and regulates the Nation’s civilian use of radioactive materials to protect public health and safety, promote the common defense and security, and protect the environment.”

- NUREG-1614 (NRC Strategic Plan)
How We Regulate

Functions

- Regulations and Guidance
- Decision Support
- Licensing and Certification
- Oversight
- Operational Experience

Standard*

“Reasonable assurance of adequate protection”

Principles**

- Independence
- Openness
- Efficiency
- Clarity
- Reliability

* When granting, suspending, revoking, or amending licenses or construction permits. (Atomic Energy Act of 1954, as amended – see NUREG-0980, v1, n7, 2005)

**NRC Strategic Plan (NUREG-1614)
RIDM and NRC’s Principles of Good Regulation

- Independence
- Openness
- Efficiency
- Clarity
- Reliability

U.S. Nuclear Regulatory Commission, “Principles of Good Regulation" (ADAMS ML14135A076)
The Role of Regulatory Research (1/2)

The Role of Regulatory Research (2/2)

Typical products (regulatory research)
- Ways to look at and/or approach problems (e.g., frameworks, methodologies)
- Points of comparison (e.g., reference calculations, experimental results)
- Job aids (e.g., computational tools, databases, standards, guidance: best practices, procedures)
- Problem-specific information (e.g., results, insights, uncertainties)

Side benefits
- Education/training of workforce
- Networking with technical community

Prioritization considerations (subject to change)
- Mission
  - Potential Risk Impact
  - Business Line Safety Priorities
  - Deterministic Evaluations
  - Improving Uncertainty and/or State of Knowledge
  - Generic Fleet Applicability
- Demand
  - Level (Internal Driver)
  - Function (Internal Driver)
  - External Drivers
- Resources
  - Leverage
  - Anticipated Completion

re•search, n. diligent and systematic inquiry or investigation in order to discover or revise facts, theories, applications, etc.
Different Communities, Different Challenges…

- Data
- Bounding/screening
- Guidance
- “Holes”
- Integration
- Imagination

Analysts/Reviewers

- Time
- Resources
- Biases/heuristics
- Communication

Developers

- Understanding
- Confidence
  - Uncertainties
  - Heterogeneity and aggregation
- Other Factors (e.g., DID, safety margins)
- Stakeholders

Users

- New science/engineering
- Operational experience
- Intended users/applications
- Computational limits
- Rewards

NRC Overview
An Evolving Budgetary Environment

NRC Research Budget (FY 1976 - FY 2019)

Budget data from NUREG-1350 (NRC Information Digest)
Regulation: Risk-informed fire protection (1/2)

- Browns Ferry Nuclear Power Plant fire (3/22/75)
- Candle ignited foam penetration seal, initiated cable tray fire; water suppression delayed; complicated shutdown
- Second-most challenging event in U.S. nuclear power plant operating history
- Spurred changes in requirements and analysis
Regulation: Risk-informed fire protection (2/2)

- Post-Browns Ferry deterministic fire protection (10 CFR Part 50, Appendix R)
  - 3-hour fire barrier, OR
  - 20 feet separation with detectors and auto suppression, OR
  - 1-hour fire barrier with detectors and auto suppression

- Risk-informed, performance-based fire protection (10 CFR 50.48(c), NFPA 805)
  - Voluntary alternative to Appendix R
  - Deterministic and performance-based elements
  - Changes can be made without prior approval; risk must be “acceptable”
  - More than 1/3 U.S. fleet has completed transition

- Methods adopted by international organizations
Licensing: Changes in plant licensing basis

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

Oversight – Reactor Oversight Program (ROP)

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

\[
\Delta \text{CDF} < 1\times 10^{-6} \\
\Delta \text{LERF} < 1\times 10^{-7} \\
1\times 10^{-6} < \Delta \text{CDF} < 1\times 10^{-5} \\
1\times 10^{-7} < \Delta \text{LERF} < 1\times 10^{-6} \\
1\times 10^{-5} < \Delta \text{CDF} < 1\times 10^{-4} \\
1\times 10^{-6} < \Delta \text{LERF} < 1\times 10^{-5} \\
\Delta \text{CDF} > 1\times 10^{-4} \\
\Delta \text{LERF} > 1\times 10^{-5}
\]
OpE - Accident Sequence Precursor (ASP) Program (1/2)

- 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 (SPAR) models

Example Uses of Risk Information

Licensee Event Reports 1969-2018
(No significant precursors since 2002)
Example Uses of Risk Information

OpE - Accident Sequence Precursor (ASP) Program (2/2)
Example Uses of Risk Information

Decision Support – Research (Frameworks/Methodologies)

**NRC-sponsored Fire PRA R&D (universities)**
- Started after Browns Ferry fire (1975)
- Developed fire PRA approach first used in industry Zion and Indian Point PRAs (early 80s), same basic approach today
- Started path leading to risk-informed fire protection (NFPA 805)

**Technology Neutral Framework**
- Explored use of risk metrics to identify licensing basis events
- Inspiration and part basis for current Licensing Modernization Program
Decision Support – Research (Reference Points)

NUREG-1150
- Continuing point of comparison for Level 1, 2, 3 results
- Expectations (“ballpark”)  
- Basis for regulatory analysis (backfitting, generic issue resolution)

SOARCA
- Detailed analysis of potential severe accidents and offsite consequences
- Updated insights on margins to QHOs

Example Uses of Risk Information
Example Uses of Risk Information

Decision Support – Research (Methods/Models/Tools)

**SPAR**
- Independent plant-specific models (generic data)
- All-hazards (many)
- Support SDP, MD 8.3, ASP, GSI, SSC studies
- Adaptable for specific circumstances

**SAPHIRE**
- General purpose model-building tool
- Multiple user interfaces

**IDHEAS-G**
- Improved support for qualitative analysis
- Explicit ties with cognitive science (models, data)
- General framework for developing focused applications (e.g., IDHEAS-ECA)
- Benefits from NPP simulator studies
- Consistent with current HRA good practices guidance (NUREG-1792)

A common (and reasonable) expectation…but not a “given:”…

- Need data/evidence for details
- Need to identify and treat sub-model dependencies
- Need to recognize potential impact of sub-model heterogeneity
Benefits of MeV

**Improved Realism: Better Completeness**

PRA Examples:

- Decision-based Errors of Commission (EOCs) and Omission (EOOs)
  - Bounded rationality model: reasons for decisions and actions (and inaction) are affected by context, including
    - scenario evolution
    - past decisions/actions
  - Dynamic modeling provides framework for context
  - Insights into difference between precursors and accidents?

<table>
<thead>
<tr>
<th>Accident</th>
<th>Possible Precursor(s)</th>
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- T/H reliability of passive systems
Improved Decision Support: Additional Insights

PRA Examples

• Human performance insights
  – Available time for action
  – Important contextual factors
  – Compounding impact of decisions and actions

• System insights
  – Complex dependencies
  – Success criteria
  – Sequences
  – Time-dependence (warning, aftershocks)

• What isn’t important as well as what is

Benefits of MeV

“Game Over”

Long-duration scenarios
Partial/intermittent failures
Recovery/mitigation actions
Improved Decision Support: Better Use of Knowledge

PRA Examples

• Phenomena
  – Direct use of knowledge encoded in model systems (models, data, guidance, reviews)
  – Not restricted to discrete-logic

• Operational experience
  Rich information source: influencing factors, mechanisms, dependencies, time scales, successes, ...
Broader Acceptance: Integration of Multiple Disciplines

- Risk-informed decision making
  - An enterprise-wide activity
  - Need broad understanding, buy-in
- Postulate: explicit, mechanistic modeling reduces need for translation
  - Disciplines can use native frameworks and terms (e.g., forces/behaviors vs. success/failure)
  - Improved comfort, trust
Benefits of MeV

Broader Acceptance: Consistency with Engineering Trends

• Increasing computational capabilities => enables more detailed models

• Improving scientific and engineering knowledge => desire to incorporate

• Changing problem solving approaches and expectations in technical community and even general public
  – routine use of simulation
  – explicit characterization of uncertainty