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Simulation-Based Analysis for Nuclear Power Plant Risk Assessment: Opportunities and Challenges

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Outline

- Simulation-based approaches for NPP PRA
- Advantages, limitations, challenges of dynamic PRA
- Risk-informed regulation at the NRC
- A view forward

Some Simulation-Based Approaches for NPP PRA

- ADAPT (OSU, USA)
  - Analysis of Dynamic Accident Progression Trees
  - “Code Agnostic” architecture – has been coupled with MELCOR
  - Originally developed to provide insight into scenario evolutions for nuclear plant severe accidents (i.e. Level 2 PSA). Extended to human action, passive systems, and integrated accident/consequence analysis.
- MCDET (GRS, Germany)
  - Monte Carlo (MC) simulation and the Dynamic Event Tree (DET) approach
  - Has been coupled with both MELCOR and ATHLET
  - Considers discrete aleatory uncertainties by the DET approach and continuous aleatory uncertainties by MC simulation.
- ADS-IDAC (UMD, USA)
  - Accident Dynamics Simulator with the Information, Decision, and Action cognitive model in a Crew context
  - Has been coupled with RELAP, MELCOR and TRACE
  - Focus on human performance modeling using IDAC model

Recent Demonstrations

- ADAPT
  - Integrated Level 2 to Level 3 dynamic probabilistic risk assessment (PRA) station blackout scenario for a PWR using MELCOR and MACCS2 (PSA-2013, INL/OSU)
  - Assessment of low probability containment failure modes for large dry containment during an SBO (PSA-2013, OSU)
- MCDET
  - Analysis of the effects of different fire fighting means in the frame of a probabilistic fire risk analysis using the Fire Dynamics Simulator code (PSA-2013, GRS)
  - Relief valve failure modeling during an SBO (PSAM-11, GRS)
- ADS
  - Comparison with traditional PRA results for MLOCA sequences (PSA-2013, PSI)
  - Accident sequence precursor analysis using dynamic PRA (PSAM-11, NRC/UMD)
  - Short and long term SBO with incorporation of SAMGs (SAND2012-9346, NRC/SNL)
- Others…
  - SBO analysis using RAVEN (PSA-2013, INL/University of Rome)
  - Genetic Algorithm DPSA (GA-DPSA) applied to LOCA for WWER-1000 (PSAM-11, Moscow Power Engineering Institute/Swedish Royal Institute of Technology)

Advantages

- Does not require traditional pinch points and other constraints
  - Flexible truncation times
  - Easier integration of non-binary information (e.g., degraded equipment)
- Increases focus on physical system behavior
  - Reduces reliance on intermediate assumptions (e.g., success criteria)
  - Forces explicit treatment of timing
  - Improves realism and ability to extrapolate results
- Integrates hardware and human performance models
  - Richer context for evaluating human performance
  - Realistic plant modeling (e.g., explicit consideration of control system interaction and procedures)
- Avoids “game over” modeling assumptions
  - End states can be readily tailored to scenarios and not limited to discrete bins
  - Recovery and mitigation actions can be explicitly modeled, including partially successful mitigation and timing variability

Limitations and Challenges

- Developing and validating models
  - Development of physical models can be resource intensive
  - Validation/accreditation of models can be difficult, particularly for rare events
- Obtaining a complete risk profile
  - Ensuring a complete solution space is examined
  - Choosing representative samples
- Aggregating, interpreting, and communicating results
  - Simulation-based approaches can produce expansive amounts of data
  - Identifying and focusing on key accident scenarios can be difficult
  - Confidence in simulation results (either overly high or low)
- Evaluating Uncertainty
  - Applying and interpreting uncertainty can difficult – particularly in the absence of a standard state-of-practice.
  - Ensuring efficient sampling scheme for uncertainty evaluation (e.g., identifying parameters and capturing dependencies)

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Risk-Informed Regulation at the NRC

- Defined regulatory infrastructure
  - Safety Goal Policy Statement (51 FR 30028, August 21, 1986)
  - PRA Policy Statement (60 FR 42622, August 16, 1995)
  - Established regulatory programs for use of PRA
    - Licensing (RG 1.174, RG 1.200)
    - Reactor Oversight (SDP, ASP)
    - Regulatory Analysis (NUREG/BR-0184)
    - Environmental Reviews (SAMA, SAMDA reviews)
    - Event Follow-up (MD 8.3)
- Established tools
  - Consensus codes and standards (ASME/ANS PRA Standard)
  - Calculational tools and state-of-practice for model development
  - Guidelines for applications (RASP Handbook, PRA Glossary – NUREG-2122)

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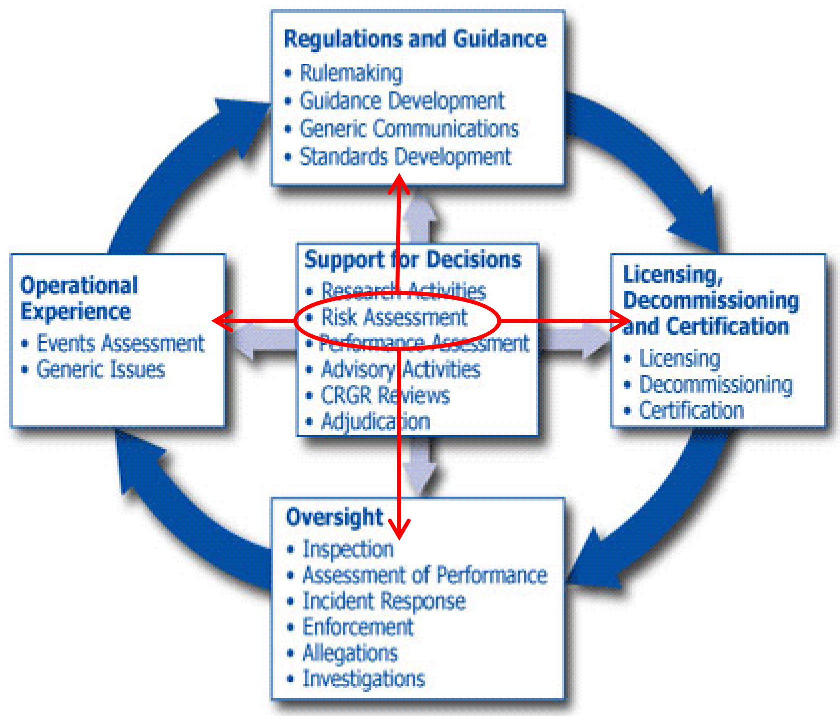
Risk-Informed Regulation at the NRC (con't)

- NRC Regulatory Programs



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Risk-Informed Regulation at the NRC (con't)

- Tested regulatory process
  - Significant experience with risk-informed applications
    - 18 years since PRA Policy Statement issued
    - Diverse range of application areas
      - Technical Specifications
      - Maintenance Rule
      - Inspection and enforcement
      - Regulatory analysis, backfitting, and generic safety issue evaluation
  - Well understood by staff
    - Substantial training programs in place
    - Integrated decision-making process
      - Applies risk metrics (CDF, LERF) within an integrated context
      - Focus on technical adequacy of PRA (and peer review process)

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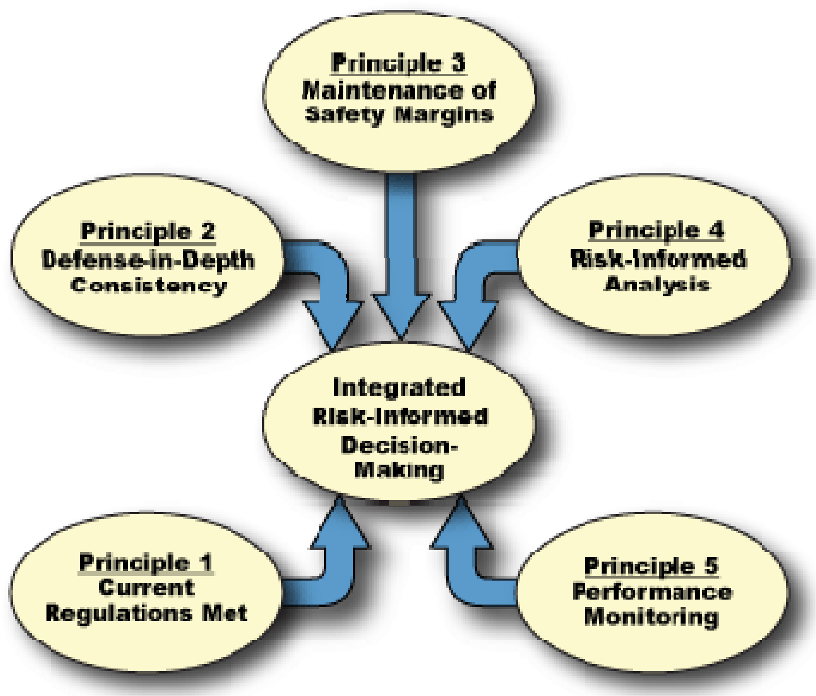
Risk-Informed Regulation at the NRC (con't)

- Key Principles of Integrated Decision-Making



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Risk-Informed Regulation - Challenges

- Risk-informed vs. Risk-based
  - Maintaining focus on risk significant insights
  - Keeping PRA results within an integrated decision-making process
- Decision-making under uncertainty
  - Distilling key insights from uncertainty results
  - Establishing and maintaining open dialogue between analyst and decision-maker
- Handling unique contexts and “non-binary” issues
  - Success criteria for specific operational events
  - Modeling degraded equipment
- Inertia associated with established processes
  - Gaining acceptance of new approaches when their value has not been fully demonstrated

Regulatory Opportunities for Simulation-Based PRA

- Event and condition assessment
  - Complex dependencies
  - Success criteria
  - Degraded equipment
  - Variability in human response (can consider more than just success/failure)
- Support expert elicitation/expert judgment based decision-making
  - Can provide useful insights and benchmarks for expert judgment process (plant response, accident phenomenology)
  - Helps establish a narrative of accident scenarios
- Insights to support traditional PRA modeling
  - Combines probabilistic and deterministic modeling approaches
  - Success criteria, human actions, event tree modeling
  - Can help foster better understanding of the consequences of uncertain assumptions

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Regulatory Challenges for Simulation-Based PRA

- Application within an integrated decision-making context
  - Selecting representative simulation scenarios (adaptive sampling and exploration approaches may help address)
  - Validating supporting models (both physical and human performance)
- Communication of analysis results
  - Avoiding bias to either reject or accept simulation results
  - Clustering, binning, ordering, simplifying results for more efficient communication
- Decision-making
  - Identifying appropriate figures of merit and decision thresholds
- Cultural challenges
  - Bridging the PRA and deterministic technical camps
  - Identifying what unique and useful insights can be provided by dynamic simulation approaches (“why do I need it?”)
  - When is a simulation “good enough”?

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The View Forward

- Promulgating best practices
  - New application areas
  - Synthesizing and communicating results and insights
  - Cross pollination among approaches
- Validation approaches for simulation models
  - Comparisons to operational data
  - Benchmarking activities (e.g., comparisons to expert panel and deterministic methods)
- Addressing calculational issues
  - Adequate solution space coverage
  - Stability of simulation engines for rare accident sequences
  - Adapting deterministic codes to better integrate with dynamic PRA methods

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The View Forward (con't)

- Gaining acceptance of simulation-based PRA as a risk tool
  - Demonstrate usefulness of simulation-based approaches
    - Ongoing research activities and international projects (such as the Integrated Deterministic Probabilistic PSA) will help
  - Make the technology approachable for a wide range of technical staff (i.e., move from research to application)
  - Developing an inventory of input models
  - Pilot "real" applications
  - Identify "champions" for the technology
- Continuing commitment to advance the PRA state-of-the-art