Overview of the Risk-Informed Safety Margin Characterization (RISMC) Pathway

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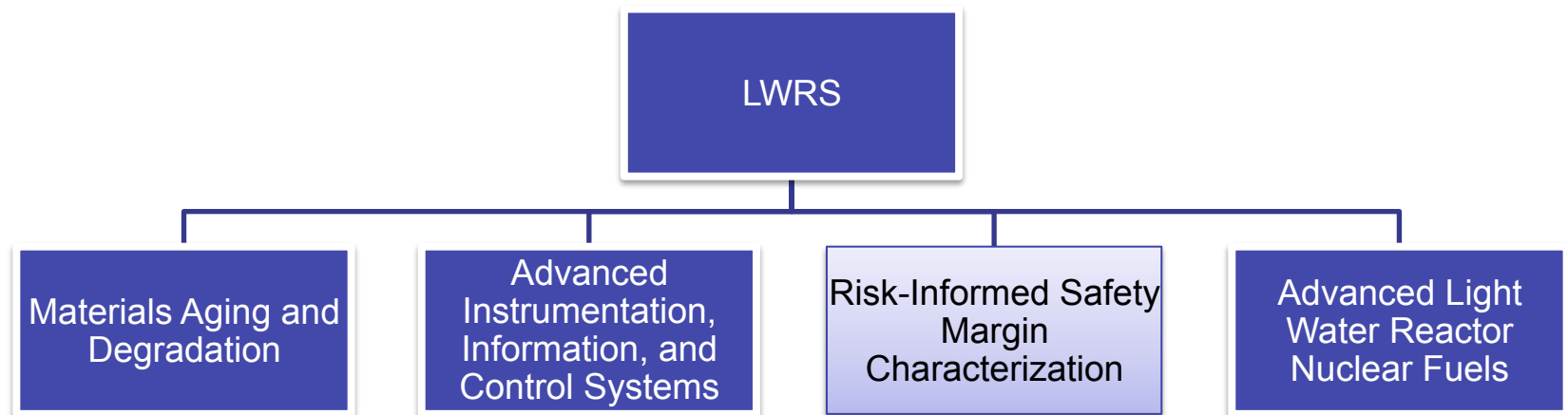# Light Water Reactor Sustainability (LWRS) Program Goals

- **Developing the fundamental scientific basis to understand, predict, and measure changes in materials and systems, structures, & components (SSCs) as they age in environments associated with continued long-term operations of the existing reactors**

- **Applying this fundamental knowledge to develop and demonstrate methods & technologies that support safe & economical long-term operation of existing reactors**

- **Researching new technologies to address enhanced plant performance, economics, and safety**

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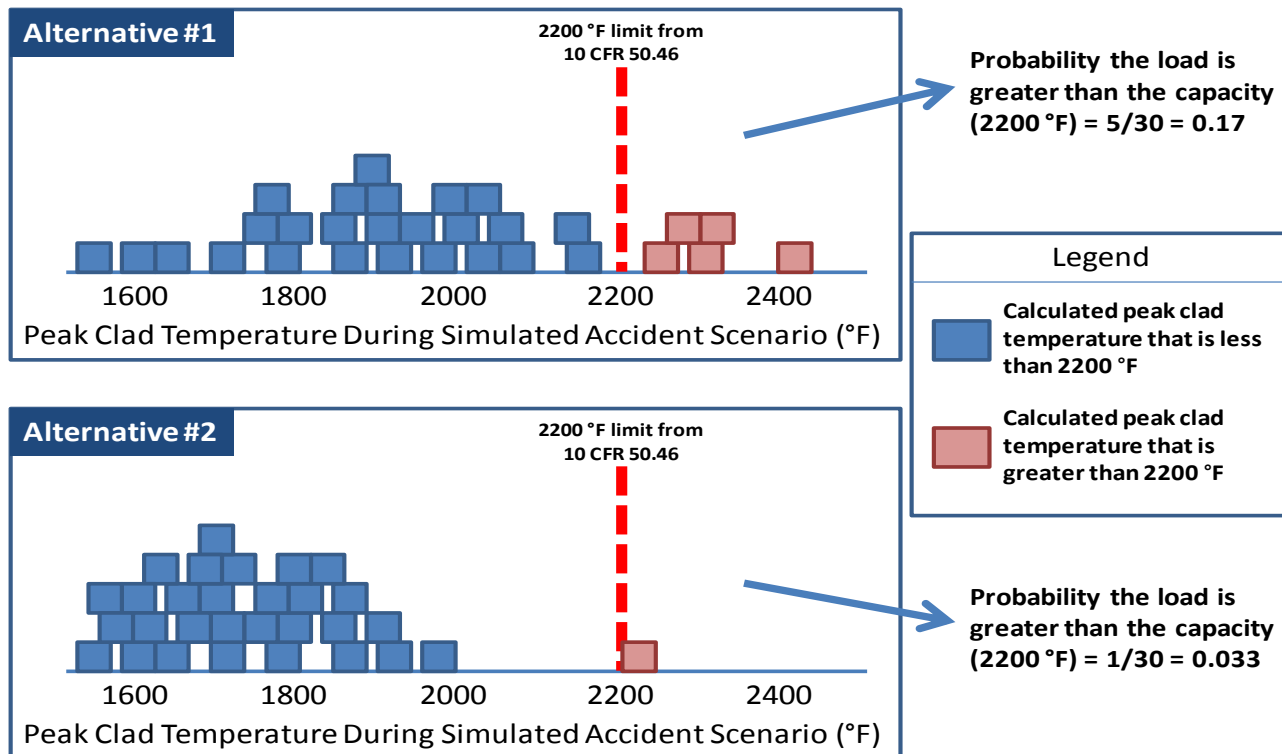Revision 1 (Final Draft)

Light Water Reactor Sustainability Program

Integrated Program Plan

February 2013

U.S. Department of Energy
Office of Nuclear Energy

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RISMC is part of the LWRS Program

LWRS

Materials Aging and Degradation

Advanced Instrumentation, Information, and Control Systems

Risk-Informed Safety Margin Characterization

Advanced Light Water Reactor Nuclear Fuels

What is Risk-Informed Safety Margin Characterization (RISMC)?

- **A systematic approach to characterization of safety margins**
  - Vital input to the owner and regulator to support decision making
- **A way to incorporate plant physical processes that govern aging & degradation in order to better optimize plant safety and performance**
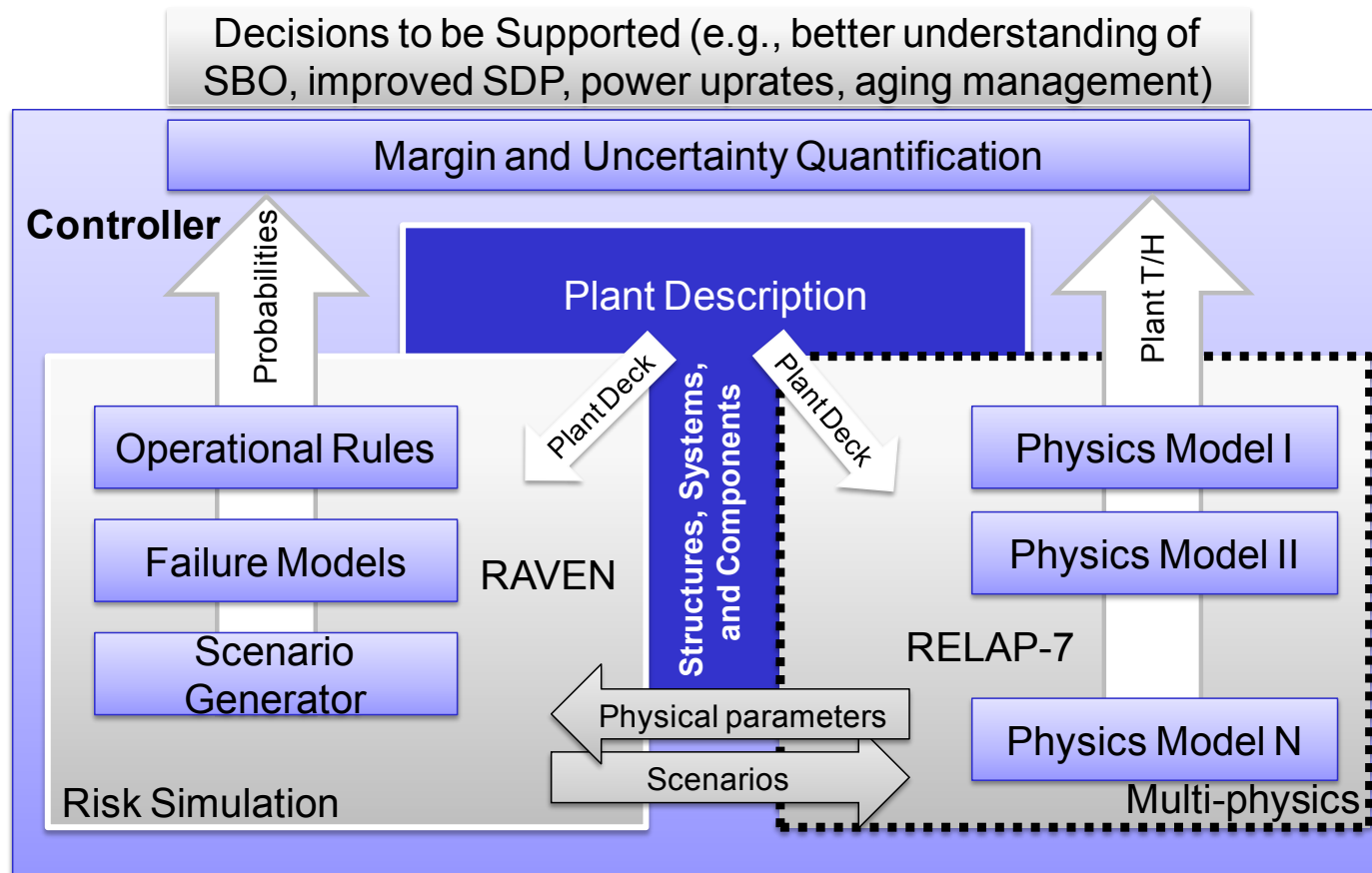
What is RISMC (cont.)?

- **Loads & capacities are uncertain and can be treated probabilistically**
  - When deterministic margins are evaluated, the analysis is typically very conservative in order to account for uncertainties
- **RISMC uses the probability-margin approach to quantify impacts in order to avoid conservatisms (where possible) and treat uncertainties**

Alternative #1

2200 °F limit from 10 CFR 50.46

Probability the load is greater than the capacity (2200 °F) = 5/30 = 0.17

Peak Clad Temperature During Simulated Accident Scenario (°F)

Alternative #2

2200 °F limit from 10 CFR 50.46

Probability the load is greater than the capacity (2200 °F) = 1/30 = 0.033

Peak Clad Temperature During Simulated Accident Scenario (°F)

Legend

Calculated peak clad temperature that is less than 2200 °F

Calculated peak clad temperature that is greater than 2200 °F

What is RISMC (cont.)?

- **Two types of analysis used in RISMC, probabilistic and mechanistic**
  - In applications, a blended approach is used where both types of analysis are combined to support a particular decision

Decisions to be Supported (e.g., better understanding of SBO, improved SDP, power uprates, aging management)

Controller

Margin and Uncertainty Quantification

Probabilities

Plant Description

Plant T/H

Plant Deck

Plant Deck

Structures, Systems, and Components

Operational Rules

Failure Models

Scenario Generator

RAVEN

Physics Model I

Physics Model II

RELAP-7

Physics Model N

Physical parameters

Scenarios

Risk Simulation

Multi-physics

RISMC strategic goals

- **Goals of the RISMC Pathway:**
  1. Develop and demonstrate a risk-assessment **method** coupled to safety margin quantification that can be used by nuclear plant decision makers as part of their **margin management strategies**
  2. Create advanced "**RISMC toolkit**" that enables more accurate representation of nuclear **plant safety margin**
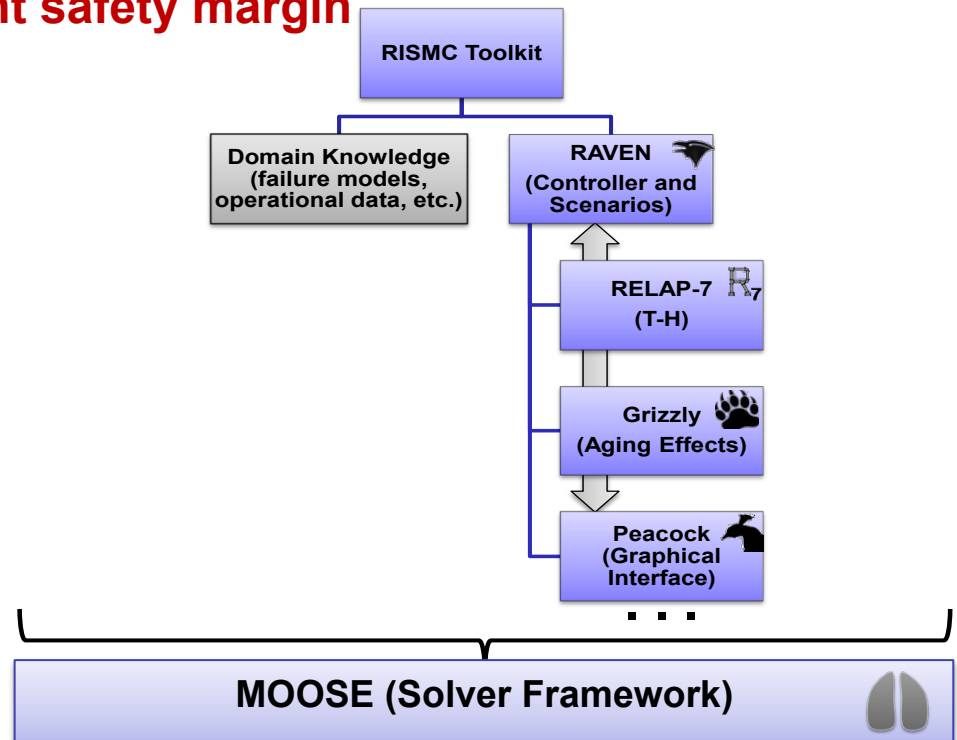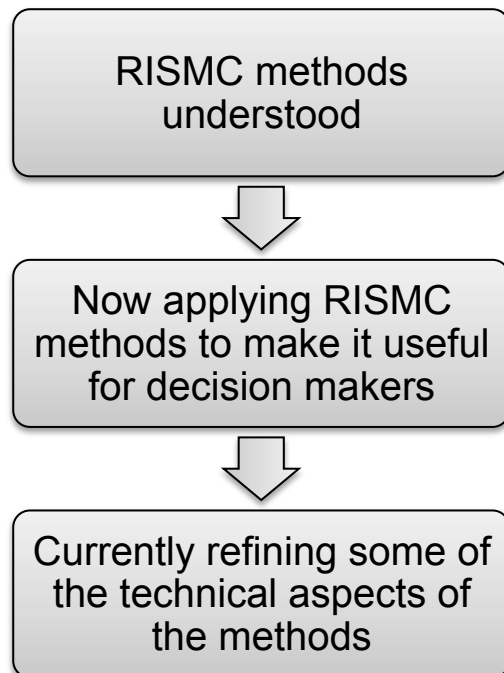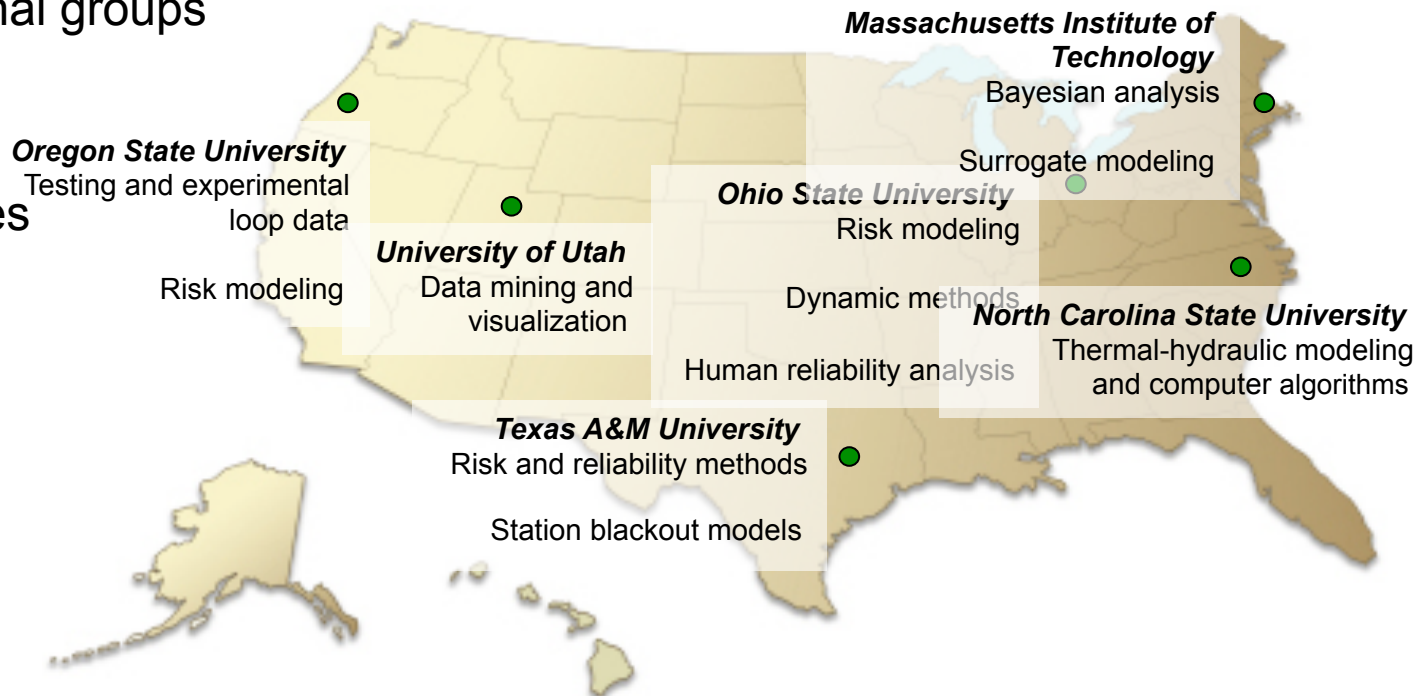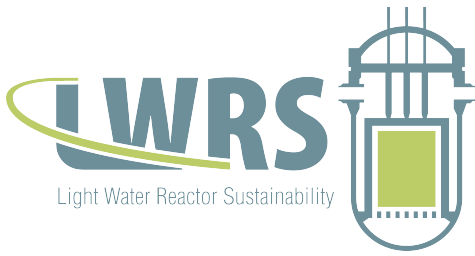
The types of decisions that will be assisted by RISMC

- **Risk-Informed Margin Management will support a variety of safety margin decisions, including recovery of or increasing safety margins…**

  - If core power levels are increased

  - If a different type of fuel or clad is introduced

  - If aging phenomena becomes more active over long periods of plant operation

  - If advanced control systems provide additional or new information during normal and off-normal plant operation

  - If plant modifications are taken to increase resiliency for hazards such as flooding and seismic events

  - If systems, structures, or components are degraded or failed

  - If under accident conditions, supporting severe accident guidelines

Interactions

- **The Pathway interacts with many different organizations through different mechanisms**

  - NEUP – Nuclear Energy University Programs
  - NEAMS – Nuclear Energy Advanced Modeling and Simulation
  - International groups
  - EPRI
  - Industry
  - Universities

Massachusetts Institute of Technology
Bayesian analysis

Surrogate modeling

Oregon State University
Testing and experimental loop data

Risk modeling

University of Utah
Data mining and visualization

Ohio State University
Risk modeling

Dynamic methods

North Carolina State University
Thermal-hydraulic modeling and computer algorithms

Human reliability analysis

Texas A&M University
Risk and reliability methods

Station blackout models

INL is making progress against the planned accomplishments

- **Development and demonstration of the methodology and tools is centered on**
  - Methods development and case studies
  - Tools development that support case studies
- **We have made progress on both case study aspects and tools**
  - RELAP-7 α 0.1 release, currently working on 2-phase flow
  - RAVEN and Peacock prototypes
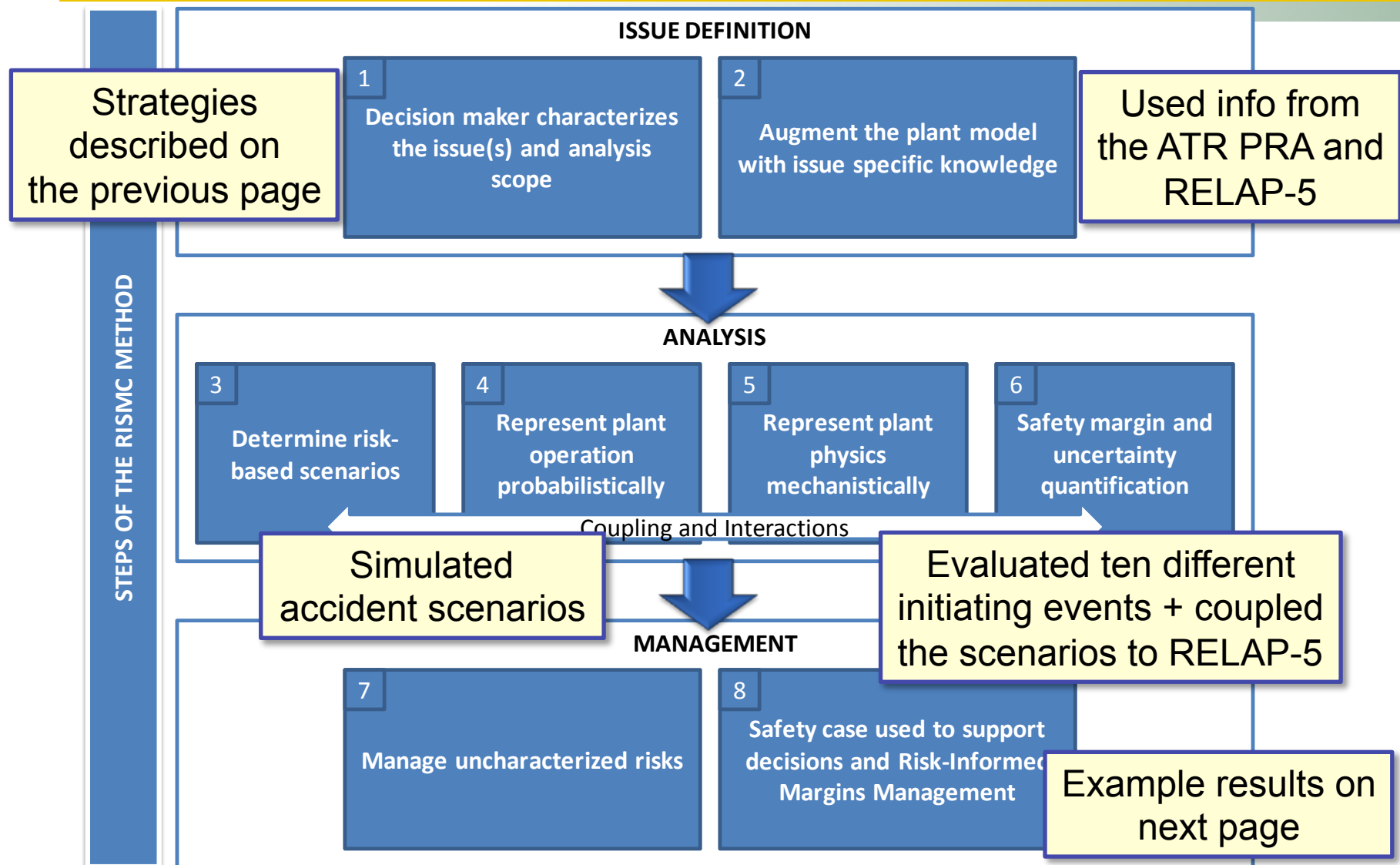 - ATR case study
  - Grizzly prototype
  - BWR SBO case studies

Advanced Test Reactor (ATR) Case Study to Demonstrate the RISMC Methodology

ATR Case Study

- **ATR asked to change how emergency backup power is used at the plant**
- **Strategies under consideration include:**
  - Keep emergency power system as is (EDG running, one in standby, commercial power as backup)
  - Commercial power as primary backup, single new EDG as backup
  - Commercial power as primary backup, existing EDGs as backup
  - Our analysis was a **demonstration**, but used the RISMC methodology
- **RISMC is different from the traditional PRA approach**
  - In PRA, core damage frequency is estimated using static fault and event tree models
    - *We do not know how close (or beyond) we are to physical safety limits (such as peak clad temperature) for most accident sequences*
  - With RISMC, we estimate how close we are (or not) to the margin, not just the frequency, providing information on how safety margin can be improved
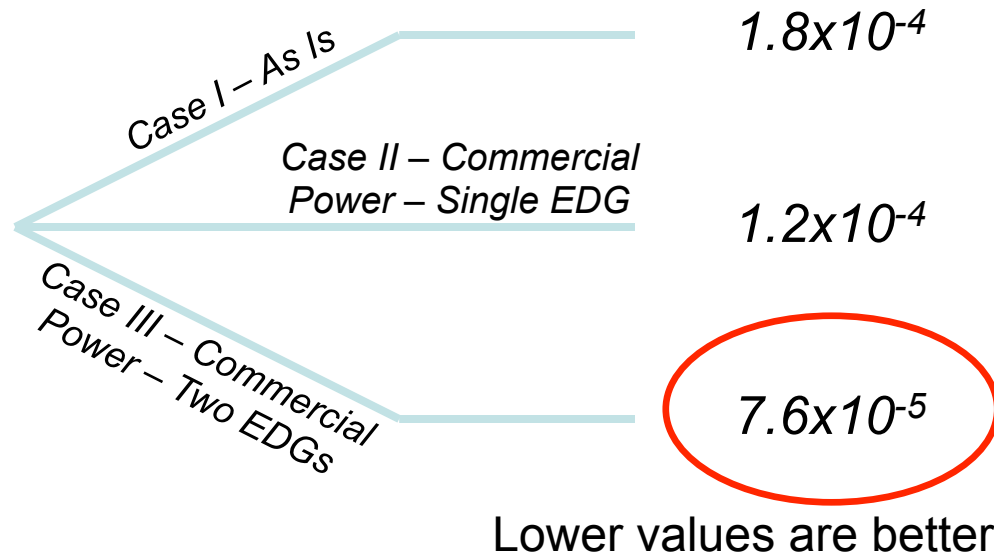
The RISMC Steps

ISSUE DEFINITION

Strategies described on the previous page

1 Decision maker characterizes the issue(s) and analysis scope

2 Augment the plant model with issue specific knowledge

Used info from the ATR PRA and RELAP-5

ANALYSIS

STEPS OF THE RISMC METHOD

3 Determine risk-based scenarios

4 Represent plant operation probabilistically

5 Represent plant physics mechanistically

6 Safety margin and uncertainty quantification

Coupling and Interactions

Simulated accident scenarios

Evaluated ten different initiating events + coupled the scenarios to RELAP-5

MANAGEMENT

7 Manage uncharacterized risks

8 Safety case used to support decisions and Risk-Informed Margins Management

Example results on next page

ATR case study decision support

Margin Management
Strategies

Safety Margin
Pr(Peak Clad T > 725°F)

Case I – As Is

1.8×10^{-4}

Case II – Commercial
Power – Single EDG

1.2×10^{-4}

Case III – Commercial
Power – Two EDGs

7.6×10^{-5}

Lower values are better

We demonstrated the validity
of the RISMC process

Provides input to decisions
makers related to margins management

Preferential Strategy

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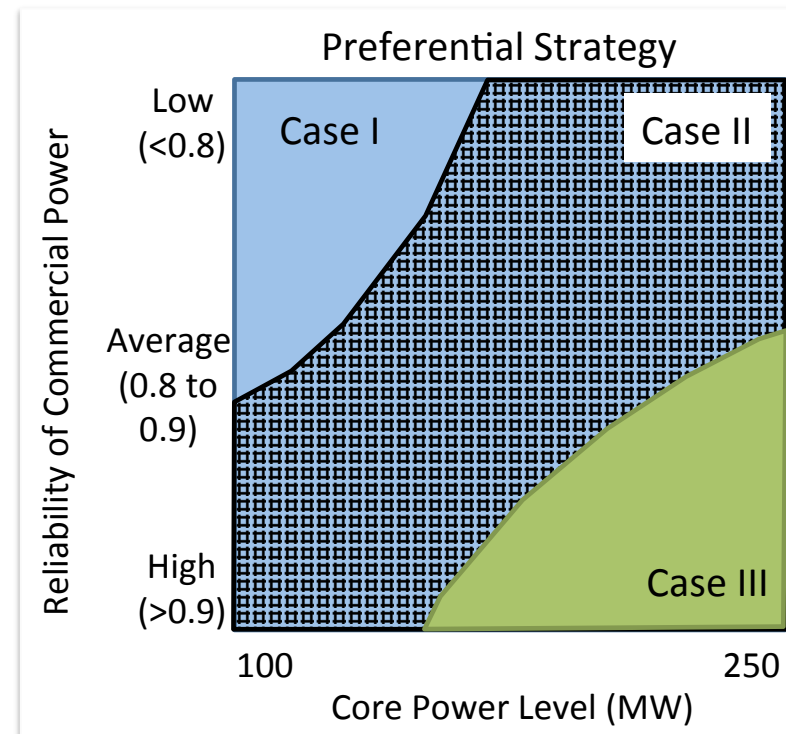
Moving to use the entire Toolkit for future case studies

ANALYSIS STEPS		RAVEN	RELAP-7	Grizzly	Peacock
3	Determine risk-based scenarios	Provides plant-specific scenarios including operational aspects			Provides a GUI to create plant-specific model "input decks"
4	Represent plant operation probabilistically	Provides SSC and operator behavior responses based upon probabilistic models			Provides a GUI to represent SSC operation such as system states and control logic
5	Represent plant physics mechanistically	Provides a control and interface mechanism to the plant phenomena models	Provides plant phenomena (T-H and neutronics) conditional upon scenarios	Provides aging phenomena conditional upon plant scenarios	Provides a GUI to describe how plant physics affects SSCs
6	Safety margin and uncertainty quantification	Produces and processes load and capacity distributions to quantify the safety margin	Provides (to RAVEN) load distribution	Provides (to RAVEN) capacity and load distributions	Provides a GUI to display safety margin results and other analyses such as sensitivity calculations

← Transfer of Mechanistic Info →

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