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Light Water Reactor Sustainability Program

RISMC Advanced Safety Analysis Project Plan
FY 2015 – FY 2019

Ronaldo H Szilard
Curtis L Smith
Robert Youngblood

September 2014

DOE Office of Nuclear Energy

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Idaho National Laboratory
Idaho Falls, Idaho 83415

http://www.inl.gov/lwrs

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SUMMARY

In this report, a project plan is developed, focused on industry applications, using Risk-Informed Safety Margin Characterization (RISMC) tools and methods applied to realistic, relevant, and current interest issues to the operating nuclear fleet.

RISMC focuses on modernization of nuclear power safety analysis (tools, methods and data); implementing state-of-the-art modeling techniques (which include, for example, enabling incorporation of more detailed physics as they become available); taking advantage of modern computing hardware; and combining probabilistic and mechanistic analyses to enable a risk informed safety analysis process. The *modernized* tools will maintain the current high level of safety in our nuclear power plant fleet, while providing an improved understanding of safety margins and the critical parameters that affect them. Thus, the set of tools will provide information to inform decisions on plant modifications, refurbishments, and surveillance programs, while improving economics. This set of tools will also benefit the design of new reactors, enhancing safety per unit cost of a nuclear plant.

The proposed plan will focus on application of the RISMC toolkit, in particular, solving realistic problems of important current issues to the nuclear industry, in collaboration with plant owners and operators to demonstrate the usefulness of these tools in decision making.

This work proposes a five-year plan (including resources, scope, and timelines) for a set of high value applications, in collaboration with industry stakeholders. These Industry Applications (IA) are:

IA1 – Integrated Cladding/ECCS Performance Analysis
IA2 – Enhanced Seismic/External Hazard Analysis
IA3 – Reactor Containment Analysis
IA4 – Long Term Coping Studies

In this report, we define and describe how the above applications fit in the overall DOE-NE R&D portfolio. We discuss, primarily, the role of the RISMC R&D Pathway, and how these safety analysis industry applications fit into the mission of the LWRS Program.

Lastly, we provide an integrated task list of activities for the above four industry applications, for the next five years, with the end goal of developing risk-informed safety analysis guidelines for the fleet owner/operator. With full collaboration and participation from our industry stakeholders, these guidelines will serve as recipes for industry adoption of the RISMC tools.

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RISMC Advanced Safety Analysis Project Plan – FY 2015 – FY 2019

1. INTRODUCTION

1.1 What is Advanced Safety Analysis

Classical safety analysis is formulated to support findings regarding reasonable assurance of adequate protection based on a specific surrogate for "safety." In particular, specific "design-basis" accidents serve as proxies for a certain portion of the spectrum of challenges to plant safety functions; satisfactory performance in these types of accidents (as demonstrated based on conservative analysis) is considered to be evidence of a certain kind of "safety."

What makes an analysis *advanced* is the way in which it supports a decision (or, more narrowly, resolution of a safety issue). Rather than simply quantifying performance of a safety proxy, an advanced safety analysis develops a state-of-knowledge representation of the relevant performance metrics addressing the full issue space relevant to the decision.

The computational power available to safety analysis has grown remarkably and is expected to continue to increase. However, classical safety analysis done faster, even with more and better graphical output, is not advanced. The improvements to be accomplished as part of this proposition are made possible by computational improvements and the inclusion of multiple types of physics that interact and impact safety. Specifically, advanced safety analysis aims to support new types of decisions or answering typical decision in new ways.

The general answer to why should we advance safety analysis tools and methods have been discussed in the open literature and in the Light Water Reactor Sustainability (LWRS) Risk Informed Safety Margins Characterization (RISMC) Pathway technical program plan. [1]

The general theory of decision-making under uncertainty is highly developed and it shows how best to reconcile a given decision with the decision-maker's priorities and with the decision-maker's current state of knowledge. In practice, classical nuclear safety analysis that is done for licensing purposes has relied on the following two kinds of simplifications:

- Focus on a selected set of events that are supposed to envelope probabilistically significant events of potential concern
- Analyze those events in a systematically conservative way: introduce approximations and assumptions that tend to make the results worse than reality; therefore, if system performance is found to be acceptable for a given event within that body of approximations and assumptions, there is a high probability that it really is acceptable for that event.

In general, both categories of simplifications come at a cost; they both potentially distort the idea of being adequately safe by distorting the analysis of system performance, especially the uncertainties in that performance. *Advanced* safety analysis is formulated specifically to reduce those costs by doing the following:

- Avoiding pitfalls associated with focusing on only a few events defined in a stylized way
- Replacing systematic conservatism with comprehensive analysis of uncertainty
- Representing, as closely as practicable, risk in terms of how things fail in actuality
- Capturing the complexity of scenarios by integrating multiphysics-based mechanistic models with probabilistic ones.

Recent and ongoing evolutions in regulatory, economic, design, and safety practices can be discussed in terms of these ideas; however, they can be discussed more broadly in the sense that technical advances to be undertaken in advanced safety analysis are applicable to any analysis domain where decisions have been limited by potentially misleading methods, by lack of tools, and by models that do not empower decision-makers to ask the right questions.

1.1.1 Why Do We Need to Do Better?

Conservatism is suboptimal from a formal point of view; it leads to rejection of system designs and operating practices that are, in fact, good enough, incurring an associated cost. For example, this conservative approach has limited the licensed power level of many plants; the so-called best estimate plus uncertainty analysis has been formulated specifically to recapture that margin. While best estimate plus uncertainty analysis is a special case of some of the general ideas behind advanced safety analysis, it is still predicated on specific events, but at least it is meant to redress the conservatism embodied in applicable models.

The hallmark of *advanced* safety analysis is the replacement of argument based on proxies with argument based on comprehensive analysis of risk (e.g., scenarios, frequencies, and consequences) within a well-characterized issue space, including state-of-knowledge quantification of uncertainty. Specific implications for tools, methods, and data are derived later in this document from consideration of use-cases, but certain implications are noted as follows:

- Historically, it has been harder than originally expected to be sure of what is “bounding” and what is not. It will be seen later that the machinery of advanced safety analysis is adaptable to applications such as this, and, similarly, to “vulnerability searches” that were too computationally intensive to be thinkable for previous generations of analysts.
- Much more analytical effort will need to be expended in characterization of uncertainty in models and data used in advanced safety analysis. Specifically, this expenditure refers to the assembly and analysis of evidence pertinent to the quantification of key uncertainties.

Most current analyses are neither strictly “classical” in the above sense, nor truly advanced; they are hybrids. Advanced safety analysis is driven, in part, by the realization that it is not only possible, but highly desirable to the future of our industry, to do better, including reducing unnecessary conservatisms where possible and making the safety-analysis process itself more efficient.

1.1.2 A Risk-Informed Focus

Advanced safety analysis focuses on modernization of nuclear power safety analysis tools (including methods and data); implementing state-of-the-art modeling techniques; taking advantage of modern computing hardware; and combining probabilistic and mechanistic analyses to enable a risk-informed safety analysis process. The *modernized* tools will maintain the current high level of safety in our nuclear power plant fleet, while providing an improved understanding of safety margins and the critical parameters that affect them. Thus, the set of tools will provide information to inform decisions on plant modifications, refurbishments, and surveillance programs, while improving economics. The set of tools will also benefit the design of new reactors, enhancing safety per unit cost of a nuclear plant.

Risk-informed approaches provide a technical basis for understanding and managing hazards (i.e., safety risks). [1] In addition, risk-informed approaches can be used to estimate costs (i.e., economic risks) to support safety decisions. While the focus of advanced safety analysis is on “facility” safety, it should be noted that these facilities are managed by diverse organizations, including those listed in Figure 1 (i.e., the nuclear industry, the Department of Energy (DOE), and associated oversight organizations). The benefits to be derived from the RISMC products will be applicable to all three groups.

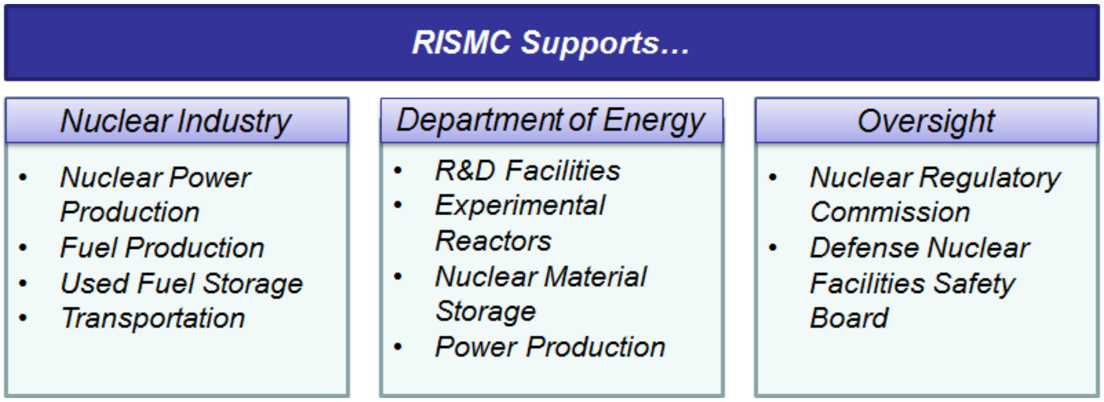


Figure 1. RISMC Stakeholders.

1.1.3 Advanced Safety Analysis Mission

Mission	**To provide cost-beneficial approaches to safety by leveraging modern methods, augmented (a combination of existing and new) tools, and repurposed (existing, but used in a new way) data.**

A key part of the advanced safety analysis mission is on the focus of “cost-beneficial” safety approaches. We are *not* proposing to perform traditional safety analysis *faster* using newer computational tools or approaches. The current safety tools are adequate for making decisions that underlie their original creation. Instead, we are focusing on supporting **new types of decisions** (e.g., decisions that are difficult using traditional approaches) or answering **typical decisions in new ways** (e.g., describing how resources can be saved while maintaining existing safety margins).

The nuclear power industry has a variety of “safety margins” on the likelihood of events and the consequences of those events due to robust facility designs. However, it (and the regulator) is also faced with unknowns, where *unknowns* represent the difference in actual versus synthetic (or analyzed) risk. The nuclear industry addresses these unknowns through the following five risk management practices that are also integral to RISMC:

1. Use engineering best practices
2. Provide for defense-in-depth
3. Maintain sufficient safety margins
4. Provide analysis to support adequate safety
5. Monitor performance and capture operational feedback.

These risk management practices will be enhanced as part of the RISMC implementation. The benefit is improved owner/operator understanding of their plants’ responses to accident scenarios, improved quantification of safety margins, better decisions on additional defense-in-depth features, efficient safety analysis practices, and enhanced economics via risk-informed decisions.

RISMC will be very beneficial in improving the future designs of advanced reactors while removing the excess conservatism when applicable, providing better understanding of the technical safety basis, and improving the defense-in-depth features to reduce risk further in some areas. As a result, through reduction of excess conservatism, the cost of future plants may be reduced without sacrificing safety.

In summary, through a systematic science-based R&D process, advanced safety analysis should:

- Provide value on safety issues by improving our understanding of safety margins and critical parameters that affect them

- Provide value on economic issues (by improving resource allocation, regulatory interactions, minimization of precursors, and the prevention of accidents).

- Leverage existing tools, methods, and data to the extent possible. Extend the use of these by providing enhancement or using them in novel ways when needed.
- Augment existing tools, methods, data with improvements when feasible, where *feasible* means that it will provide value because it is important (cost/benefit), easy to improve, or both.
- Provide a risk management approach that integrates performance metrics (e.g., safety and cost); phenomena; system and subsystem interactions.
- Provide risk informed decision making for advanced reactor designs and defense-in-depth needs for existing reactors.

1.2 The Use-Case Approach

The motivations for U.S. Government involvement in reactor safety research and development are summarized in this section. It is important to recognize that advanced safety analysis is driven, in part, by the realization that it is not only possible, but highly desirable, to the future of our industry to do better when focusing on safety.

Our approach to describing the proposed work is to first identify issue spaces that are of interest because of safety implications and have potential gaps that can be resolved via advanced methods. At a high level, this approach is depicted in Figure 2. Previous reports provide the details of such approach. [2,3]

For each issue space, there are one or more use-cases that attack the potential gaps from a technology standpoint. The operational definition of a *use-case* is:

Use-Case: Specification of an analysis to support resolution of a given safety issue, including definition of the issue space and the model attributes that are needed to adequately support resolution of the issue.

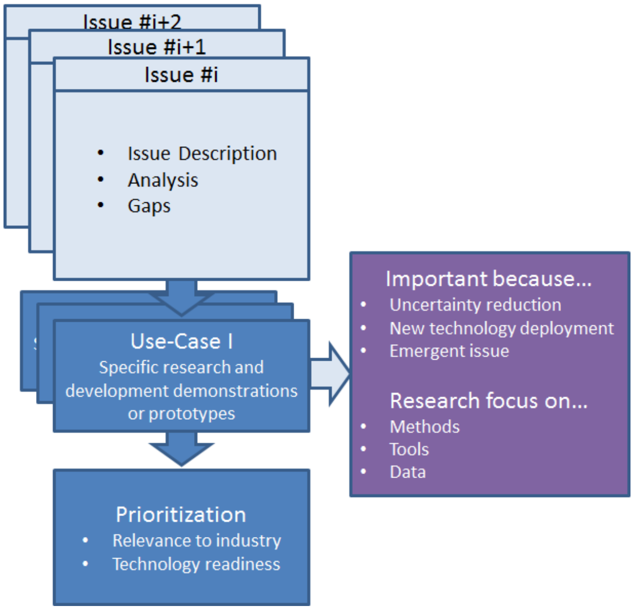


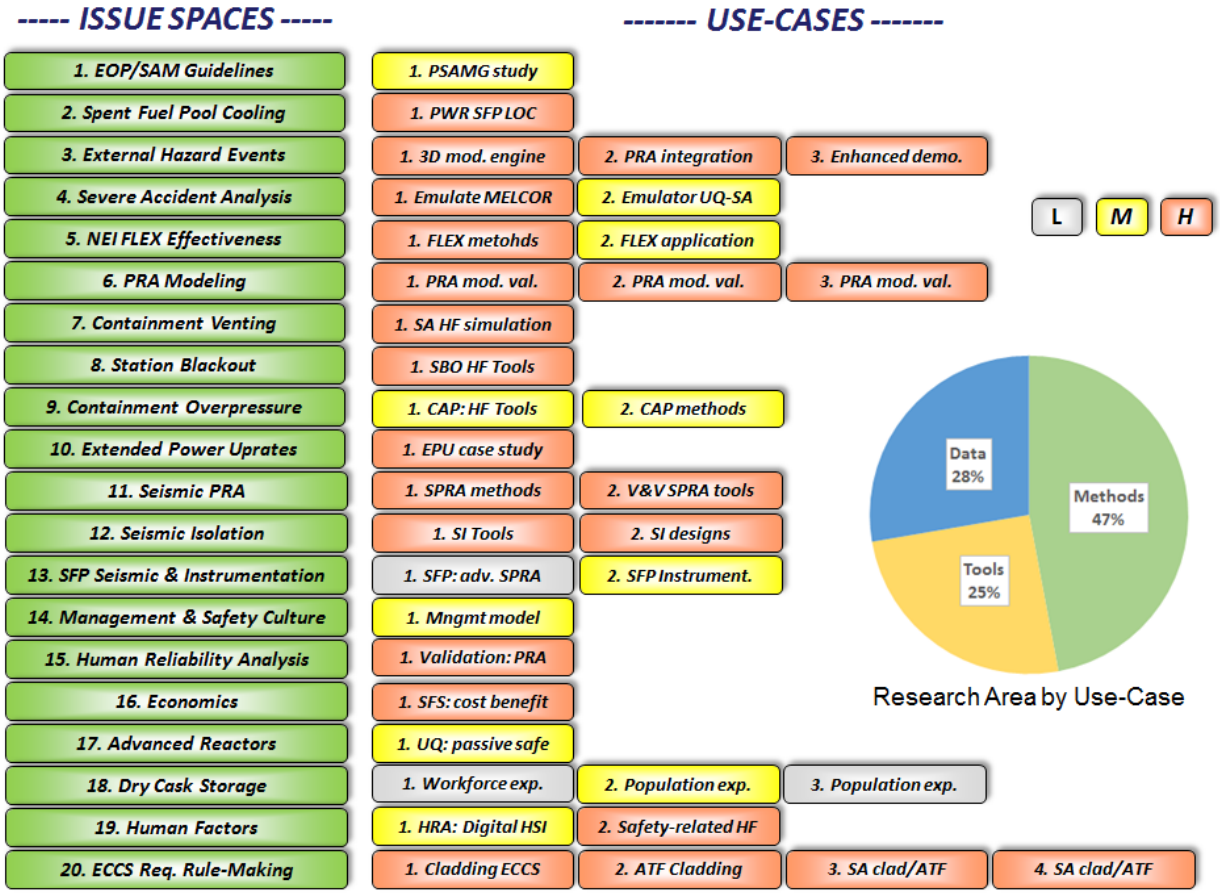
Figure 2. General flow identifying issues, use-cases, and prioritization. [2]

The research focus for the use-cases is further characterized into the following three focus areas (see also Figure 3):

- Methods
- Tools
- Data.

To develop the initial issue spaces and use-cases, we had safety domain practitioners generate a list in order to have a broad picture of the types (i.e., breadth) and complexities (i.e., depth) of the safety issues facing the nuclear industry. In previous work, [2] it has been identified a total of 20 initial issue spaces; however, these should not be considered to be comprehensive; instead, they are representative safety challenges. The initial list of issue spaces are as follows (see also Figure 3):

1. Emergency Operating Procedures/Severe Accident Management Guidelines
2. Spent Fuel Pool Cooling
3. External Hazard Events
4. Severe Accident Analysis
5. Effectiveness of Nuclear Energy Institute (NEI) FLEX
6. Probabilistic Risk Assessment Modeling Issues
7. Containment Venting (Hardened and Filtered Vents)
8. SBO Related Issues
9. Containment Overpressure and Accident Pressure Issues
10. Extended Power Uprates
11. Seismic Probabilistic Risk Assessment
12. Seismic Isolation
13. Seismic and Instrumentation Issues for Spent Fuel Pool
14. Effect on Plant Safety of Process Management and Safety Culture
15. Human Reliability Analysis
16. Economics
17. Advance Reactor Issues
18. Dry Cask Storage
19. Human Factors
20. NRC Rule-Making on Emergency Core Cooling System (ECCS) Requirements.



----- ISSUE SPACES -----	------- USE-CASES -------			
1. EOP/SAM Guidelines	🟨 1. PSAMG study			
2. Spent Fuel Pool Cooling	🟧 1. PWR SFP LOC			
3. External Hazard Events	🟧 1. 3D mod. engine	🟧 2. PRA integration	🟧 3. Enhanced demo.	
4. Severe Accident Analysis	🟧 1. Emulate MELCOR	🟨 2. Emulator UQ-SA		
5. NEI FLEX Effectiveness	🟧 1. FLEX metohds	🟨 2. FLEX application		
6. PRA Modeling	🟧 1. PRA mod. val.	🟧 2. PRA mod. val.	🟧 3. PRA mod. val.	
7. Containment Venting	🟧 1. SA HF simulation			
8. Station Blackout	🟧 1. SBO HF Tools			
9. Containment Overpressure	🟨 1. CAP: HF Tools	🟨 2. CAP methods		
10. Extended Power Uprates	🟧 1. EPU case study			
11. Seismic PRA	🟧 1. SPRA methods	🟧 2. V&V SPRA tools		
12. Seismic Isolation	🟧 1. SI Tools	🟧 2. SI designs		
13. SFP Seismic & Instrumentation	⬜ 1. SFP: adv. SPRA	🟨 2. SFP Instrument.		
14. Management & Safety Culture	🟨 1. Mngmt model			
15. Human Reliability Analysis	🟧 1. Validation: PRA			
16. Economics	🟧 1. SFS: cost benefit			
17. Advanced Reactors	🟨 1. UQ: passive safe			
18. Dry Cask Storage	⬜ 1. Workforce exp.	🟨 2. Population exp.	⬜ 3. Population exp.	
19. Human Factors	🟨 1. HRA: Digital HSI	🟧 2. Safety-related HF		
20. ECCS Req. Rule-Making	🟧 1. Cladding ECCS	🟧 2. ATF Cladding	🟧 3. SA clad/ATF	🟧 4. SA clad/ATF

Figure 3. Industry Use-Cases.

Use-cases describe the analysis approach (RISMC methods, tools, and data) from the user's point of view, meaning we describe the user-specific analysis characteristics to be performed and the intended decisions to be supported. This use-case concept is particularly suited for modern methods, tools, and data development since any one safety use-case is supported by a number of technical solutions. However, no use-case requires *all* of the proposed advances in safety and one advance (say, for example, enhanced 3D modeling) may be used effectively in many different use-cases. In a sense, use-cases are requirements in themselves, helping to effectively communicate the RISMC objectives and products to prospective users and stakeholders and serves as benchmarks to document and measure success.

1.3 The DOE-LWRS RISMC R&D Pathway Expanded

The purpose of the Risk Informed Safety Margins Characterization (RISMC) Pathway R&D is to support plant decisions for risk-informed margins management with the aim to improve economics, reliability, and sustain safety of current NPPs over periods of extended plant operations.

The goals of the RISMC Pathway are twofold:

1. Develop and demonstrate a risk-assessment method that is coupled to safety margin quantification that can be used by NPP decision makers as part of risk-informed margin management strategies.

2. Create an advanced RISMC Toolkit that enables more accurate representation of NPP safety margins and their associated impacts on operations and economics.

Margin Management Strategies

Proposed alternatives (i.e., changes to SSCs or plant procedures) that work to control margin changes due to aging or plant modifications. Alternatives that off-set, or mitigate, reductions in the safety margin are known as margin recovery strategies.

One of the primary items inherent in the goals of the Pathway is the ability to propose and evaluate margin management strategies. If a situation exists that causes margins associated with one or more safety functions to become degraded, the methods and tools developed in this Pathway will serve to model and measure margins for active and passive SSCs for normal and off-normal conditions. These evaluations will then support development and evaluation of appropriate alternative strategies for consideration by decision makers to maintain and enhance the impacted margins as necessary. When alternatives are proposed that mitigate reductions in the safety margin, these changes are referred to as margin *recovery* strategies. Moving beyond current limitations in safety analysis, the Pathway will develop techniques to conduct margins analysis using simulation-based studies of safety margins.

While simulation methods in risk and reliability applications have been proposed for several decades, the availability of advanced mechanistic and probabilistic simulation tools have been limited. But, as noted by researchers such as Zio, [4] "…simulation appears to be the only feasible approach to quantitatively capture the realistic aspects of the multi-state system stochastic behavior." Consequently, the approach we are using for the RISMC Pathway is to use simulation tools to model plant behavior and determining safety margins.

The RISMC Toolkit is being built using MOOSE, a computer simulation framework that simplifies the process for modeling complicated physics as represented by mechanistic models. [5] The MOOSE framework was developed by INL by using existing computer code and numerical libraries from proven scalable numerical tools developed at universities and DOE. The result is a framework with a number of high-level features that includes built-in parallelization and advanced geometry meshing capabilities. The constituent pieces of the overall RISMC Toolkit are shown in Figure 4.

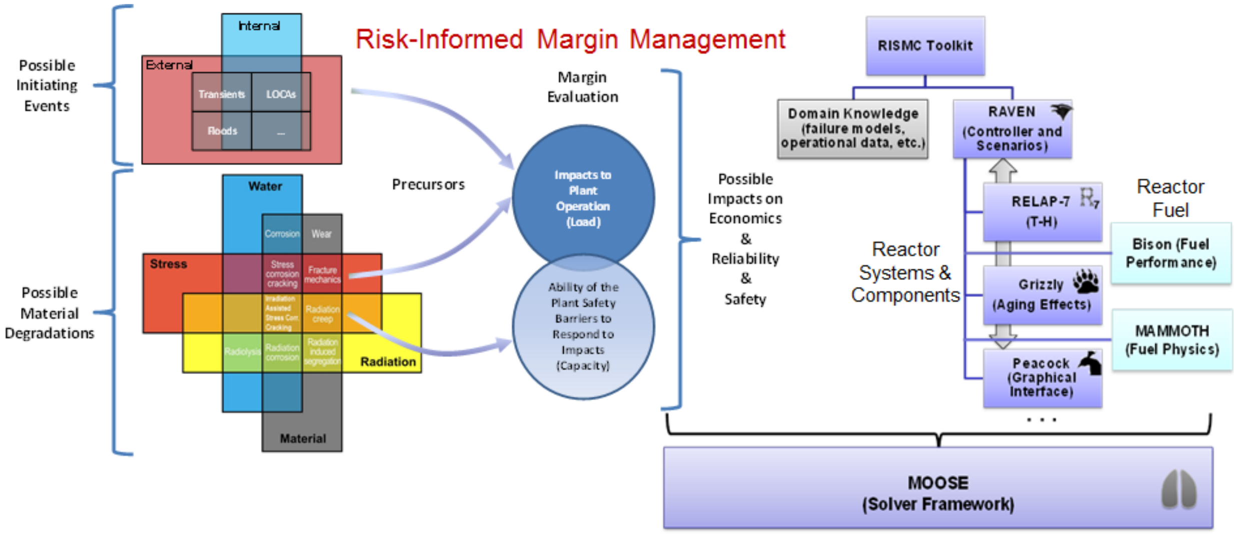


Figure 4. RISMC Toolkit brings together probabilistic and mechanistic ideas. [1]

As the RISMC Pathway matures, the focus on “demonstration” of methods described above in goal 1 becomes more important. In fact, for industry adoption of the RISMC Toolkit, it is important to demonstrate and validate, with confidence, that the tools developed achieve the intended goal to aid industry in its long term operation safety and economics challenges. Plant owners, operators, and vendors, can maximize the benefits of the proposed methodology while the burden associated with introducing new technologies is minimized. In this case, the burden of proof to demonstrate and validate that these tools perform as well or even more effective than legacy tools relies primarily with the developer. Figure 5 shows schematically the proposed activities in this plan, and its relationship with the existing DOE Light Water Reactor Sustainability R&D Program and its industry stakeholders. At the top, we show the DOE LWRS Program and its four main technical R&D pathways. The next level shows the RISMC Pathway alignment with the proposed technical activities for FY15 and beyond, with the two main goals of the Pathway identified as:

- RISMC Toolkit Development
- Risk-Informed Margin Management Applications

The toolkit development has been previously described in Figure 4, [1] with its execution well under way. The Risk-Margin Management (RIMM) Applications activities are the focus of the plan proposed in the next sections, with the intent of developing Safety Analysis Guidelines for relevant industry issues that can be used to aid plant operating guidance and procedures. Central to the RIMM Applications are the High Impact Industry Applications, carefully selected to timely demonstrate the effective use of the RISMC toolkit for the industry user.

The next level of the diagram labeled “RISMC Activities” shows essential tasks executed in order to accomplish the RISMC goals. As discussed in details previously, the RISMC Toolkit develops tools that are easily integrated through a modern framework, with multi-physics, multi-scale, and realistic analysis characteristics. These tools are validated and applied through RIMM Applications for effective industry adoption. The spectrum of tools, methods, and data development must be exercised in order to achieve a successful industry implementation. The industry stakeholders play an important role on RIMM Applications. The four initial high impact Industry Applications have been closely selected with industry recommendations, [6] and it is essential that these application demonstrations be coordinated with these stakeholders. This coordination and collaboration will ensure that the technical challenges and decisions are fully met as we develop the RISMC Toolkit.

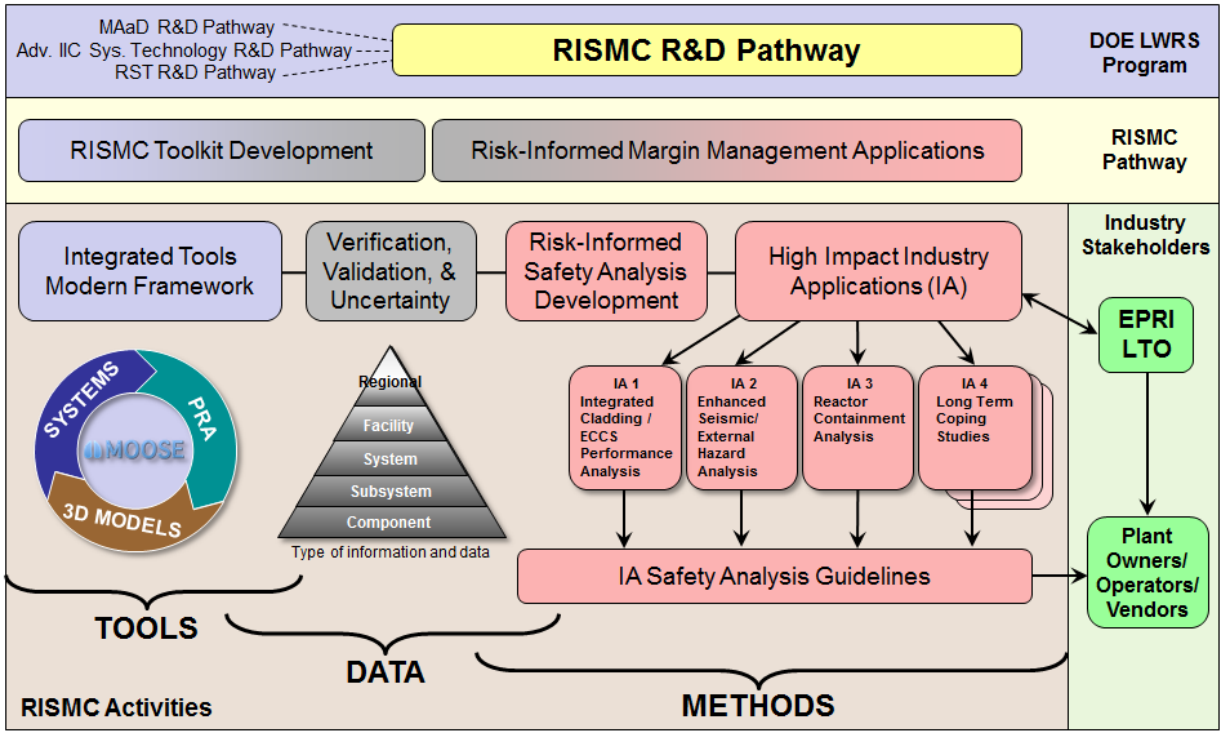


Figure 5. The RISMC R&D Pathway Expanded.

1.4 Risk-Informed Margin Management (RIMM) Applications

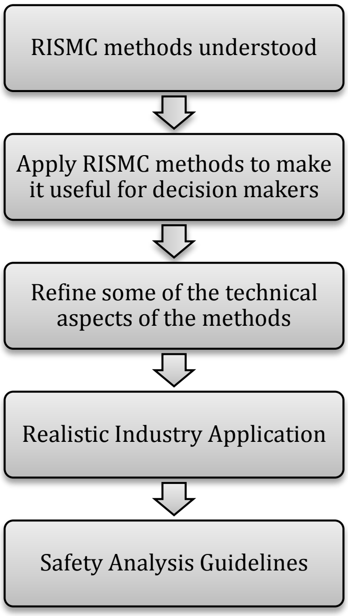


Figure 6. The RISMC R&D Pathway Maturity Stages.

The methods and tools provided by RISMC are essential to a comprehensive and integrated Risk-Informed Margin Management (RIMM) approach that supports effective preservation of margin for both active and passive SSCs. The evolution of RISMC throughout time is illustrated in Figure 6, and, as described in the previous section, shifts the focus of the Pathway towards the application of the RISMC toolkit as maturity of the tools progresses.

As shown in Figure 6, the maturity stages of RISMC toolkit development leads us to a successful implementation of such tools in an industry context.

RIMM Applications basically consists of two parts (see Figure 5):

- Risk-Informed (RI) Safety Analysis Development
- High Impact Industry Applications (IA)

Strategies and guidelines to support plant operations is one of the primary goals of the Risk-Informed Safety Analysis Development. Parallel to this activity, there is the High Impact Industry Applications, designed to address current, relevant issues in today’s fleet operations (the focus of this Plan). Together, these two parts will determine the content of the Risk-Informed Safety Analysis Guidelines. These guidelines will be the basis for industry adoption of the tools and methods developed under the RISMC Toolkit.

1.5 Industry Applications Selection and Prioritization

Based on a priority ranking method developed by EPRI and INL, [6] we combine issue spaces (shown in Figure 3), by category, to arrive at a final concise grouping of today's most relevant industry issues shown in Table 1 [6] below.

Table 1. Use-case prioritization list. [6]

ID	Case Study Description	Combined Score	Rank	Issue Space Grouping
CS 1	Integrated Cladding/ECCS Performance Analysis	49	1	4.20
CS 2	Enhanced Seismic/External Hazard Analysis	42.3	2	4.3 + 4.11 + 4.12
CS 3	Long Term Coping Studies	41.5	3	4.5 + 4.8
CS 4	Reactor Containment Analysis	39	4	4.7 + 4.9
CS 5	Spent Fuel Pool Analysis	35	5	4.2 + 4.13
CS 6	Advanced Reactor Analysis	31	6	4.17

These case studies are the top candidates for further analysis, and are the subject of the plan presented in the next sections. They are industry applications of the RISMC methodology, which includes development of advanced tools and methods, and application of existing data in realistic scenarios. Scores, ranking, and Issue Space groupings, as presented in Table 1, are discussed in detail in previous reports. [2,3]

Further selection and prioritization of the above cases, [6] arrives at the main technical topics of this report. These are the most relevant industry topics of today that can potentially impact plant operations in a significant way, in the near future, making them interesting, relevant, applications for the RISMC toolkit. The following are the highest priority Industry Applications (IAs) to be addressed:

IA1 – Integrated Cladding/ECCS Performance Analysis
IA2 – Enhanced Seismic/External Hazard Analysis
IA3 – Reactor Containment Analysis
IA4 – Long Term Coping Studies

We will define and describe the technical scope of the above Industry Applications in the next sections.

2. INDUSTRY APPLICATIONS – SCOPE

The primary **purpose** of industry applications in advanced safety analysis is to demonstrate advanced risk-informed decision making capabilities in relevant industry applications. The end **goal** of these activities is the full adoption of the RISMC tools by industry applied to their decision making process.

The four elements of the above proposition are further explored below:

(a) Demonstrate

- Provide confidence and a technical maturity in the RISMC methodology (essential for broad industry adoption)
- Strong stakeholder interaction required
- Address a wide range of current relevant issues (see also item (d))
- Three phase approach
    (1) Problem definition (3-6 months)
    (2) Early Demonstration (eDemo) (limited scope) (6-12 months)
    (3) Complete Application and Validation (Long Term- Methods, Tools, Data) (1-5 years)

(b) Advanced

- Analyze multi-physics, multi-scale, complex systems
- Use of a modern computational framework
- A variety of Methods, Tools, and Data can be utilized (e.g. use of legacy tools and state-of-the-art tools)
- Be as realistic as practicable (with the use of appropriate supporting data)
- Consider uncertainties appropriately and reduce unnecessary conservatism when warranted

(c) Risk-Informed decision making capabilities

- Use of an integrated decision process
- Integrated consideration of both risks and deterministic elements of safety

(d) Relevant industry applications

- There are four Industry Applications (IA) carefully selected to cover a wide range of current industry issues (in order of importance):
    IA1 – Performance-Based ECCS Cladding Acceptance Criteria
    IA2 – Enhanced External Hazard Analyses (multi-hazard)
    IA3 – Reactor Containment Analysis
    IA4 – Long Term Coping Studies/FLEX

The description and proposed scope with associated schedule, and timelines of the four applications above is discussed in the next sections.

2.1 IA-1 Integrated Cladding / ECCS Performance Analysis

For several reasons, NRC is considering a rulemaking that would revise requirements in 10 CFR 50.46 (the ECCS rule). Fairly recently, work sponsored by NRC suggested that the current regulatory acceptance criteria are actually non-conservative for higher-burnup fuel (i.e., that embrittlement mechanisms not contemplated in the original criteria exist and the 17% limit on oxidation is not adequate to preserve the level of ductility that NRC originally deemed to be warranted for adequate protection).

At this writing, a rulemaking is being contemplated to address several points, including the above. In interest of accuracy, key excerpts from SECY-12-0034 are provided as follows:

SUMMARY:

The staff has prepared a proposed rule … that would replace the current regulations for ECCS, found in § 50.46, by establishing performance-based requirements. The proposed rulemaking would incorporate recent research findings which identified previously unknown cladding embrittlement mechanisms and expanded the U.S. Nuclear Regulatory Commission's (NRC or the Commission) knowledge of previously identified mechanisms. The proposed rule would also expand applicability of ECCS acceptance criteria to all light water reactors, regardless of fuel design or cladding materials (as per Commission direction, and the request of petition for rulemaking (PRM) PRM-50-71). Finally, the proposed rule would require licensees to evaluate the thermal effects of crud and oxide layers which may have developed on the fuel cladding during normal operation.

…

Information developed through the NRC's high burnup fuel research program has identified that the current criterion for preventing fuel cladding embrittlement may not be adequate to ensure the health and safety of the public. As discussed in Sections II and V of this Statement of Considerations, zirconium-based alloy fuel cladding materials may be subject to embrittlement at a lower combination of temperature and level of oxygen absorption (17 percent) than currently allowed under § 50.46(b)(1) due to absorption of hydrogen during normal operation. The proposed rule would correct those limits initially established to prevent embrittlement of zirconium-based alloy cladding material based on the new research information. In addition, the research work has identified new phenomena, such as breakaway oxidation and oxygen diffusion from the cladding inside surfaces, which are believed to further adversely affect the fuel cladding embrittlement process. Thus, post quench ductility (which is necessary to ensure coolable core geometry)[*] is not guaranteed following a postulated LOCA. The proposed rule would establish new requirements for zirconium-based alloys to prevent breakaway oxidation and account for oxygen diffusion from the oxide fuel pellet during the operating life of the fuel. In sum, the NRC believes that imposing the requirements of the proposed rule is necessary to prevent embrittlement of fuel cladding and to restore the rule to the level of reasonable assurance of adequate protection to public health and safety.

[*] *The Commission concluded, as part of the 1973 Emergency Core Cooling System rulemaking, that retention of ductility in the zircaloy cladding material was determined to be the best guarantee of its remaining intact during the hypothetical loss-of-coolant accident, thereby maintaining a coolable core geometry. See Acceptance Criteria for Emergency Core Cooling Systems for Light-Water-Cooled Nuclear Power Reactors, CLI-73-39, at page 1098 (December 28, 1973).*

…

With respect to current nuclear power plant licensees, the NRC assumes that imposition of the proposed rule would constitute backfitting as defined in § 50.109(a)(1). However, the NRC believes that the proposed rule must be imposed upon current nuclear power plant licensees in order to ensure adequate protection to the public health and safety by restoring that level of protection (i.e., reasonable assurance of adequate protection) which the NRC thought would be achieved (throughout the entire term of licensed operation) by the current rule. Therefore, the NRC has determined that the proposed rule is necessary to ensure that the facility provides adequate protection to the health and safety of the public, and that a backfit analysis as described in §§ 50.109(a)(3) and (b) need not be prepared under the exception in § 50.109(a)(4)(ii).

The proposed rule would apply to an LWR and to all cladding types, including ATF. For present purposes, the key points are as follows.

- Cladding performance cannot be evaluated in isolation. Cladding performance and ECCS performance need to be considered together. It is the plant-level response that matters.

- Models for cladding performance even within the design basis will need to be updated for regulatory purposes.
- Effort needs to be expended in searching regulatory issue space for the limiting casein addition, for novel cladding, there may be more stringent reporting requirements on the analysis ("ECCS performance must be demonstrated for a range of postulated loss-of-coolant accidents of different sizes, locations, and other properties, sufficient to provide assurance that the most severe postulated loss-of-coolant accidents have been identified. ECCS performance must be demonstrated for the accident, and the post-accident recovery and recirculation period." SECY-12-0034).

A multi-faceted comparison of today's fuel with a candidate ATF is suggested as follows:

1. Analyze today's cladding in light of the potential new requirements on design-basis analysis, including exploration of the design-basis issue space for the limiting case
2. Analyze today's cladding performance in a to be determined severe accident issue space
3. Analyze a candidate ATF technology within the design-basis issue space as that considered for today's cladding
4. Analyze the same ATF in the same severe accident issue space as that considered for today's cladding.
5. Conduct the implied comparisons.

In performing the above tasks, consider the following:

- Identification of the limiting case in the design-basis analysis is potentially labor-intensive and demonstrates that this requirement being met might be more convincing if an automated and auditable exploration of the issue space were feasible.
- New physical models and associated data need to be developed for ATF.
- Because it is plant-level response to harsh conditions and not just cladding response, a comprehensive Failure Mode and Effects Analysis (FMEA)/ Phenomena Identification and Ranking Table (PIRT) may need to be conducted to support analysis of the severe accident case, addressing non-fuel components and phenomena. [7]
- New models implied by the FMEA/PIRT will need to be developed.
- In order to explore the issue spaces adequately, either very fast simulations will be needed or emulators will need to be constructed (at least for the severe accident analysis).

Summarizing, the proposed 50.46c Rulemaking Involves the Following LOCA R&D, methodology development, and analysis scope:

1. Revise fuel vendor LOCA evaluation models to address new requirements and to evaluated cladding hydrogen concentration based equivalent cladding reacted analytical limit. Then obtain NRC approval of the revised EMs and perform new plant specific analyses of record licensees will implement.
2. Evaluate the effects of post-LOCA debris on core cooling. Most PWRs are planning to pursue the new alternate risk-informed approach. The BWRs are behind on this issue, but will probably follow the same approach as the PWRs. STP has already engaged NRC as the pilot plant and they are responding to RAIs. The NRC intends to issue a draft Reg. Guide in spring 2015. There is a group of PWR (the non-pilot plants) that have also engaged NRC and are watching the STP pilot.
3. NRC is proposing a second peak cladding temperature limit for the long-term. A second cladding heatup can occur for a number of reasons. Industry's position is that the research has not been performed (cladding failure mechanisms and thresholds established) and it is premature. Industry

wants a Reg. Guide in parallel with rulemaking. There has not been any testing of cladding specimens that have gone through a second LOCA heatup. The PWROG is doing analysis to establish the temperature envelope for the second heatup. For BWRs the spray cooling tests should be good, but the additional effect of debris needs to be tested. EPRI has proposed a program to do long-term cooling tests. BWRs probably have a challenge here.

4. Breakaway oxidation can occur if cladding remains above a high-temperature threshold (like 1700F) for more than 3000-5000 seconds. The NRC is testing cladding to establish the limit. The industry's position is that no plants violate these temperatures and times.
5. The new LOCA issue is fuel fragmentation, relocation, and dispersal. There appears to be a threshold around 55 GWd/mt-U where fuel pellets change to sand during a LOCA heatup. The NRC had decided not to include this in the 50.46c rulemaking, currently. EPRI has performed some testing to try to establish the threshold, and more testing is planned.

The above scope is considered too broad to be used in a timely industry demonstration application sense; hence we select a narrow subset of the above topics as the initial focus of the RIMM Industry Applications. The specific tasks of this Industry Application are itemized in the Integrated Priority List (IPL) in the Appendix of this report. Cost and Schedules are discussed in Section 3.1.

2.2 IA-2 Enhanced Seismic / External Hazard Analysis

Given that hazards external to a nuclear facility may negatively impact a variety of structures, systems, and components (SSCs) from direct damage (e.g., failure during a fire) or indirect damage (e.g., consequential failure from a flood following a pipe break), there is a possibility that initiating events, reduced redundancy levels, reduced reliability, or degraded safety barrier may be realized, thereby increasing the likelihood or severity of potential accident scenarios.

A class of hazards to nuclear facilities originates external to the plant. These external events are a class of initiating event that has the initial deviation caused by a hazard located outside the normal plant SSCs. Physical impacts such as fires, floods (e.g, see Figure 7), and earthquakes are typically included in this group of initiating events.

Figure 7. Actual Flooding Event.

This application focuses on plant system behavior as a result of external events influencing plant operation, in particular, multiple external events, and/or cascading events that affect the entire system behavior.

External events to be considered are:

I. Seismic Analysis
II. Multi-Hazard Analysis: Seismically Induced Flooding

I. Seismic Analysis

The following activities are proposed:

1. EPRI-INL Plant Data Study
   Deliver documentation of relevant seismic data to perform a Seismic PRA on a generic NPP, with generic soil site, and at least 2 SSCs identified. Describe tools and methods to be utilized. (1Q15)
2. Early Demonstration (eDemo)
   a. Perform a traditional SPRA on system identified in (1) (CLASSI/SAPHIRE) – analysis to be performed per NTTF recommendation 2.1 and EPRI SPID process. (1-2Q15)
   b. Perform an advanced SPRA on system identified in (1) (ABAQUS/SAPHIRE/RAVEN) – advanced analysis means utilization of RISMC tools (i.e. RAVEN) and non-linear structural mechanics tools (ABAQUS). For the early demonstration we restrict the analysis to existing tools (no tools development required). (1-3Q15)
   c. Deliver draft documentation on the above 2 items and comparison analysis of traditional vs. advanced methodologies, with recommendations on path forward. (3Q15)
3. Advanced SPRA-RISMC tools and methods
   a. Development of seismic structural mechanics and RISMC tools compatible with MOOSE (FY15/16/17)
   b. FY15 deliverable – letter report on progress of tools development (4Q15)
   c. Realistic SPRA Application – analyze effects of a past event (i.e. earthquake/tsunami) on a full NPP system (FY15/16)
   d. Draft report of realistic SPRA analysis using RISMC tools, including data validation of full NPP system choice (4Q15)
4. Seismic Isolation Demonstration (key existing components only) (FY16)
5. Seismic induced Flooding Analysis (FY15/16) (see section II below)

II. Multi-hazard Analysis

We need to represent external hazards directly by creating a virtual nuclear facility model that is impacted by potential hazards such as fire, floods, or seismic events.

A variety of steps are required for this simulation analysis. First, we construct a model representing the various structures at the nuclear facility. Then, as part of the simulation, we are going to represent an external hazard (which occur stochastically) and look at implications to the onsite structures. Second, the simulation continues by translating the physics-based mechanistic calculation into an impact in the accident scenario. For example, if a SSC becomes degraded, this state would be applied to the component in the model (perhaps it is a wall or a pipe) using another stochastic model (in this case, a degradation model). Once the SSC state is specified, then the scenario would continue because the SSC may experience further damage. Third, we simulate the spatial types of interactions that are unique to the hazard being represented by using physics-based 3D environments that have been developed for industries such as visualization and environment depictions (e.g., virtual reality). These 3D environments are capable of mimicking realistic physics such as flowing water and objects impacting other objects. Fourth, as the spatial interactions are being represented in the 3D environment, the accident scenario generator continues because the hazard may (later in time) fail collateral SSCs (say a pump in the same room as a leaking pipe). At this point in the scenario, we are representing a complete external hazard scenario (see Figure 8).

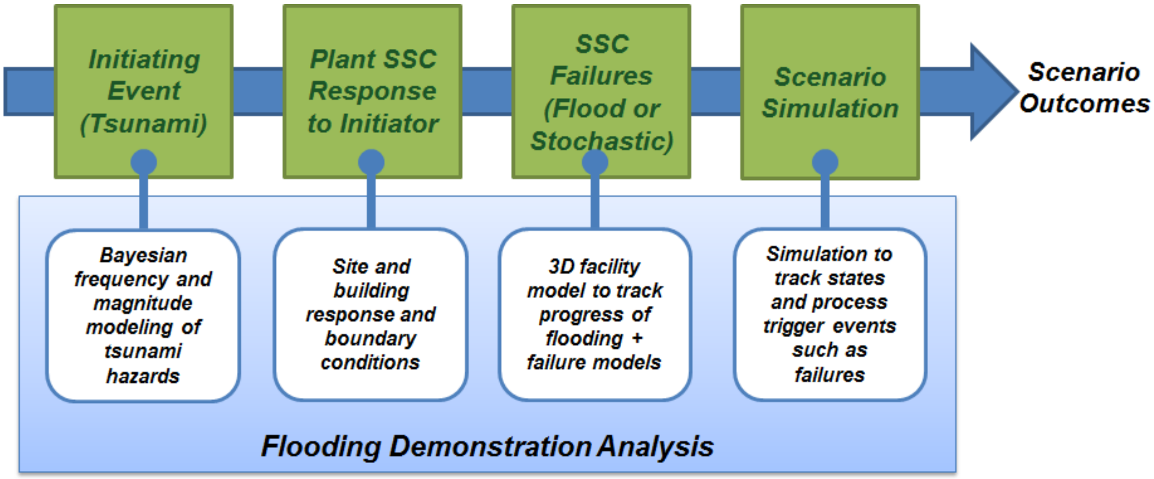


Figure 8. Realistic Flooding Demonstration Flowchart. [8]

The development of the 3D modeling engine to represent external hazards has been identified as a potential initial application of the methods, tools, and data RISMC activities. For the industry applications, we will focus on the following:

1. Implement a 3D modeling engine that is capable of representing the physical dimensions of key SSCs, including physical properties such as mass, inertia, momentum, and frictional interfaces.
2. Implement a 3D modeling engine that is capable of representing the spatial interaction of objects due to the failures of SSCs.
3. Implement a 3D modeling engine that is capable of large-scale particle tracking in order to represent hazards such as flooding. This 3D physics engine will be capable of representing fluid flow entering the facility site through the facility infrastructure (e.g., entering penetrations or doors in buildings and moving to lower levels through stairwells) and fluid flow around the facility SSCs.
4. Implement an enhanced PRA controller to use emulators (or reduced-order models) as a surrogate for other models when possible, including providing a mechanism to use adaptive sampling during simulation when possible.
5. Implement a 3D physics engine that is capable of representing the motion of objects and to manage the collisions of objects.
6. Implement a simulation engine that is capable of enabling specific physics-of-failure models for SSCs as needed as part of a scenario.
7. Implement a simulation engine that is capable of storing and passing information between other engines (e.g., between the physics-of-failure engine and the 3D physics engine); this engine will be capable of providing scenario-based results to analysts.
8. Implement a simulation engine to provide the ability to find vulnerabilities (i.e., potential weaknesses related to hazards and associated scenarios) as part of the integrated simulation approach.
9. Implement a simulation engine to provide a mechanism to allow users to specify and track (as part of the analysis) the safety outcomes of interest.

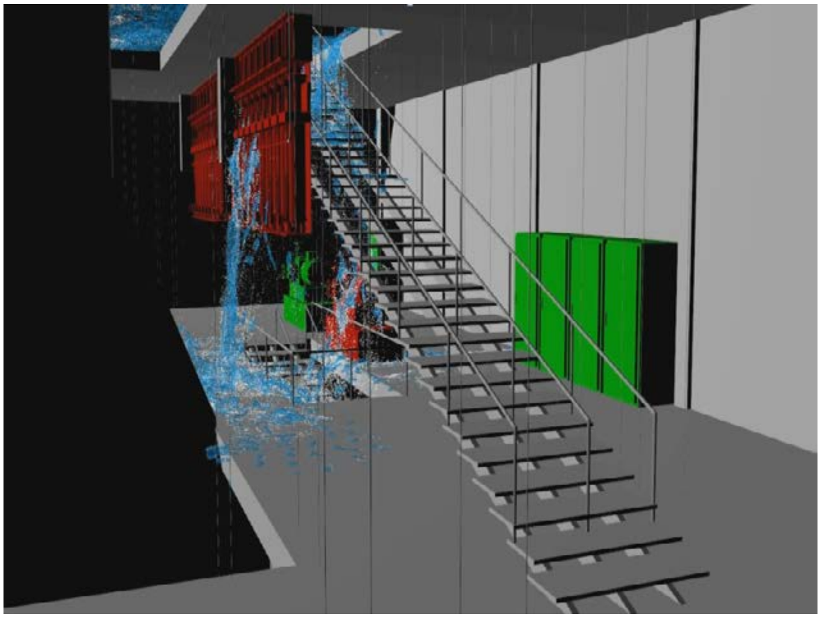


Figure 9. Realistic Component Modeling in Flooding Analysis.

Some of the above items are well under development (for more information on the modeling work, see examples in References [8,9]). In Figures 9 and 10 we illustrate examples of some of these models developed for the detailed flooding simulation. The specific tasks to apply these models into a realistic Multi-Hazard Industry Application are itemized in the Integrated Priority List (IPL) in the Appendix of this report. Cost and Schedules are discussed in Section 3.1.

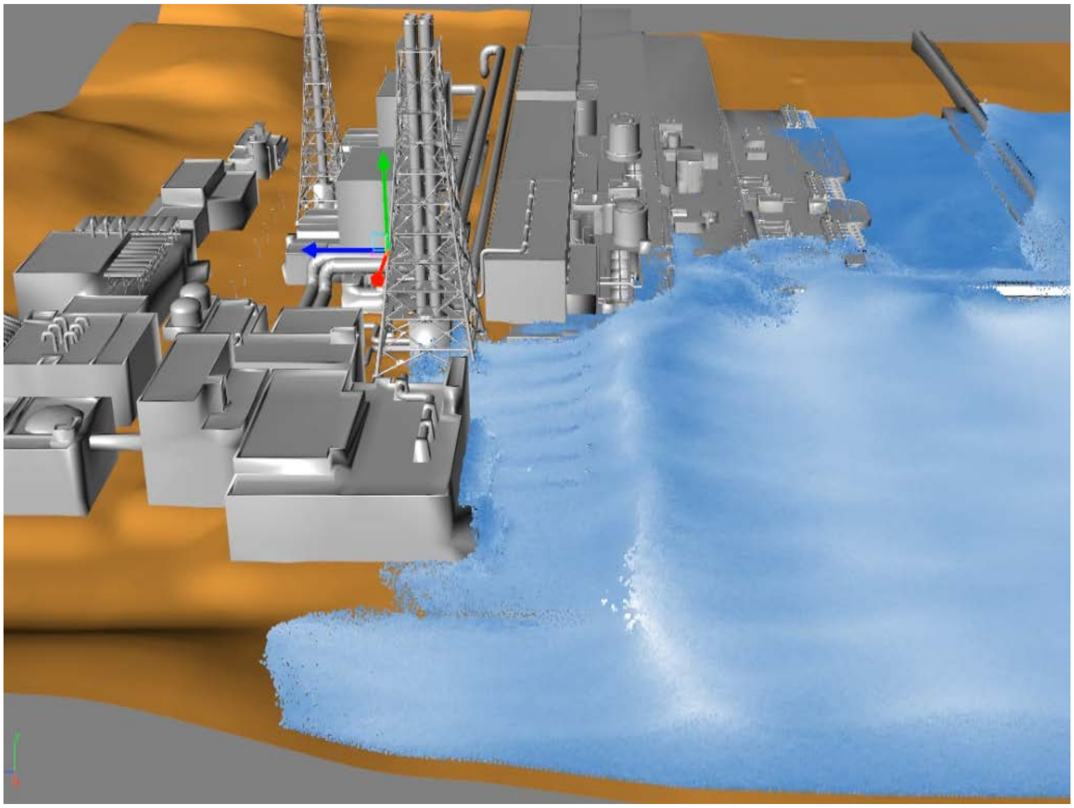


Figure 10. Plant and Terrain Modeling in a Tsunami Scenario.

2.3 IA-3 Reactor Containment Analysis

One of the safety improvements mandated by the NRC following the accident at the Fukushima Daiichi nuclear facility is to have reliable, hardened containment venting systems capable of operating under beyond-design-basis (BDA) and severe accident (SA) conditions and installation of containment engineered vent filtration systems to reduce the release of radioactive materials should a SA occur for Mark I and Mark II containments [10,11]. Given the relatively small volumes of Mark I and II containments which depend on suppression pools and have no mitigation for hydrogen, ensuring the availability of reliable, hardened containment vents will provide plant operators with improved methods to vent containments during wide range of BDA accidents (but before core melt). Venting containment can help prevent or delay the loss of, or facilitate recovery of, important safety functions such as reactor core cooling, reactor coolant inventory control, containment cooling, and containment pressure control. However, the industry has stated that the addition of filters to hardened containment vents may require modifications to vent design. EPRI study indicated that the containment venting alone is not effective. It has to be combined with active debris cooling to be effective. [12] Hence, accident sequences need to be better understood to determine under what conditions the filters are beneficial or non-beneficial.

Another important factor in containment analysis has to do with containment overpressure. Containment overpressure is the pressure above atmospheric inside the containment caused by the energy release during the accident. That pressure, when added to the static head, can keep the water pressure inside the ECCS pump from dropping below the vapor pressure. However there are concerns that there are possible accident scenarios where containment overpressure might not be available. One such scenario involves a stuck-open safety relief valve. In such scenario, the steam bypasses the drywell to flow directly through the vent system into the wetwell. The suppression pool water gets heated before the drywell gets pressurized. Containment overpressure is not guaranteed for this scenario. There are other events that could result in the loss of containment overpressure such as valves not closing properly, pipes leaking or the wetwell's walls cracking. The ACRS has consistently expressed concerns with the use of this margin because it represents a decrease in the safety margin available to deal with a phenomenon that is subject to large uncertainties, namely, maintenance of adequate NPSH for ECCS pumps during accident. [13]
The containment behavior under accident conditions involves complicated multi-scale and multi-physics phenomena. The multi-physics phenomena simulated will include multi-phase fluids flow, heat transfer, fission product transport and deposition in containment, hydrogen transport and detonation, chemical reactions, and thermo-mechanical responses. The multi-scale simulation will include from millimeter scale to hundred-meter scale spanning from capturing boundary layers from small scales such as condensation layer with non-condensable gas and hydrogen plume to large scale simulations such as the entire containment recirculation pattern. The current containment analysis codes rely on lumped parameter approach and could not capture the important multi-dimensional phenomena in the containment.

The new containment analysis module, coupled to the RELAP-7 code, will be developed to have multi-physics and multi-scale simulation capability with the goal to greatly reduce uncertainty in containment safety analysis and have science-based predictability in safety transient behaviors.
In this new module, a multi-dimensional analysis capability will be developed to analyze large open spaces within a containment or confinement building to replace traditional lumped parameters approach or pseudo two-dimensional field simulation. (The pseudo two-dimensional field simulation normally contains simplified turbulence models or even no turbulence model at all and with outdated numerical methods which cannot take advantage of modern high performance computing such as parallelization.) Three-dimensional hydrogen transport and detonation capability and fission product transport and deposition capability will be developed with emphasis on verification and validation.

The following are the proposed activities to perform containment analysis:

1. Select a plant model
   A BWR with Mark I containment will be selected as the target plant to be analyzed. The Peach Bottom plant is likely to be the candidate plant.
2. Obtain existing analysis tools from the following list:
   a. RELAP5 (INL)
   b. MAAP (EPRI)
   c. GOTHIC (EPRI)
   d. MELCOR (Sandia)
3. Establish input files (decks) for the target plant model using the existing tools or review existing analysis results.
4. Demonstration and evaluation of the capability of the existing analysis tools
   a. The BWR Station Blackout (SBO) accident will selected as the accident scenario to be analyzed.
   b. Analysis of SBO accident will be performed with selected existing tools. Various scenarios will be analyzed such as without containment venting, with containment venting, filtered vents, etc. The tools will be calibrated with each other on the simulation capability, predictive capability and performance. The peak clad temperature and peak containment pressure will be used as the figure of merits (FOM) for the comparison of the codes performance.
   c. Perform sensitivity analysis of the SBO accident simulations.
   d. Suggest RISMC analysis methodology to study the venting strategies such as when to vent, where the vents should be located, etc.
5. Demonstration of the initial RELAP-7 analysis capability for containment
6. Develop long term models and methods plans
   a. Develop a long term development plan for analysis tools for containment analysis.
   b. Develop a long term development plan for RISMC methodology for containment analysis.
   c. Develop containment analysis module for RELAP-7

Proposed Milestones:

1. FY15*: One milestone report will be delivered after completing tasks 1 thru 3 to document the progress on establishing the plant containment simulation models with the existing tools.
2. FY15*: One milestone report will be delivered after completing task 4 & 5 to document the analysis results and the analysis capabilities of the existing tools as well as RELAP-7.
3. FY16: Extend RELAP-7 capability to perform BWR Mark I containment analysis.
4. FY17: Verification and Validation of BWR containment analysis capability of RELAP-7.
5. FY18: Extend RELAP-7 containment analysis capability to PWRs.
6. FY19: Verification and Validation of LWR containment analysis capability of RELAP-7.

*Note: Activities may not start in FY15, depending on funding and resources availability.

2.4 IA-4 Long Term Coping Studies

Diverse and Flexible Coping Strategies (FLEX) [14] (see Figure 11) aim at increasing defense-in-depth for beyond-design-basis scenarios to address an extended loss of off-site (ac) power and loss of normal access to the ultimate heat sink (LUHS) occurring simultaneously at all units on a site. The objective of FLEX is to establish an indefinite coping capability to prevent damage to the fuel in the reactor and to maintain the containment function by using installed equipment, on-site portable equipment, and pre-staged off-site resources. The coping can be thought of as occurring in three phases:

Phase 1: Cope relying on installed plant equipment
Phase 2: Transition from installed plant equipment to on-site FLEX equipment
Phase 3: Obtain additional capability and redundancy from off-site equipment until power, water, and coolant injection systems are restored or commissioned.

The primary objective of establishing the FLEX analysis capability is to establish a RISMC framework which uses the system safety analysis tools to 1). Better understand the accident sequence and recovery strategies, and 2). Search any vulnerability that might exist with FLEX. The FLEX case study requires coordination with the external hazard analysis and containment analysis case studies. The external hazard analysis and containment analysis case studies emphasize more on the deterministic analysis tools development while the FLEX case study emphasizes on RISMC methodology development and applications.

The following are the proposed activities to perform FLEX analysis:

1. Select a plant model

   A BWR with Mark I containment will be selected as the target plant to be analyzed. The Browns Ferry or Peach Bottom plant is likely to be the candidate plant.
2. Obtain existing analysis tools
   a. RELAP5 (INL)
   b. MAAP (EPRI)
   c. GOTHIC (EPRI)
   d. MELCOR (SNL)
3. Establish input files (decks) for the target plant model using the existing tools or review existing analysis results.
4. Demonstration and evaluation of the capability of the existing analysis tools
   a. The BWR extended loss of AC power (ELAP) and loss of ultimate heat sink (ULHS) as the accident scenario for Phase 1 to be analyzed.
   b. Analysis of the ELAP + ULHS accident will be performed with selected existing tools.
   c. Establish a framework with the RAVEN code to demonstrate dynamic PRA analysis with the existing tools for Phase 1
5. Develop a long term models and methods development plan
   a. Develop a long term development plan for RISMC methodology for FLEX.
   b. Develop FLEX analysis module for RAVEN

Proposed Milestones:

1. FY15*: One milestone report will be delivered after completing tasks 1 thru 3 to document the progress on establishing the ELAP + LUHS simulation models with the existing tools.

2. FY15*: One milestone report will be delivered after completing task 4 to document the analysis results and the analysis capabilities of the existing tools.
3. FY16: Extend RAVEN capability to perform BWR FLEX analysis to Phase 2.
4. FY17: Extend RAVEN capability to perform BWR FLEX analysis to Phase 3.
5. FY18: Extend RAVEN capability to perform PWR FLEX analysis to PHASE 1 & 2.
6. FY19: Extend RAVEN capability to perform PWR FLEX analysis to PHASE 3.

*Note: Activities may not start in FY15, depending on funding and resources availability.

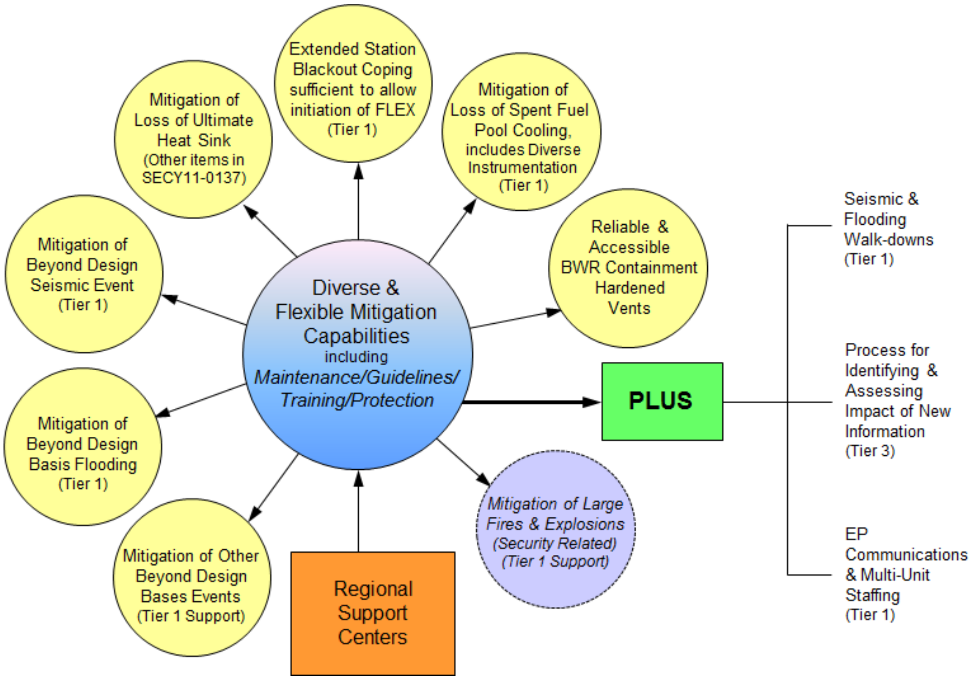


Figure 11. The Nuclear Industry Diverse and Flexible Coping Strategies (FLEX). [14]

2.5 Other Industry Applications

As result of the prioritization and selection process [6] of the Industry Applications, many issues important to the nuclear industry were considered. The four top ranked industry issues were selected and proposed in the above sections as part of the RISMC Pathway activities within the DOE LWRS Program. Other industry issues that also ranked high, but are not included in this plan, may be of interest to other DOE R&D activities, and could be considered for further analysis by other programs.

Two of these high-ranked activities (also listed in Table 1) are:

- Advanced Reactor Analysis
- Spent Fuel Pool Analysis

For further detail on these issue spaces, refer to the Use-Case Analysis document, in reference [2].

3. INTEGRATED ADVANCED SAFETY ANALYSIS ACTIVITIES

In Section 2, we described the initial steps of activities designed to use RISMC methodology to address the nuclear industry issues of high value to the operating nuclear fleet. In this section we will provide additional detail about these applications, integrating these activities into the overall RISMC Pathway process.

3.1 Combined Industry Applications Cost and Schedule

The Industry Application activities (IA1 through IA4) are part of the overall RIMM Applications process (see also Figure 5), which is outlined below in Figure 12.

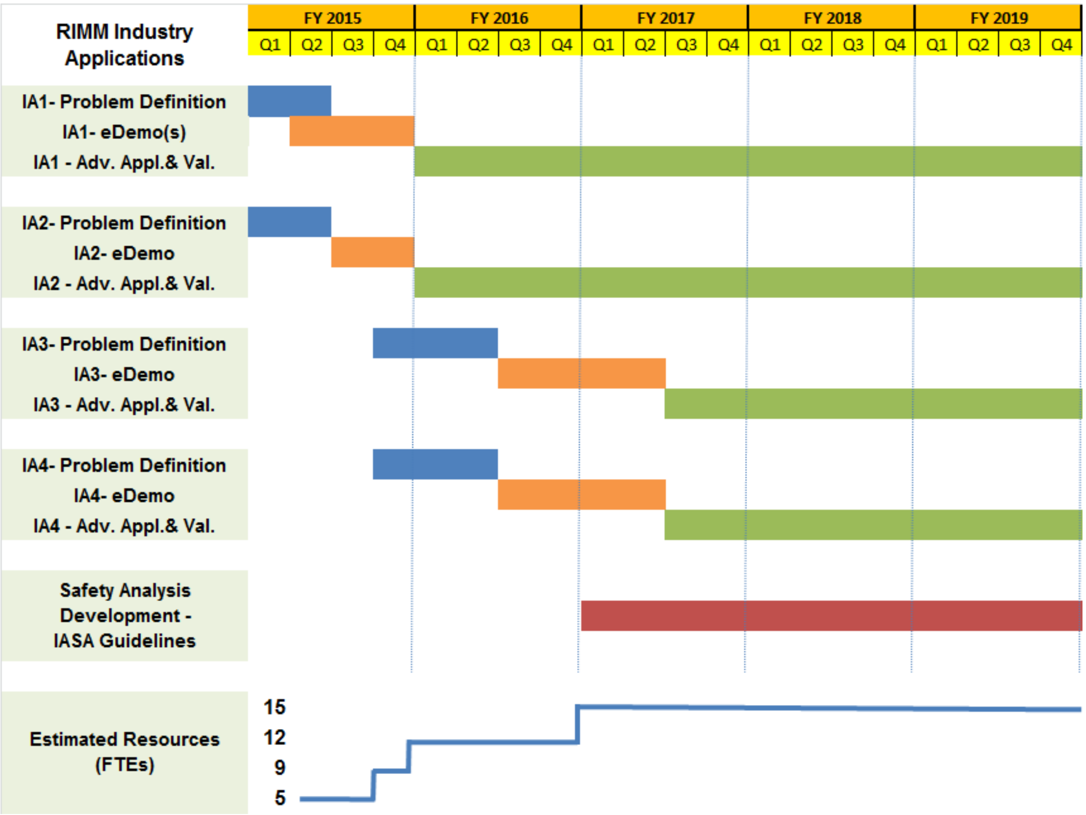


Figure 12. Overall schedule and proposed resource allocation for the RIMM Applications.

It is anticipated that the initial project startup level will be approximately 5 FTEs in FY15, focusing on the first two applications (IA1 and IA2). The cost to develop all four proposed Industry Applications is estimated to be 9 FTEs, initially, but this may not be achieved until FY16 (subject to funding and resources availability). As the program ramps up, with additional resources dedicated to the early demonstrations, the full application and validation of the identified problems, and development of the respective safety analysis guidelines, we estimate a ramp rate of approximately 3 FTEs per year. Since the schedule has been designed to address four industry applications concurrently, a target investment to successfully carry out the applications and R&D is achieved at approximately 15 FTEs per year. Additional parallel activities, associated with the RISMC Toolkit Development and the validation of the methods, tools, and data for the industry applications will be conducted over the same time period, however estimated resources for these activities are not included here.

It is expected that DOE would support development, conduct workshops to inform the users of the capabilities, and perform initial validation activities. It is expected that, once industry applications are completed, the end users would fund their own adoption, installation, and training.

The development of the Safety Analysis Guidelines is directly tied to the execution of the four proposed Industry Applications, and ultimately tied to the relevancy of the industry Issue Spaces discussed in Section 1.2. As the demonstration of the Industry Applications progresses, it is expected we further determine scope, schedules and priorities for the Safety Analysis Guidelines. In principle, there could be one or more guidelines per Issue Space, as it has been shown in Figure 3. This work is not expected to take place at least two years into the Industry Applications project execution, circa FY17.

3.2 Stakeholder Interaction Activities

For the RISMC development, we defined above a set of industry applications for RISMC methods, tools, and data that provides a straw-man to be discussed with stakeholders as we continue the program planning activities. Note that the prioritized list of industry applications is not exhaustive, this allows for the addition of future applications as needed. Further, we anticipate that as stakeholder interactions continue, the industry applications list will continuously be updated. As the top selection by the industry stakeholders, these applications provide the most important demonstration cases with a focus on (a) near-term practical applications such as its potential to improve economics and maintain safety; (b) urgency in addressing an ongoing and relevant stakeholder issues; and (c) the establishment of the RISMC methodology’s strengths, viability, and utility.

The industry community, identified as stakeholders of the LWRS Pathway (see Figure 5), are essential to the success of the industry applications execution. They can be classified as:

- Nuclear reactor vendors, such as Areva , GE-Hitachi, Holtec, mPower, NuScale, and Westinghouse
- Nuclear power plant owner/operators
- Nuclear industry consultants such as simulator, safety analysts, and software companies
- Nuclear industry R&D organizations, such as EPRI
- Universities engaged in nuclear R&D (including NEUP)
- DOE National Laboratories
- DOE R&D Programs: NEUP, LWRS, NEAMS, CASL, FCRD
- Non-U.S. organizations (e.g., Halden Reactor Project)

The program would also interface with the NRC through constant and effective updates of progress.

Stakeholders, including specific end-users, are an effective and important part of the RISMC methods, tools, and data development. They are involved in every aspect of the project formulation, from planning to scope definition, to execution, and ultimately, to successful application of the RISMC products.

The DOE National Laboratories involvement would be through applications such as severe accident code development (past and present) at Sandia National Laboratories (MELCOR), at INL and other laboratories[1] through a new state-of-the-art integrated computational framework (MOOSE) that supports RELAP-7, [15] or through other DOE Laboratory safety activities.

EPRI would play an important role in high-level technical steering and in detailed planning and execution of application cases. EPRI also would assist in engaging other industry stakeholders to support development and evaluate technical results from the method, tools, and data developments.

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[1] MOOSE license agreements are available free of charge, and are currently held by six U.S. National Laboratories, five foreign national laboratories, twenty-four universities, five U.S. industry entities, and one foreign industry entity.

4. CONCLUSIONS AND RECOMMENDATIONS

In section 1, we described how advanced safety analysis can support DOE's mission of sustaining operation of the U.S. nuclear fleet for long extended periods of time. We proposed, in Section 2, a set of applications, designed to address important, relevant issues for the operating nuclear fleet. Schedules, timelines, and integrated plans were discussed in Section 3 to present the industry with methods, tools, and data that could aid in their decision making process.

In summary, the plan presented here, if fully implemented, is designed to:

- Apply DOE capabilities effectively to help the operating nuclear fleet achieve high confidence in safe operations with optimized economic efficiency for long periods of time;
- Work closely with the industry to analyze, with realism, industry challenges, and overcome obstacles while minimizing the impacts in safety and economics;
- Help the industry fully realize the benefits of modern modeling and simulation in their day-to-day operations and business decision making.

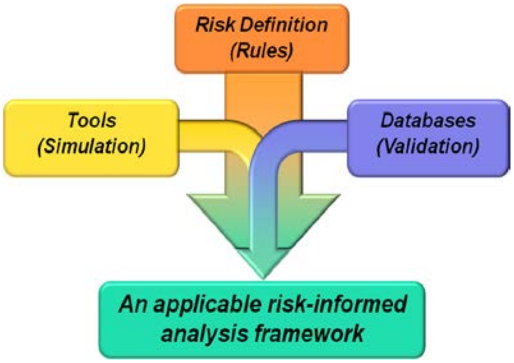

Figure 13. An advanced Risk-Informed Framework – Methods, Tools, and Data.

It is important to recognize that highly complex systems, such as nuclear power plants, can be better understood through advanced modeling and simulation, in ways that were not possible 30 years ago, when most of the existing fleet was built. An advanced computational framework, integrating physics-based tools at multiple levels can provide better representation of reality and predict performance in ways that can help the plant owner and operator achieve improving performance with increasing safety (see Figure 13).

Also, the prioritization process we engaged with the stakeholders in selecting the proposed industry applications, revealed preferences in addressing certain types of problems in the broad range of safety topics. This is illustrated in Figure 14. The 'pyramid' illustration shows high interest in solving problems associated with accident **prevention** mechanisms (base of the pyramid), and less interest in focusing on mitigation phenomena (top of the pyramid). Given the constraint in resources available to address safety analysis issues, it is important to recognize that the bulk of the efforts should be directed to the base of the pyramid. The level of resources shown in Figure 14 should be only viewed in a notional generic sense. The four levels indicated (0-3) are an analogy to PRA levels. Our four high impact proposed industry applications have the characteristics described above.

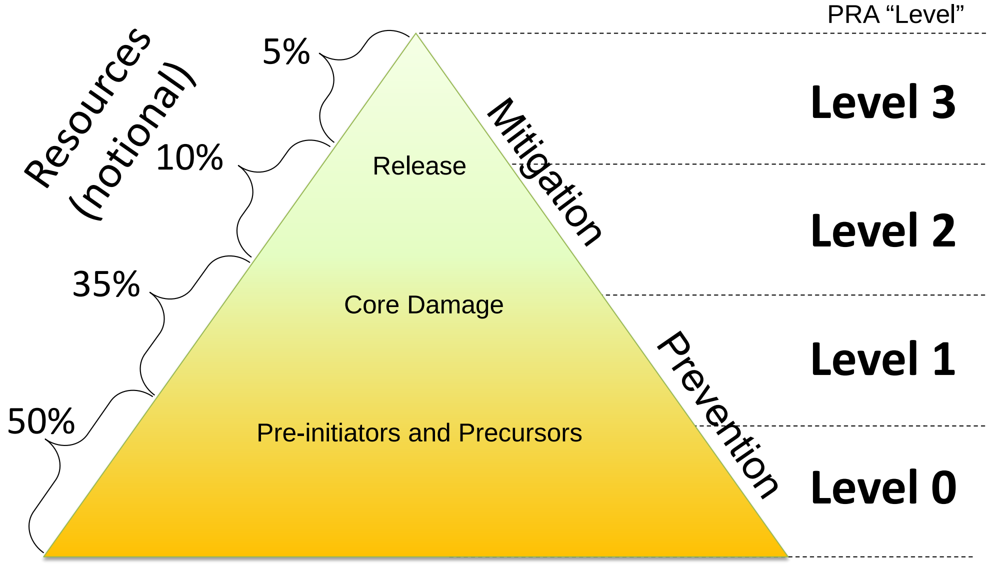

Figure 14. Emphasis on Prevention vs. Mitigation for Modeling and Simulation Resources.

Lastly, the nuclear industry is interested in applying, effectively, the types of advances we advocate here. In particular, risk-informed applications to multiple scenarios that are of interest to the plant owner/operator or the regulator. US regulators, the NRC, are also interested in the effective use of risk-informed methodologies in regulation. During February 2014, the NRC and Industry (NEI) initiated a Joint Risk-Informed Steering Committee to discuss these types of issues, how to better apply risk-informed analysis in licensing applications. This is important in light of the recommendations issued by NRC Fukushima Task Force, which may translate into various types of licensing application submittals by industry in the near-term. The Industry Applications we are proposing are designed to support and address these issues.

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Appendix – Integrated Priority List (IPL)

Scheduling and resources for the four proposed Industry Applications is combined into one list, shown below. The information tabulated in the Integrated Priority List (IPL) below is based on scope presented in Section 2, and costs and schedule, presented in Section 3.

The IPL tabulates the following information:

(a) RIMM High Impact Industry Applications – Industry realistic application focus

IA1 – Performance-Based ECCS Cladding Acceptance Criteria

IA2 – Enhanced External Hazard Analyses (multi-hazard)

IA3 – Reactor Containment Analysis

IA4 – Long Term Coping Studies/FLEX

IA5 – Advanced Reactor Analysis (not included in this Plan)

IA6 – Spent Fuel Pool Analysis (not included in this Plan)

(b) Industry Application (IA) Phases

1. Problem definition (3-6 months)
2. Early Demonstration (eDemo) (limited scope) (6-12 months)
3. Advanced Applications and Validation (Long Term- Methods, Tools, Data) (1-5 years)

(c) Activity Categories

- (M)ethods
- (T)ools
- (D)ata

(d) Task Classification (sub-phase activities)

- (I)NL Task
- (E)PRI Task
- (M)ilestone, deliverable – Level 1 (M1) through Level 4 (M4)
- (O)ther

(e) Other Assumptions

- Case Studies numbered by order of preference
- Cost: quantified by man-months (mm) and FTEs (full-time-equivalent) (1FTE=12 mm)
- FY15 approx. cost: IA1: 2.6 FTEs, IA2: 2.2 FTEs, IA3: 2.5 FTEs, IA4: 1.8 FTEs, → Total ~ 9 FTEs
- IA1-4 assumed to start in FY15
- Lead Demonstration: IA1 or IA2 (TBD) (eDemo ready by end of Feb 2015) – to be defined in coordination with EPRI in October/November 2014 (FY15)
- Safety Analysis Guidelines: Commence as demonstration project ends ~ FY17

Table A-1. High Impact Industry Applications Integrated Priority List (IPL) (IA1 - IA4)

Industry Application (IA 1-4)	Phase (1-3)	Category (M,T,D)	Task # (I,E,M, O)	Activity/Milestone Description	Duration (elapsed time)	DOE Resources (man-mos)	Comments
IA1	1	T, D	1.I, E	Problem definition – describe sub-system physics to be analyzed; identify tools; identify data; identify existing and new experiments	6 mos.	3 mm	Define stakeholder participation: EPRI, lead plant, contractors; collect data
IA1	1	T, D	1.M3	Problem description Report – with description of systems, tools and methods to be used, data identification from lead plant systems, describe potential economic impact on industry	0	0.5 mm	Data – identify fuel and cladding options to be analyzed. Tools – identify tools to be used (risk- how fast can we obtain non-DOE tools)
IA1	2	M	1.I	eDemo 1 – Evaluate the effects of post-LOCA debris on core cooling using a risk-informed approach (RISMC tools)	6 mos.	8 mm	
IA1	2	M	1.M3	eDemo 1 Report	0	0.5 mm	
IA1	2	M	2.I	eDemo 2 – PCT Limit RISMC Search Mechanism – demonstrate how RISMC can search for correct solution space; describe analysis of post-LOCA long term heat up data analysis, Emulator functionality	8 mos.	16 mm	Emulator RISMC capabilities may need to be contracted
IA1	2	M	2.M3	eDemo 2 Report	0	0.5 mm	IA1 total resources needed for FY15 – 31 mm (2.6 FTEs)
IA1	3	T	1.I	Advanced Fuels Performance Tool kit Development	Beyond FY15	1 mm (FY15)	Coordinate with CASL, NEAMS, FCRD
IA1	3	T	2.I	Advanced Systems Analysis kit Development – fully coupled with fuels performance tool	Beyond FY15	1.5 mm (FY15)	Coordinate with CASL, NEAMS, FCRD
IA1	3	D	3.I	RISMC advanced application – Accident Tolerant Fuels (ATF) – Data selection and analysis			Coordinate with FCRD
IA1	3	M	4.I	RISMC advanced application – ATF systems performance (compared to existing fuel cladding performance)			Coordinate with FCRD
IA1	3	D	5.I	Validation of RISMC tools for ATF application			

Industry Application (IA 1-4)	Phase (1-3)	Category (M,T,D)	Task # (I,E,M, O)	Activity/Milestone Description	Duration (elapsed time)	Resources (man-mos)	Comments
IA2	1	T, D	1.I, E	Plant and Model Selection – focus on multi-hazard analysis; outline data needed	2 mos.	1 mm	Work with EPRI in problem definition, plant, data needed
IA2	1	D	1.M3	Case Study Plant Report – select candidate plants, outline problem scope, describe data needed (existing and new if applicable); seismic data analysis, describe potential economic impact on industry	0	0.5 mm	Focus on data report
IA2	2	M, T	1.I	Perform Seismic PRA of selected system	1 mo.	0.5 mm	Follow NTTF recommendation 2.1, EPRI SPPID
IA2	2	T, D	2.I	External and Internal Flooding problem setup, with advanced visualization models	1 mo.	0.5 mm	Using lead plant
IA2	2	M	3.I	Perform RISMC analysis; describe seismic induced flooding problem; identify tools; identify plant, building, equipment options; data	4 mos.	6 mm	
IA2	2	M,T,D	3.M2	Demonstration Report of RISMC analysis of seismic induced flooding; prepare presentations for different target groups (executive, DOE, technical, detailed)	0	1 mm	Prepare presentation to external stakeholders - NSIAC
IA2	3	T	1.I	Development of Advanced Seismic Tools	12 mos.	12 mm	Obtain new data; define advanced methodology; define advanced mechanistic solvers; define advanced PRA tools
IA2	3	M, T	1.M3	RISMC Advanced Tools and Methods for Seismic Analysis	0	0.5 mm	
IA2	3	M	2.I	RISMC Seismic Isolation Application	10 mos.	3 mm (FY15)	Start development of RISMC analysis with seismic isolation considerations; identify experiments/data needed
IA2	3	M	2.M3	Report on RISMC-SI			
IA2	3	D	3.I	Identify additional external hazard to be analyzed	Beyond FY15	1 mm (FY15)	IA2 total resources needed for FY15 – 26 mm (2.2 FTEs)
IA2	3	M,T,D	3.M3	RISMC analysis with specific external hazards identified; develop correlation methodology for multiple hazards			Coordinate with Ohio State NEUP
IA2	3	D	4.I	Verification and Validation of RISMC multi-hazard analysis			

Industry Application (IA 1-4)	Phase (1-3)	Category (M,T,D)	Task # (I,E,M, O)	Activity/Milestone Description	Duration (elapsed time)	DOE Resources (man-mos)	Comments
IA3	1	M	1.I, E	Plant and Model Selection	3 mos.	2 mm	Work with EPRI in problem definition, specifically reliable hardened containment vents
IA3	1	D	1.M3	Plant Options Report – select candidate plants, outline problem scope, describe data needed (existing and new if applicable), describe potential economic impact on industry	0	0.5 mm	Address BWR Mark I candidate, and respective data set
IA3	2	T	1.I, E	Obtain existing analysis tools	5 mos.	7 mm	RELAP5(INL), MELCOR(SNL) Work with EPRI – MAAP and GOTHIC
IA3	2	T	1.M3	Establish input files (decks) for the target plant model using the existing tools and review existing analysis results – report on methods and tools	0	2 mm	
IA3	2	M, T	2.I, E	Demonstration and evaluation of the capability of the existing analysis tools (eDemo)	7 mos.	9 mm	
IA3	2	M, T	2.M2	Existing containment tools demonstration Report – SBO analysis with selected tools; sensitivity analysis of accident simulations; recommendations for future development	0	0.5 mm	Containment analysis of SBO accident will be performed with selected existing tools and candidate plant; apply limited RISMC M/T
IA3	2	T	4.I	Demonstration of the initial RELAP-7 analysis capability for containment	3 mos.	6 mm	
IA3	3	T	1.I	RELAP7-3D MOOSE Tools kit development	FY15/16	6mm* (FY15)	Initiate development of MOOSE 3D components to be coupled to RELAP7 to
IA3	3	T	1.M3	Initial testing of 3D simulation (single-phase, steady-state, thermal-fluids) of a generic PWR using PRONGHORN/MAMMOTH	0	9 mm*	perform fully coupled, detailed 3D analysis where needed*
IA3	3	T, D	2.M3	Demonstrate coupling of 3D simulator (PRONGHORN) to RELAP7 for a benchmark PWR transient problem	0	9 mm*	*ESAAP – Reference [17], part of the RISMC Toolkit Development activities (not scoped in this Plan)
IA3	3	M, T	3.M3	Long term Containment models and methods development plan – Analysis tools plan; RISMC methodology plan; containment analysis module for RELAP-7 (eDemo)	0	3 mm	IA3 total resources needed for FY15 – 30 mm (2.5 FTEs) *not including 2 FTEs for ESAAP [17] (tools development)
IA3	3	M, T	4.M3	Extend RELAP-7 to include 3D capability to perform BWR Mark I containment analysis			
IA3	3	D	5.M3	Verification and Validation of BWR containment analysis capability of RELAP-7			
IA3	3	M, T	6.M3	Extend RELAP-7 containment analysis capability to PWRs			
IA3	3	D	7.M3	Verification and Validation of LWR containment analysis capability of RELAP-7			

Industry Application (IA 1-4)	Phase (1-3)	Category (M,T,D)	Task # (I,E,M, O)	Activity/Milestone Description	Duration (elapsed time)	DOE Resources (man-mos)	Comments
IA4	1	D	1.I, E	Select a plant model	3 mos.	1.5 mm	BWR/Mark I containment will be selected as the target plant to be analyzed (Browns Ferry or Peach Bottom possible candidates)
IA4	1	D	1.M3	Plant model report	0	0.5 mm	Selected plant description and supporting database (collaboration with EPRI)
IA4	2	T	1.I, E	Obtain existing analysis tools	5 mos.	3 mm	RELAP5(INL), MELCOR(SNL) MAAP – see IA3.2.1.I task
IA4	2	T	1.M3	Establish input files (decks) for the target plant model using the existing tools and review existing analysis results – report on methods and tools	0	5 mm	
IA4	2	M, T	2.I, E	eDemonstration and evaluation of the capability of the existing analysis tools	5 mos.	8 mm	
IA4	2	M, T	2.M3	eDemo Report	0	0.5 mm	a. The BWR extended loss of AC power (ELAP) and loss of ultimate heat sink (ULHS) as the accident scenario for FLEX-Phase 1 to be analyzed. b. Analysis of the ELAP + ULHS accident will be performed with selected existing tools. c. Establish a framework with the RAVEN code to demonstrate dynamic PRA analysis with the existing tools for FLEX-Phase 1
IA4	3	M	1.I	Develop a long term models and methods development plan	3 mos.	3 mm	
IA4	3	M	1.M3	Methods plan report	0	0.5 mm	c. Develop a long term development plan for RISMC methodology for FLEX d. Develop FLEX analysis module for RAVEN
IA4	3	T, M	2.M3	Extend RAVEN capability to perform BWR analysis of FLEX-Phase 2			IA4 total resources needed for FY15 – 22 mm (1.8 FTEs)
IA4	3	T, M	3.M3	Extend RAVEN capability to perform BWR analysis of FLEX-Phase 3			
IA4	3	T, M	4.M3	Extend RAVEN capability to perform PWR analysis of FLEX-Phases 1 & 2			
IA4	3	T, M	5.M3	Extend RAVEN capability to perform PWR analysis of FLEX-Phase 3			