INL/EXT-18-51012

Light Water Reactor Sustainability (LWRS) Program
Risk-Informed Systems Analysis (RISA) Pathway

RISA Industry Use Case Analysis

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Executive Summary

The Risk-Informed Systems Analysis (RISA) Pathway within the Light Water Reactor Sustainability (LWRS) Program has been developed to conduct collaborative research that applies risk-informed technology to assist operating nuclear power plants to reduce costs and support their adaptation to the changing economic and generating environment. The RISA strategy emphasizes the identification and conduct of scalable pilot applications with partnering utilities that address issues of current relevance to both the host utility and the industry as a whole.

The RISA Pathway is being performed within the framework of specific Use Cases which are intended to provide a pathway for rapid technology development, deployment, and dissemination throughout the operating US nuclear power plant fleet to address issues of pressing economic, operational, or safety significance. Four specific Use Case categories have been incorporated into the RISA Pathway:

- Enhanced resilient plant concept (including adoption of accident tolerant fuel technologies)
- Cost reduction and risk categorization
- Margin recovery and operating cost reduction
- Market economics (wholesale pricing, energy policy, etc.)

Each of these Use Cases addresses one or more issues of critical importance to ensuring the safe and economic operation of the US fleet of commercial nuclear plants.

This report provides a status of development of utility RISA Use Case applications for which potential sponsoring utility partners have been identified. These applications were developed with utility participation during meetings held at Idaho National Laboratory (INL) on 15 May 2018. Each of these Use Case applications meets the needs of both plant owner / operators and the objectives of the LWRS Program. These applications also meet the needs of the host utilities and the overall industry in that they can be accomplished within a timeframe that can provide economic value to both the sponsoring host utility and the current operating fleet. In particular, the methods and tools that will be developed during these Use Case applications are be designed with the intent that they can be in place and supporting near term resolution of the issue (i.e. within the next 5 years) across the industry.

This report provides descriptions of seven potential Use Case applications for which potential host utilities have been identified and with whom discussions have commenced. Potential Use Case applications have been developed in the following areas:

- Fire Probabilistic Risk Assessment
- Risk-Informed Asset Management
- Plant and System Health Management
- Digital Instrumentation and Controls
- Fuel Enrichment and Burnup Extension to Enable 24 Month PWR Cycles
- Terry Turbine Extended Operating Band Research

- Strategic Risk-Informed Enhancements

With the exception of the last application, an interested host utility / plant has been identified for each application and discussions between the LWRS Program and the prospective host utility are in progress to define project objectives, scope, and schedule. Because the development and deployment of key strategic enhancements (e.g. accident tolerant fuel and passive cooling technologies) is a priority for both the Department of Energy and the industry, it is believed that collaboration with industry organizations (i.e. the Electric Power Research Institute and operating utilities) supporting these efforts will result in identification of one or more lead utilities to provide sponsorship for this Use Case application as well. This report describes the current state of development for each identified Use Case application providing discussions of the following: (1) industry issue statement, (2) problem statement, (3) technical approach, (4) minimum viable product definition, and (5) long term vision.

Because the primary objective of the RISA Pathway is for operating nuclear power plants to successfully adopt and apply LWRS developed technologies to address issues of critical importance to plant safety and economics, significant effort is being expended on obtaining direct input and feedback from plant owner / operators. As a result, the RISA pathway is forming an industry working group that consists of key industry experts to provide technical and programmatic input, as well as participation on pilot demonstrations of RISA technology. This working group includes a broad array of experts from across the industry with representation from utilities (NPP owner / operators), reactor vendors, engineering service providers, NEI, and EPRI.

Contents

Figures

Tables

Acronyms

AHP	Analytic Hierarchy Process
AI	Artificial Intelligence
AMP	Aging Management Program
API	Application Programming Interface
AR	Action Request
ATF	Accident Tolerant Fuel
ATWS	Anticipated Transient Without Scram
BDBA	Beyond Design Basis Accident
BWR	Boiling Water Reactor
CASL	Consortium for the Advanced Simulation of LWRs
CPRR	Containment Protection and Release Reduction
DEC	Design Extension Condition
DOE	(United States) Department of Energy
EMRALD	Event Modeling Risk Analysis using bLock Diagrams
EPRI	Electric Power Research Institute
ER	Equipment Reliability
ERP	Enhanced Resilient Plant
EWRG	Equipment Reliability Working Group
FF	Functional Failure
FLEX	Diverse and Flexible Coping Strategies
ILCM	Integrated Life Cycle Management
INL	Idaho National Laboratory
INPO	Institute of Nuclear Power Operations
IR	Incidence Report
LOCA	Loss of Coolant Analysis
LOTUS	LOCA Toolkit for the U.S.
LTO	Long Term Operation
LWR	Light Water Reactor
LWRS	Light Water Reactor Sustainability
M&D	Maintenance and Diagnostics

M&S	Modeling and Simulation
MOOSE	Multiphysics Object Oriented Simulation Environment)
MPFF	Maintenance Preventable Functional Failure
MSO	Maintenance Strategy Optimizer
MSPI	Mitigating Systems Performance Index
MVP	Minimum Viable Product
NEAMS	Nuclear Energy Advanced Modeling and Simulation
NEI	Nuclear Energy Institute
NPP	Nuclear Power Plant
NRC	(United States) Nuclear Regulatory Commission
NSUF	Nuclear Science User Facility
PRA	Probabilistic Risk Assessment
PWR	Pressurized Water Reactor
R&D	Research and Development
RAVEN	Risk Analysis Virtual Environment
RCIC	Reactor Core Isolation Cooling
RCP	Reactor Coolant Pump
RIA	Reactivity Insertion Accident
RIMM	Risk-Informed Margins Management
RISA	Risk-Informed Systems Analysis
SSC	Structures, Systems, and Components
SLR	Second License Renewal
TDAFW	Turbine Driven Auxiliary Feedwater
TTEXOB	Terry Turbine Extended Operating Band
US	United States

1. Introduction

The Risk-Informed Systems Analysis (RISA) Pathway of the US Department of Energy (DOE) Light Water Reactor Sustainability (LWRS) Program has been developed to conduct collaborative research applying risk-informed technology to assist operating nuclear power plants (NPPs) to reduce costs and adapt to the changing economic and generating-mix environment. The RISA strategy emphasizes the identification and selection of scalable pilot applications with partnering utilities that address issues of current relevance to the host utility as well as the industry as a whole. The outcome associated with each RISA pilot project is to validate technical feasibility and to demonstrate the value of the approach. The RISA Pathway intends to form a working group of utilities and other industry stakeholders to provide input to the project and to share in its outcomes; thus ensuring transfer of results and technology to the industry. As pilot applications are successfully completed, the technologies that are developed and applied are intended to be scaled-up to support applications by a community of users that encompass the entire commercial nuclear power sector.

The RISA Pathway is being performed within the framework of specific Use Cases which are applied by NPP owner / operators. These Use Cases are intended to provide a pathway for rapid technology development, deployment, and dissemination throughout the operating US NPP fleet to address issues of pressing economic, operational, or safety significance. To ensure the RISA Pathway provides impactful research that supports the current and near-term needs of the operating US NPP fleet, Use Cases are designed to be conducted in areas where cost and risk assessment methods / tools can help address issues that, if solved, support closing the economic gap in NPP performance. To achieve this objective, four specific Use Case categories have been identified for the RISA Pathway:

- Enhanced Resilient Plant (ERP) including NPP adoption of Accident Tolerant Fuel (ATF)
- Cost reduction and risk categorization
- Margin recovery and operating cost reduction
- Market economics (wholesale pricing, energy policy, etc.)

Each of these Use Cases addresses one or more issues of critical importance to ensuring the safe and economic operation of the US fleet of commercial NPPs. It should be noted that because these Use Cases can address a wide range of issues, they are not mutually exclusive. As a result, it is expected that applications identified by NPP operating utilities may have aspects that address more than one of these Use Cases. As an example, although ATF is widely recognized as a technology that can result in reduced consequences and likelihood of a severe accident (i.e. contribution to safety enhancement as part of an ERP), the technology also has the potential to contribute to margin recovery and operating cost reductions by serving as an enabling technology for power uprates, fuel enrichment enhancements, and fuel burnup extensions [1].

The primary focus of this report is to provide a current status of development of utility RISA Use Case applications. These applications were developed with utility participation during meetings held at Idaho National Laboratory (INL) on May, 15th 2018. The applications described in this report represent applications identified by the participating utility personnel. Each of these has the characteristic that they meet both the needs of NPP owner operators and the objectives of the US DOE LWRS Program (i.e., (1) maintaining operation of the current fleet to provide reliable, economic, carbon-free electricity and (2) providing a pathway for transition to deployment of advanced reactor technologies). Additionally, these applications meet the needs of utilities in that they can be accomplished in a timeframe that can provide economic value to support both the sponsoring utility and the current fleet of operating NPPs across the US. This characteristic represents an important consideration to accelerate the path from research initiation to deployment. In particular, the Use Case applications described in this report are structured so that the methods and tools developed will be in place and providing value to solve the issue within the next 5 years (i.e. achievement of an end state where the issue has been resolved across the industry). Achieving this objective requires that the methods and tools developed to address the Use Case applications must be usable within the next 2 – 3 years so that they can be applied to address the issue across the industry within the following 2 – 3 years.

In the evaluation of utility Use Case applications, six criteria were developed to support review of proposed applications for further discussions with potential host utilities and eventual selection. These criteria are listed below.

1) The Use Case is consistent with the RISA scope and mission.
2) A utility is identified to host and sponsor the use-case.
3) A "Minimum Viable Product" (MVP) can be defined to demonstrate feasibility and benefits to NPPs.
4) The Use Case is scalable and adaptable to larger scope, more users, or other applications.
5) The Use Case employs technology innovation or demonstrates technology readiness.
6) Results of the Use Case address a critical near-term need of NPPs.

During the meeting at INL on 15 May, breakout sessions were conducted to identify potential Use Case applications in the areas of (1) Risk and Safety, (2) Asset Management, and (3) Engineering and Operations. These sessions identified a candidate list of potential applications. In a subsequent session, these candidate applications were reviewed against a combination of utility interests (to identify potential host utilities) and the list of criteria provided above to identify the most promising set of applications which would be pursued further as part of the RISA Pathway.

For conduct of the applications, a broad suite of computational codes are anticipated to be used within the RISA Pathway. These include both mature codes and advanced simulation codes being developed by the Nuclear Energy Advanced Modeling and Simulation (NEAMS) program and the Consortium for Advanced Simulation of Light Water Reactors (CASL). The current codes identified for use within the RISA Toolkit that will be used in the initial industry pilot applications described in this report are shown in Figure 1-1. As Use Case applications progress and mature, it is anticipated that additional codes will be brought into the RISA Toolkit.

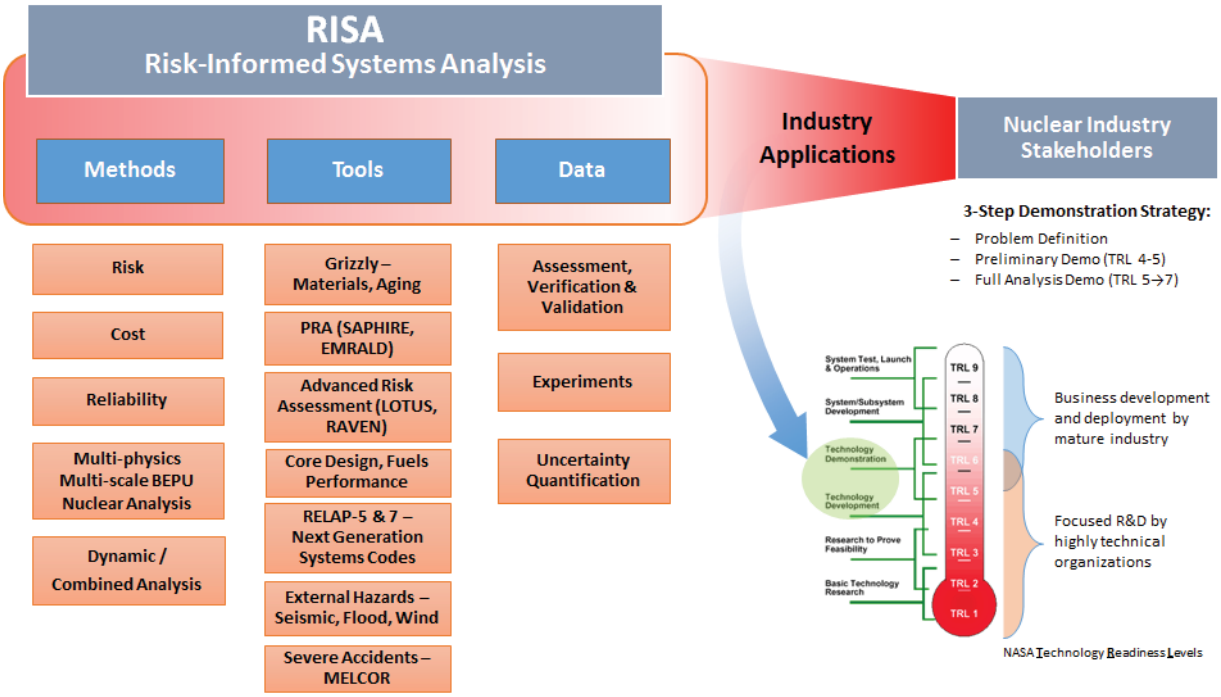

Figure 1-1. The RISA Toolkit and Industry Applications.

2. Strategy, Vision, Mission, and Goals

The RISA Pathway provides enhanced capabilities for analyzing and characterizing LWR systems performance by developing and demonstrating methods, tools, and data to enable risk-informed margins management (RIMM).

The purpose of the RISA Pathway R&D is to support plant owner/operator decisions with the aim to improve the economics, reliability, safety, and sustainability of current nuclear power plants over periods of extended plant operations. The goals of the RISA Pathway are twofold:

- To demonstrate risk assessment methods coupled to safety margin quantification that can be used by decision-makers as a part of their margin recovery strategies.
- To apply the “RISA toolkit” to enable more accurate representation of safety margins for the long-term benefit of nuclear assets.

A strategy to accomplish the above RISA Pathway goals employs the following:

1. Conduct research to develop and demonstrate industry applications through Use Cases employing the RISA methodology in collaboration with organizations from the U.S. commercial nuclear power industry.
2. Align the RISA Pathway Use Cases with existing RISA methods and tools capabilities.
3. Leverage demonstrations with individual U.S. plants to address gaps needed by the entire industry to demonstrate the use of risk-informed techniques to improve plant efficiency

and increase confidence in their use through validation and further development of the RISA methodology.

The RISA Pathway has two primary focus areas to guide R&D activities. The first involves developing a set of tools and methods that can be used to develop the technical basis to assess and manage plant margins and support their use in applications of risk-informed decision-making. In this report we refer to such an approach as Risk-Informed Margin Management (RIMM) These methods are under development and will be described in the RISA Pathway Technical Program Plan, scheduled for completion in September 2018. The second focus area is on industry Use Case demonstrations using modern software and associated tools to quantify safety margins that can be used for commercial deployment. This set of tools, collectively known as the RISA Toolkit, will enable risk analysis capabilities that currently do not exist, as well as to augment ones that currently are in use.

To better understand the approach to characterize and employ safety margins in risk-informed engineering, two types of analyses used in this pathway are integrated: probabilistic and mechanistic analyses, as shown in Figure 2-1. Note that in actual applications, a combined approach is essential where both types of analysis are used to support any one particular decision.

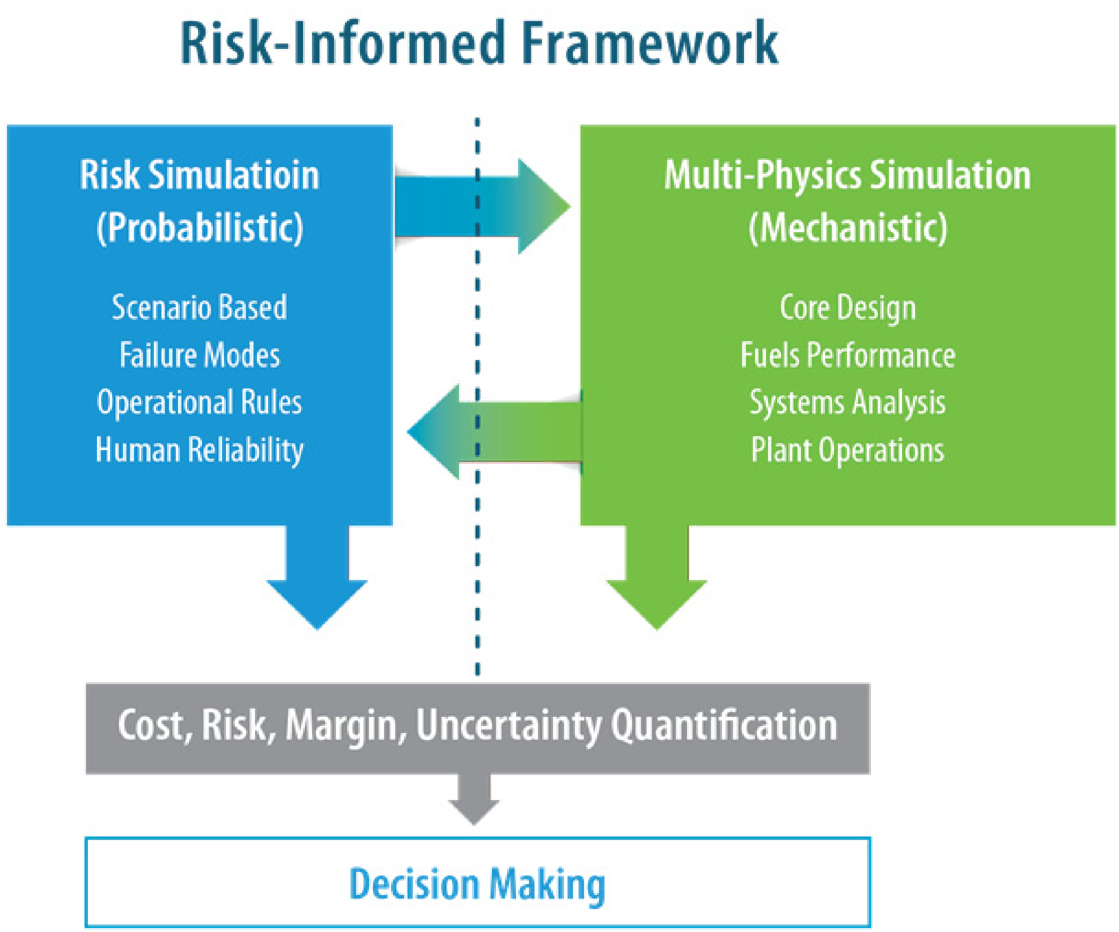

Figure 2-1. Types of analysis that are used in the RISA Pathway.

3. Relevant Industry Use Case Categories

The RISA Pathway used a rigorous process to eventually arrive at a small set of Use Cases, associated utility pilot studies, and longer-term strategies to evolve these pilot studies into larger utility applications. This process is described in some detail in this chapter. The activities which constituted the process and the results of those individual activities are summarized in Figure 3-1 below.

RISA Activity	RISA Activity Result
RISA has developed products: methods, tools, data, and expertise to support risk-informed analysis.	RISA Products constitute a RISA "Tool Kit".
Utilities have pressing needs to which this "Tool Kit" can be applied.	Seven (7) critical utility needs are identified.
RISA settled on Use Case categories with a significant intersection of utility needs and RISA capabilities.	Four (4) Use Case Categories are identified.
RISA solicited candidate Use Case projects.	25 Candidate Use Cases are identified for further consideration to be RISA projects.
Criteria for selection of candidates were proposed.	Six (6) Use Case application selection criteria are identified.
High priority Use Case applications chosen for further development of utility pilot studies.	Use Case pilot study applications are identified for 3 of 4 Use Cases
These Use Cases and their proposed pilot studies are currently under development.	Seven (7) Use Case Pilot Studies are presented in Chapter 4 as RISA Applications.

Figure 3-1. Matrix of RISA activities and results.

The process began with the recognition that over recent years the RISA Pathway has developed a considerable number of risk-informed products in the form of methods, tools, and data sets that are available for use. Some of these resources include:

- RAVEN code [2] for analysis/M&S control, uncertainty quantification, results visualization.
- External events analysis and modeling process enhancements and standardization of Dynamic PRA methods via the EMRALD code [3].
- Multi-physics codes with MOOSE integration framework [4].
- Risk-informed safety, operational, and cost margins characterization.

- LOTUS [5], a LOCA methodology framework for risk-informed analysis of LOCA; and explicitly performance-based analysis for 10CFR50.46c.
- Risk of material degradations over time (Grizzly code) [6].
- A framework for a computational environment that uses Big Data Technology, cloud computing, Artificial Intelligence (AI), Cognitive Analysis, and open source data libraries and applications to speed up development, reduce costs and risk, and encourage collaboration.

In addition the RISA staff, collaborators, and contractors have expertise in applying and adapting such methods, tools, and data to future problems. These resources together with the expertise of the RISA staff constitute a valuable "Tool Kit" for the Use Case projects. It is important that the Use Case applications that are considered for utility demonstration projects by RISA draw upon this Tool Kit – products and expertise.

The next step in the process was to investigate the most pressing needs of utilities to which this "Tool Kit" can be applied. The emphasis is on near-term needs and on cost-saving opportunities. However, the investigation was not limited to providing near-term cost savings. Sometimes the need is for near-term efforts to demonstrate or enable the longer-term sustainability of the plants. Seven critical utility needs are identified and are listed below:

- Near-term and continuing cost reduction in all cost categories – O&M, capital expenses, and fuel
- Continuing high reliability and safety simultaneous with achievement of cost reductions
- Risk reduction relative to costs, reliability, asset protection, or safety
- Opportunities for increased power output and availability from fewer or shorter outages
- Adapting to an evolving smart power grid and a new generating-mix environment
- High performance and low costs in Long Term Operations to 60 or 80 years
- Employing new information technology – Big Data, Artificial Intelligence, Modeling and Simulation, advanced optimization schemes – in NPP processes

After the RISA strengths – products and expertise – and pressing utility needs were identified, the next step was to develop a small number of robust categories for RISA Use Cases that would make best use of the RISA Pathway strengths to support the identified utility needs. RISA settled on four Use Case categories with a significant intersection of utility needs and RISA capabilities. These four RISA Use Case Categories are:

- Enhanced Resilient Plant (ERP)
- Cost reduction and risk categorization
- Margin recovery and operating cost reduction
- Market economics (wholesale pricing, energy policy, etc.)

RISA then solicited candidate Use Case applications from throughout the industry that could reasonably fall within these categories. There were 25 Use Case topics identified that met these criteria. These potential applications were not initially assigned to specific Use Case categories.

The reasons for this decision are that these candidates were to be reviewed, prioritized, and recommended for selection by a diverse group of utility experts and that the specific categories were not important for their evaluation by this group. The categories were determined to be important after selection of the applications to properly manage their development, implementation, and eventual wide-spread use in the industry. Therefore, the candidate list presented in Figure 3-2 below has the projects categorized more closely with the particular work process that they would support at a nuclear plant. The assignment to RISA Use Case Categories is described later. Note that the numbers do not specify any priority assignments or ranking.

CANDIDATE USE-CASES FOR LWRS PROGRAM RISA PATHWAY

MARGINS AND RISK FOR ENGINEERING AND OPERATIONS

- RI 50.46C demo (1)
- RI 50.69 tool/demo (5)
- RI Tech Spec tool/demo (21)
- Aggregate risk/margins impact of DNP changes (8)
- RISMC margins assessment tool/demo (3) *
- Risk/benefit assessment for Flexible Operations (18)
- Margins/risk/benefit of ATF (9)
- Risk/benefit assessment for digital I&C/ autono-mous operation (19)
- RI fuel reload design and risk assessment process/ demo (22)
- Analysis of high enriched high burnup fuel for longer cycles (24)

PRA and PRA-BASED METHODS

- PRA Safety Benefits including FLEX / Fukushima mods (6)
- RI Significance Determination Process (SDP) tool/demo (4)
- Risk/benefit assessment of Dynamic Natural Circulation (DNC) (17)
- Margins/risk of containment functions w/ RISMC tool (15)
- "Loss of Plant" end-state demo with RISMC tool (11)
- Dynamic PRA tool/demo (10)
- Integrated external event PRA method/demo (2)
- Aggregated full scope PRA method/demo (20)
- "Reverse Engineering" PRA to identify mods and ops changes to reduce cost (23)

ASSET/RISK MANAGEMENT

- Enterprise Cost/Risk/ Benefit (ECRB) tool for remaining life refurbish/ replace decisions (12) **
- ECRB model of plant in LTO w/o Power Uprate (13)
- ECRB model of plant in EPU or ultra-PU (14)
- Life Cycle Optimization process/demo using integrating asset/aging/risk management (16)
- RISMC margins method/ demo for dynamic plant health monitoring (7)
- Automating risk-informed plant processes using AI and Big Data (25)

* RISMC margins tool (3) is applicable to 9, 11, 15, 17, 18, and 19 above
** ECRB tool (12) is applicable to 13 and 14 above

Figure 3-2. Listing of candidate RISA Use Case applications discussed at 15 May meeting at INL.

Now that the candidate Use Case applications were formulated, it was necessary to establish a set of selection criteria that was agreed upon by all of the participants in the selection process. These criteria are:

- Results of Use Case application will address a critical near-term need of NPPs
- The Use Case application is consistent with the RISA scope and mission.

- A utility is identified to host and sponsor the Use Case application.
- A "Minimum Viable Product" (MVP) can be defined to demonstrate feasibility and benefits to NPPs.
- The Use Case application is scalable and adaptable to larger scope, more users, or other applications.
- The Use Case application employs technology innovation or demonstrates technology readiness.

These criteria are self-explanatory, except for the fourth one regarding Minimum Viable Product (MVP). This concept is an important element of the RISA strategy for developing Use Case applications. MVP is a development technique in which a new product is developed with sufficient features to satisfy an early adopter for a narrow application. The final, complete set of features is only designed and developed after considering feedback from the product's initial users. The MVP is designed with the intent to expand its user base, scope of applications, and analytical sophistication. The benefit of adopting a MVP approach for these applications is that it provides an effective mechanism to rapidly increase technology readiness as measured on a scale such as previously shown in Figure 1-1.

The next step in the process was conduct of a meeting of utility representatives, industry experts, and RISA staff to "brain-storm" the list of candidate Use Case applications shown in Figure 3-2 with the intention of selecting a small set of high priority use-cases with likely utility sponsors for pilot demonstrations in the near future. The selection criteria were used to guide the discussions.

Seven candidate Use Case applications were selected by the group, and each was assigned to one of the four Use Case Categories described above. These seven Use Cases and their assigned category are:

- Use Case Category: Margin recovery and operating cost reduction

Application: Aggregated Integrated external event PRA method/demo

> The specific pilot application will be a demonstration of Dynamic PRA to simulate fire spreading events to improve estimates of timing and to reduce model conservatism.

Application: Analysis of high enriched high burnup fuel for longer PWR operating cycle.

> The specific pilot application will be demonstration of best estimate analysis with uncertainty of 6% enriched fuel for a 4-loop Westinghouse cycle extension to 24 months

Application: Risk/benefit assessment for digital I&C/ autonomous operation

> The specific pilot demonstration will be determining the risk and reliability analysis and testing for a replacement integrated reactor protection system

(RPS) and/or engineered safety feature actuation system (ESFAS) to support business decision-making to procure the system and to license it.

- Use Case Category: Cost reduction and risk categorization

  Application: Automating risk-informed plant processes using AI and Big Data

  The specific application will be for automatic analysis of failure data for Maintenance Rule Monitoring.

  Application: Life Cycle Optimization process/demo using integrating asset/aging/risk management

  The specific pilot demonstration will be an optimization schedule for capital replacement/refurbishment of major equipment for Subsequent License Renewal to 80 years.

- Use Case Category: Enhanced Resilient Plant (ERP)

  Application: Margins/risk/benefit of Accident Tolerant Fuel (ATF)

  The specific pilot demonstration will be an analysis of the safety and operational benefits of ATF in association with other plant modifications such as FLEX.

  Application: Terry Turbine Extended Operating Band (TTEXOB)

  The specific pilot demonstration will be on investigating the true operating limits of Terry turbines and RCIC from the component level to the system level both computationally and experimentally to allow utilities to take credit for extended emergency core cooling via RCIC.

- Use Case Category: Market economics (wholesale pricing, energy policy, etc.)

  No Use Case applications were selected in this category.

The specific pilot demonstrations and the longer term RISA applications that they support are discussed in detail in Chapter 4 for the above seven Use Case applications.

4. Industry Applications

In this section, the seven industry Use Case applications that are undergoing active development are described. Each of these applications was developed with utility participation during meetings held at Idaho National Laboratory on 15 May 2018. The candidate applications were assessed using the criteria presented in Section 1 of this report. To facilitate the discussion of each of the Use Case applications, each is presented to provide the following information.

(1) Industry Issue Statement: Provides a short description of the overall industry issue the Use Case application will address.

(2) Problem Statement: Provides a detailed description of the industry application with specific discussion of the basic project schedule, milestones, and deliverables. This section will also describe the roles of each partner (utility, DOE, others) during the project.

(3) Technical Approach: Provides technical details of how the analyses will be conducted. It includes a description of applicable tools and methods including underlying technology that will be applied.

(4) Minimum Viable Product: Presents a restatement of the issue and approach with a definition of what constitutes a successful outcome (i.e. demonstration of feasibility and value). This section also includes a discussion of short term project deliverables.

(5) Long Term Vision: Addresses scalability, transportability, and identification of gaps to enhance quality/usability/confidence in results obtained. This section also will identify potential future applications and extensions.

The following sections provide discussions of each of the utility Use Case applications that have been selected for further development.

4.1 Fire Probabilistic Risk Assessment

(1) Industry Issue Statement

Requirements by NRC have necessitated extensive resources to gather data and develop fire PRA models. Much of the time is spent on scenarios within a plant fire PRA that includes identifying the significant components or cables for each scenario and where those targets are spatially in relation to the initiator itself. After running a fire analysis, plant staff identifies what impact failure of components or cables have on the analysis followed by additional tracing of those failures to subsequent failures (failure propagation). Significant scenarios are then further analyzed to try and remove as much conservatism as possible using the given existing tools and methods. Most of this effort is focused on demonstrating that scenarios are not significant to plant risk. Consequently little effort can be expended on identification of areas that need improvement or development of contingency operations. Efficient methods and tools are needed to both help reduce labor costs in building and analyzing basic fire model scenarios and in reducing conservatism in critical sequences.

(2) Problem Statement

The NRC with EPRI and the National Institute of Standards and Technology (NIST) conducted a research project to verify and validate five fire models used for Nuclear Power Plant (NPP) applications. The results of this effort are documented in a seven volume NUREG report, NUREG-1824 [7], Verification & Validation of Selected Fire Models for Nuclear Power Plant Applications. More recently, NUREG-1934 [8] provides information on the use of fire models in support of various commercial NPP fire hazard analysis applications. Extensive work has been done in modeling fire risk using the methods described in these reports. EPRI, in conjunction with NRC, also has conducted workshops on the development and use of a Fire PRA model.

This research team, together with members of industry, identified portions of the fire PRAs that numerically presented the greatest problems within the industry and tasks that required substantial resources to implement. From this a twofold purpose and tasks were identified for the Industry Fire Research. The first area includes the modification of tools to incorporate immediate industry needs into reducing manual effort required to improve and analyze existing models for daily plant use. The second part of the research will look at combining these tools with dynamic capabilities to identify key relationships and timings which can be used to further inform and modify current PRA models to improve their realism and reduce conservatisms.

(3) Technical Approach

The first portion of the research will target the reduction of the costs for current fire PRA activities. This will be done with the modification and development of a visualization tool to enable users to do the following:

- View/add/modify the spatial relationships of components in fire zones and their failure properties.
- Run or import a fire simulation (via CFAST or FDS software tools) and determine component/cable failures.
- Quickly show and trace subsequent component failures or basic events due to cable failures.

For most US NPPs, relational data currently exists in a FRANX fire model and can be directly used as a starting point. Then, basic assumptions or missing information can be determined and then gathered from the user. Much of the detailed spatial relationship data are currently in schematics and walk-down notes. This visualization tool, as seen in Figure 4-1, will make it easy to enter such data and, once entered, will remove the need for frequent reference back to the notes. This tool will vastly reduce the time analysts spend on tracing fire analysis consequences and speed up identification of improvement areas.

A large source of conservatism with current fire analysis is with respect to evaluation of event timing information. CFAST and FDS fire simulations determine the progression of the fire over time and they are used to determine component failures; it should be noted that most of the time the failure time cannot be captured in traditional modeling. In a large portion of scenarios this may not be of concern, but several critical fire scenarios result in a high CDF contribution. The second area of research will build and use the tools and information from the initial research and development, adding dynamic analysis. This will include timing of operator actions, component failure from fire simulation times, and varying sampling methods. This advanced analysis will be used to identify scenario improvements for the static PRA by identifying critical modeling areas, such as more precise success criteria, operator actions binning times, and possibly fluid dynamic timings. By using the dynamic PRA results to inform the traditional PRA model, no costly V&V or additional regulation approval would be necessary and the analyses can be performed using utility staff; thus minimizing analysis costs.

The initial model and scenario for testing in this Use Case application will be a main control room or switchgear room fire scenario. Results from the dynamic models will be compared to results from the static PRA to see where improvements can be made if it is determined that certain scenarios are overly conservative. This will help determine what level of improvements can be expected for doing advanced analysis and the effort required.

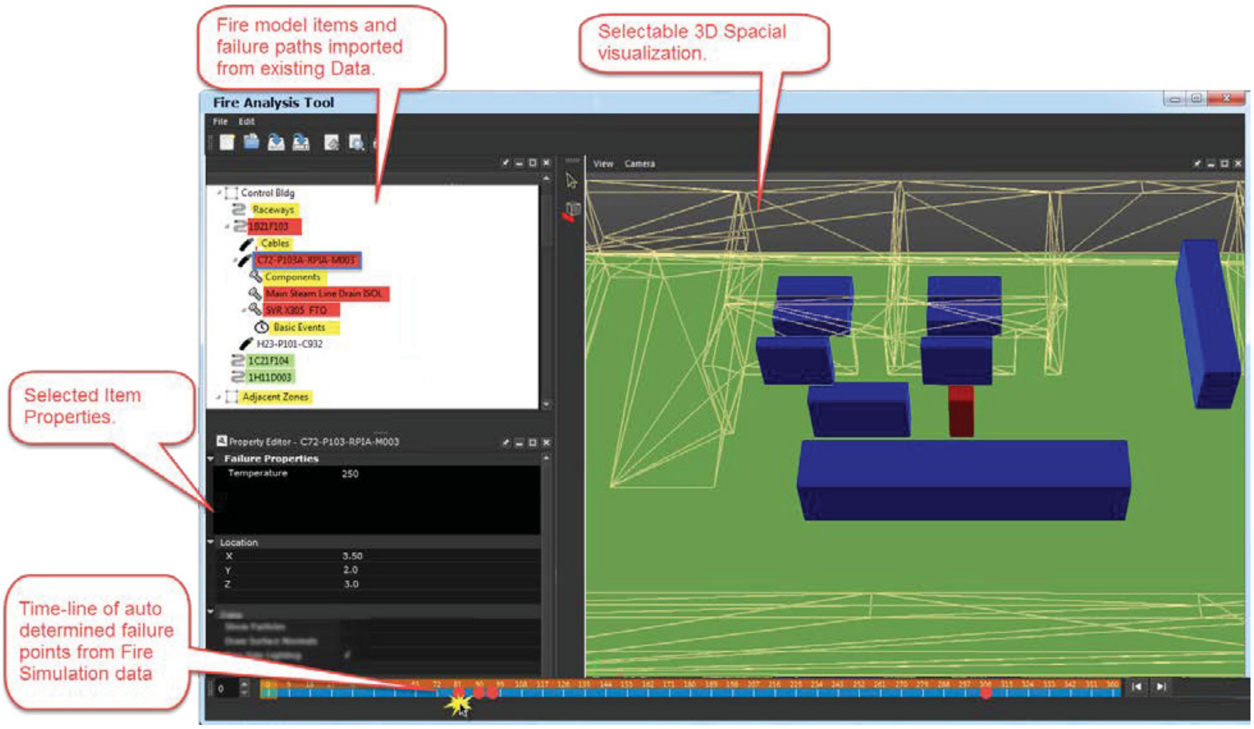

Figure 4-1. Mockup UI to assist in fire modeling and analysis showing special relationships with failure criteria and propagation.

(4) Short Term Deliverables and Minimum Viable Product

This Use Case pilot application is designed to produce a Minimum Viable Product (MVP) which can be applied by all NPPs using their current fire modeling methods. The initial scope of work is intended to be small enough to be completed in a short period of time and used by facilities for the majority of their fire analysis work providing a substantial cost reduction. This initial scope will then be expanded to apply the dynamic analysis to reduce conservatisms in the more complex and significant fire contribution scenarios.

Specifically, the short-term deliverables are identified as follows:

- Provide an application for component spatial relationships and fire failure consequences.
- Couple the PRA modeling capabilities that are developed with fire simulation and visualization tools.
- Evaluate the margins gained from use of the dynamic Fire PRA analysis results used to modify initial static model.

(5) Long Term Objective

The long-term vision for this Use Case application is to provide effective methods for using Dynamic PRA analysis in natural hazard events. Then using those results, develop more generally applicable methods and tools that can be used to augment current PRA methods to more realistically model external hazard events.

(6) Selection Criteria

This fire Use Case application meets all six items of the criteria presented in Chapter 1 of this report. Issues associated with fire risk analysis was one of the first items brought up by industry for collaborative work with immediate needs that could support reductions in facility costs. Initial work will produce a MVP to be piloted and used immediately at a NPP facility, demonstrating applicability not only it to the pilot application host plant, but to the broader commercial NPP fleet. Then, further work will use the backend of this code along with current RISA tools for advanced dynamic fire PRA, meeting the goals of RISA scope/mission. The overall long term objective is to apply the methods and tools developed across the industry to reduce misleading plant model conservatisms associated with fire and external events. Direct work with the utility host facility will allow for quick compilation of statistics to support an assessment of benefits and cost reductions that are derivable from this research and development.

4.2 Risk-Informed Asset Management

(1) Industry Issue Statement

As commercial NPPs pursue extended plant operation in the form of second license renewal (SLR), opportunities exist for these plants to provide capital investments to ensure long term safe and economic performance. At the current time, several utilities have announced an intention to pursue extended operation for one or more of their NPPs via SLR. The goal of this research is to enhance the long term safety and economics of NPPs during the SLR period of operation by providing a structured risk-informed approach to evaluate and prioritize plant capital investments made in preparation for and during the period of extended plant operation.

(2) Problem Statement

In this industry application, the partner utility indicated the need to evaluate the costs associated with major capital refurbishments that would occur during the period of the plant’s SLR. Specifically, this Use Case application is intended to develop and apply methods and a tool to risk rank major capital refurbishments/replacements of SSCs for SLR with the ability to actively manage these costs between the time of funding approval and implementation to support operation during the period of SLR. The objective of this Use Case application is to risk-inform the capital improvements for SLR that includes assessment of the expected useful life of the SSCs and the likelihood and impacts of unanticipated occurrences that could impact their performance during this operating period. The Use Case application would be used to specify the optimal conditions and timing for replacement/ refurbishment based on anticipated conditions with appropriate assessments performed to address uncertainties.

The research will be carried out jointly with the pilot project utility. The participating utility will provide specific project planning information (project descriptions, estimated costs, constraints, etc.) and relevant host plant information. The host utility will provide in-kind support for data collection and participation and review of analysis with LWRS Program staff and with the reporting of results.

(4) Technical Approach

For this Use Case application, the host utility has developed a list of potential capital improvements to support plant operation throughout the period of SLR. Example candidate plant refurbishment / replacement projects include plant digital I&C upgrades (note the relationship to the digital I&C replacement Use Case application described in Section 4.4. below), refurbishment or replacement of Reactor Coolant Pumps (RCPs), replacement of buried piping (including the potential use of reinforced carbon fiber pipes), main generator replacement, and main condenser replacement. The primary objective of this Use Case application is to develop and apply methods and tools that are capable of assessing and managing the risks and likelihood of failure of these SSCs during this operating period. In addition, secondary objectives for this application are to identify an optimal allocation of the capital expenditures for these SSCs and to manage these expenditures (via re-optimization) as circumstances change from initial approval through the end of the SLR operating period.

EPRI has developed the Integrated Life Cycle Management (ILCM) approach [9] to address management and optimization of large capital expenditures for the purposes of extended plant operation. This Use Case application proposes to utilize this approach as a starting point to develop mechanisms to meet the Use Case objectives.

To address this issue a structured approach will be necessary. First, the anticipated operational lifetimes for critical plant SSCs need to be evaluated to determine the likelihood that they could fail during the period of extended operation. In this Use Case application, this set consists of those high capital cost SSCs identified by the host utility for which refurbishment or replacement may be necessary to support operation during the period of SLR. To accomplish this a number of approaches could be applied including using methods such as developing physics of failure models and use of expert elicitation approaches such as the Delphi technique or Analytic Hierarchy Process (AHP). Note that the EPRI ILCM Process was developed to permit use of one or more of these methods based on the preference of the operating NPP. For illustrative purposes, an example likelihood of failure curve from an early ILCM pilot application is provided in Figure 4-2. [10]

Once the likelihood of failure curves for the critical SSCs are developed, the next required step would be to develop applicable maintenance strategies (which can include replacement or comprehensive refurbishments). For the purpose of this Use Case application, the strategic alternatives (i.e. refurbishment or replacement) previously developed by the host utility will be used as a starting point for the analyses. Once the various strategic alternatives are developed, the projected life cycle costs associated with the SSCs of interest are determined and evaluated for key financial metrics (e.g. cash flow, net present value (NPV), or other metrics used by the utility decision-makers) using applicable economic models. The final step required would be to conduct optimization studies that evaluate proposed investment alternatives to identify the strategy that provides maximal value to the utility over the projected plant lifetime (i.e. through the period of SLR). This represents a very complicated optimization problem due to the myriad constraints that are imposed (e.g. prescribed system outage start dates and durations, annual cash flow limitations, supply chain constraints, etc.).

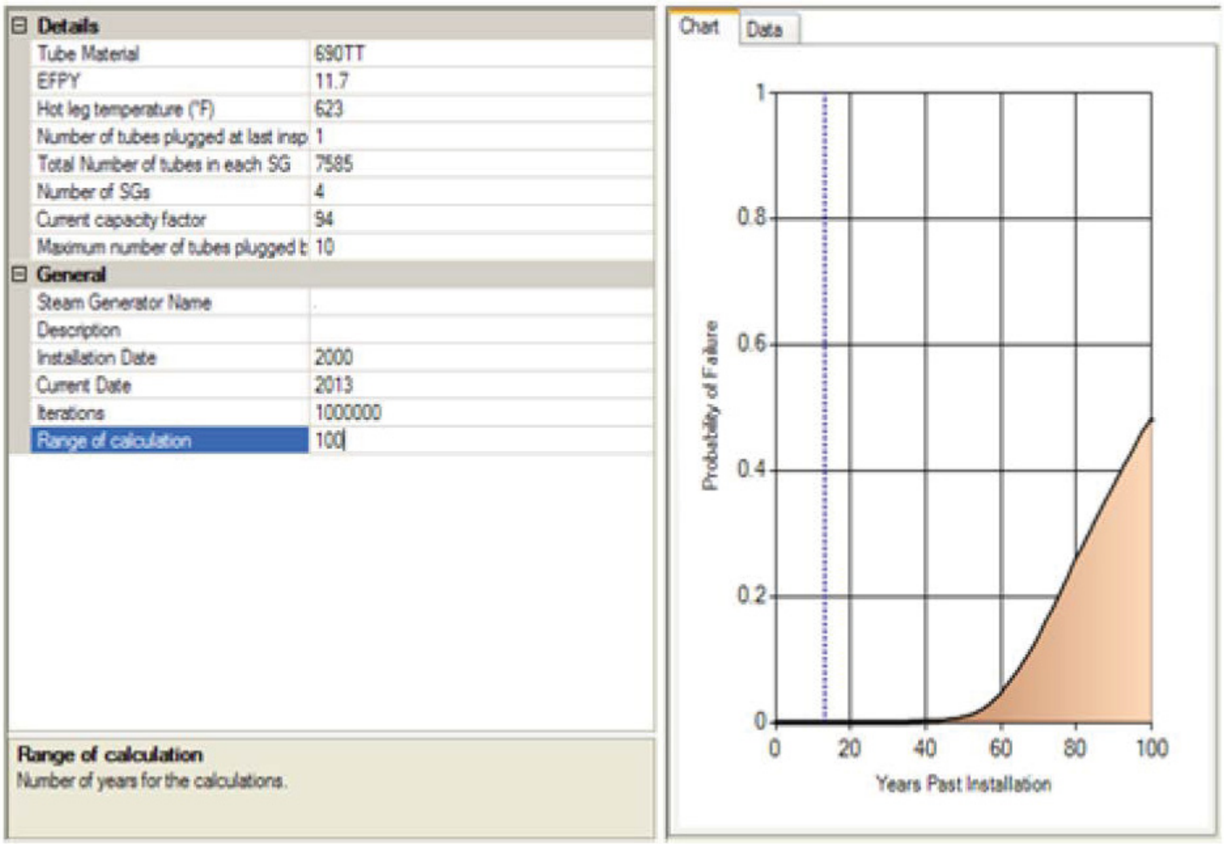

Figure 4-2. Example Steam Generator Likelihood of Failure Curve [10].

(4) Short Term Deliverables and Minimum Viable Product

This pilot application is designed to produce a MVP which can be applied by all NPPs that are planning for SLR. The scope of work is intended to be small enough to be completed in a short period of time and to support cost planning estimates that will be filed with state utility regulatory agencies. The initial scope is intended to demonstrate that the pilot application can be scaled up with reasonable cost and effort to support periodic evaluations and optimizations that will occur due to changing economic circumstances over time (e.g. macroeconomic market changes that impact plant profitability, market changes that impact projected supply chain costs, changes in regulatory requirements, etc.). The application also will be conducted to permit rapid and straightforward expansion for use at other NPPs that are considering SLR. The pilot application will be structured as a modeling and simulation application based on the INL RAVEN analysis framework. At the present time it is proposed that RAVEN be interfaced with the EPRI ILCM software; however the approach will be more fully developed and specified as a result of ongoing discussions with the host utility.

Specifically, the short-term deliverables are identified as follows:

- Demonstrate a risk-informed process to evaluate a proposed portfolio of planned plant refurbishment/replacement projects identified to support SLR at the host NPP.
- Demonstrate capability for the process and suite of applied software tools to develop optimized investment plans at the host NPP.
- Enhance the selected life cycle management software application used in the process for improved functionality and usability; this enhancement may occur via a controller such as RAVEN.
- Develop enhanced guidance via project documentation to permit extension of the approach for use by other NPPs considering SLR applications.

(5) Long Term Objective

The long-term vision for this Use Case application is to provide an integrated process and suite of support tools that can be used to inform executive planners and decision makers in the planning and selection of capital investment (including refurbishment and replacement projects) to support plant SLR. The approach and tools will be structured so they can support periodic reevaluations and optimizations in response to changing conditions. They also will be developed to permit evolution and incorporation of improvements throughout the period of extended operation.

(6) Selection Criteria

This use case meets all six of the project selection criteria developed during the project selection meeting at INL with interested utilities and described previously in Chapter 1. Because many NPPs are currently in the early stages of the decision and planning phases for SLR decisions, this Use Case application presents an excellent opportunity to apply risk-informed methods and tools to support these decisions. This use Case application also provides adequate time to develop and mature the technologies so that they can achieve widespread adoption across the industry.

4.3 Plant Health Management

(1) Industry Issue Statement

Industry Equipment Reliability (ER) Programs are an essential element that supports safe and economic plant operation. The effectiveness of these programs is addressed in several industry-wide and regulatory programs. All US NPPs have implemented the ER process defined in INPO AP-913 “Equipment Reliability Process Description” [11]. Additionally, performance of plant SSCs is monitored within a regulatory context within the Maintenance Rule 10CFR50.65 [12] and the Mitigating Systems Performance Indicator (MSPI) program [13]. However, as currently implemented, these programs are labor intensive and expensive. There is an acute industry need to leverage advanced monitoring technology (including pattern recognition, diagnostics, and prognostics) to reduce costs and improve engineering effectiveness.

Although the use of advance monitoring has been successfully implemented to assess equipment and system performance in a number of industries (e.g. commercial and military aviation, transportation, gas turbine electrical generation), these technologies have not penetrated extensively into the commercial nuclear power sector. As a result, deployment of these technologies has the potential to provide significant improvements in the performance of critical SSCs (e.g. via detection and diagnosis of degraded performance at an incipient stage) and reduce costs associated with monitoring and regulatory compliance. The Use Case application described in this section provides an initial step in the process of deploying these technologies while the integrated approach described in the long term vision provides a pathway to implementing fully integrated advanced monitoring systems into plant ER programs. It should be noted that this Use Case application will likely provide additional benefits (compounding effect) when coupled with the Digital Instrumentation and Controls Use Case application described in Section 4.4.

(2) Problem Statement

For this industry application, one utility indicated an overall objective to leverage advanced computational capabilities to support enhanced system performance and health management. A fundamental objective of this effort is to integrate various elements of system health monitoring, management, and reporting in a manner that is significantly less labor intensive and is at least as technically effective as current programs. This Use Case application is intended to support and augment utility efforts and to permit demonstration of advanced computational capabilities (methods/tools) to permit broader adoption across the US commercial nuclear industry. It is envisioned that achieving this overall objective will consist of several distinct Use Case applications that are anticipated to be completed in phases over several years.

The research will be carried out jointly with the pilot project utility. The participating utility will provide specific plant information from the host plant (e.g. information on reported plant issues and Maintenance Rule classifications from relevant plant/corporate data sources). The host utility will provide in-kind support for data collection and participation and review of analysis with LWRS Program staff and with the reporting of results. Since the intent is to automate the analyses within the utility's information management systems, the utility will coordinate interfaces between the project team (LWRS staff and utility personnel) and third party software vendors that provide the various sources of data and data management/visualization platforms used to disseminate information across the organization.

(3) Technical Approach

In discussions with the host utility, monitoring of plant structures, systems, and components (SSCs) to meet requirements of the Maintenance Rule (10CFR50.65) [12] represents significant effort (time and labor) to evaluate and classify identified deficiencies that occur at the plant. Industry guidance for compliance with the Maintenance Rule provided in NUMARC 93-01 ("Industry Guideline for Monitoring the Effectiveness of Maintenance at Nuclear Power Plants") [14] requires operating NPPs to assess and monitor failures of plant SSCs that result in loss of critical safety related functions. These events are referred to as functional failures (FFs). In addition, the guidance requires assessment of these FFs to determine which are maintenance preventable (referred to as Maintenance Preventable Functional Failures – MPFFs). Currently this activity is predominantly conducted manually. The objective of this initial Use Case pilot application is to develop and apply advanced computational capabilities to reduce the number of incidence reports (IRs) that require manual review. Historical data from the host utility indicate that on the order of 15,000 IRs typically are generated each year at a two-unit NPP site. This population of IRs contains a small fraction of events that are eventually classified as an FF or MPFF (typically on the order of 10 – 15 per year for this host utility's NPP sites).

The objective of this Use Case application will be to reduce the number of IRs that require manual review by a factor of at least an order of magnitude with a specific target of less than 500 IRs/yr requiring manual review at each site. The technical objective is for the computational algorithms to be sufficiently robust to ensure that the set of IRs that are identified to require manual review to contain all events that are eventually classified as FFs/MPFFs (and thus not subjecting the plant to potential regulatory impact) while simultaneously minimizing the number that do not represent a FF/MPFF condition (i.e. "false positive").

This pilot application consists of the following technical activities.

- Develop search algorithms and statistical decision logic for discrimination of FFs/MPFFs. Apply machine learning algorithms to test data (training sets) from selected plant IRs to demonstrate the approach.

- Validate optimized search/discrimination algorithms on independent test data via bootstrap approach to assess performance and apply deep learning algorithms to optimize discrimination (including assessment of missed FFs/MPFFs and false alarm rates).

- Create an Application Programming Interface (API) with selected utility dashboards and data integration platforms. Deploy optimized search algorithms and the API for use in utility Maintenance Rule Programs.

(4) Short Term Deliverables and Minimum Viable Product

Because all operating US NPPs have formal ER, Maintenance Rule, and MSPI programs, the technology developed in this Use Case application will be directly transferable across the industry. The MVP for this project will be the development of computational algorithms that can be applied to evaluating plant event reports to screen FFs and MPFFs. The scope of work is intended to be small enough to be completed in a short period such that it can be demonstrated to the US NRC as part of industry efforts to develop an alternate approach to Maintenance Rule implementation. This initial application also is intended to demonstrate that the approach can be scaled up with reasonable cost to develop and implement integrated monitoring in NPP ER programs.

Specifically, the short-term deliverables are identified as follows:

- Demonstrate that advanced algorithms can effectively be applied to evaluate plant IRs to reduce (with the intent being to eventually eliminate) the need for manual review and characterization.

- Create and deploy an API with selected utility dashboards and data integration platforms. Deploy optimized search algorithms and the API for use in utility Maintenance Rule Programs.
- Develop plans for follow-on Use Case applications that address the additional ER improvements described below. Note that this planning will consider the potential for identification of additional utility partners and integration with related activities in the LWRS Plant Modernization Pathway.

(5) Long Term Objective

It should be noted that this application is an initial step in the development of an advanced approach to perform integrated system health management. This advanced system health program will leverage a variety of data sources to effectively manage system health; it is envisioned that additional applications related to this Use Case demonstration that develop and implement advanced information technology will be conducted over the next several years. As a result, these potential Use Case applications will be explored during the remainder of 2018 to identify appropriate objectives, resources, and schedules for their application. The following constitutes a listing of these potential Use Case applications that will be investigated.

- Automated System Health Evaluations

  This Use Case application is an extension of the application described above but will encompass a much broader focus. It will include extension to a much broader array of data sources (e.g. Action Requests (ARs) or similar plant deficiency reporting system, Aging Management Program (AMP) data, material condition reports, etc.). It also will extend the automation capability to include the full spectrum of system health/long-term asset management capabilities.

- Develop Necessary Linkages between System Health Program and Risk-Informed Applications

  The US commercial nuclear power industry is aggressively pursuing implementation of several risk-informed applications to reduce regulatory burden and operating costs. These applications include specification of Alternative Treatments (10CFR50.69) [15, 16] to plant SSCs and Risk-Managed Technical Specification [17]. To obtain maximum value from these applications, their execution must be strongly integrated with a robust and automated System Health program. This application will develop these interfaces and automate them to the extent practical.

- Integration of Equipment Diagnostic/Prognostics to System Health

This Use Case application will leverage equipment monitoring activities performed at the host utility's Maintenance and Diagnostics (M&D) Center. It will accelerate the deployment and use of advanced diagnostic/prognostic capabilities to develop a Maintenance Strategy Optimizer (MSO) that is intended to continuously optimize cost and SSC performance.

(6) Selection Criteria

This use case meets all six of the project selection criteria from the project selection meeting at INL with interested utilities that was described in Chapter 1. The set of Use Case applications described has widespread interest throughout the commercial US NPP fleet. For the near term application, the industry is in the process of developing an alternate approach to Maintenance Rule implementation. An initial public meeting was held with the NRC on 20 June 2018 in which industry plans were described [18]. This utility Use Case application will have a direct impact on this recent industry initiative and would be directly transferable to the entire US NPP fleet. Additionally, the application host utility has presented the envisioned set of applications described above to the INPO/EPRI sponsored Equipment Reliability Working Group (EWRG). These discussions have resulted in widespread interest in application of risk-informed approaches and tools to enhance NPP equipment reliability programs while reducing their costs.

4.4 Digital Instrumentation and Controls Risk Assessment

A commercial nuclear utility is collaborating with the RISA Pathway of the LWRS Program to develop and demonstrate a reliability and risk assessment of a safety-related digital I&C system to support its design, qualification and use. The objective of this research is to define a technical basis and approach that can be used by utility design, operational, and licensing staff to address the unique issues associated with replacing an analog, nuclear-qualified, safety-related I&C system with a modern digital system.

(1) Industry Issue Statement

Advances that support the licensing case to enable the transition from analog I&C technologies to digital technologies in the U.S. nuclear industry are greatly needed. The goal of this research is to assure the long-term safety and reliability of vital engineered systems; reduce uncertainty in licensing costs and time; and support integration of digital systems in the plant and more efficient upgrades of technology for the entire life-cycle of nuclear power plants.

To date, there has been only one US nuclear plant that has successfully licensed an integrated RPS and ESFAS system in an existing plant. That plant needed to accept some costly design features to address the regulatory concerns regarding uncertainty in the future performance of the system. Now is perhaps the time to address those uncertainty issues again, given the advances in digital technology in the years since that plant modification was licensed.

(2) Problem Statement

The problem statement is expected to be: define a risk-informed analysis process – steps, methods, and tools – to assess the safety risk and operational cost risk for a digital replacement to the RPS and/or ESFAS systems at a 3-loop Westinghouse reactor plant from the conceptual design of the system through what the operating utility deems necessary and adequate for regulatory approval and for that utility's decision to procure the system. The Use Case application will propose solutions where process gaps or unacceptable uncertainties are identified. The process will include expert reviews, table top simulations of the process, and pre-defined success criteria to verify the effectiveness and feasibility of the process.

The research will be carried out jointly with the pilot project utility. The participating utility will provide I&C design information and host plant information. They will provide in-kind support for data collection and participation and review of analysis with LWRS Program staff and with the reporting of results. The activity will be coordinated between the RISA and Plant Modernization R&D pathways.

(3) Technical Approach

For this I&C Use Case application, a well-structured, risk-informed, and graded process will be developed and applied to evaluate a specific design considered by the host utility for replacement of RPS and ESFAS with the desired integration with other safety- and non-safety systems. Such integrated systems have been specified for other industries for decades, but they have not had the rigorous regulatory scrutiny of the commercial nuclear industry. This process intends to specifically address the concerns and policies of the NRC while resulting in a design that is cost-effective and which yields the many operational and cost benefits that have been demonstrated for integrated control systems in other infrastructures.

As stated, the process will be well-structured, risk-informed, and graded. It must be well-structured to ensure that it is thorough and assures that the necessary safety and reliability requirements have been considered and met for both safety and cost due-diligence. It must be risk-informed; that is, the likelihood and consequences of any failures or spurious operations must be acceptable compared with both likelihood and consequences of the previous analog system that operated acceptably before it. Criteria, specific design processes, reliability analyses and tests, and potential design changes will be considered to address risk. Finally, the process will be graded; that is more rigorous design controls, analyses and design changes will be considered based upon the uncertainty and risk potential of specific failures of concern.

This technical approach is consistent with demonstrated good I&C design practice. An example of this approach is presented in EPRI Report 3002005326 – Methods for Assuring Safety and Dependability when Applying Digital Instrumentation and Control Systems [19]. This guideline could be considered as a possible technical foundation for the use case.

The process begins with a conceptual design of a proposed I&C system modeled at the channel logic level with a detailed design and functional specification. It then goes through various stages of risk and reliability evaluation sequentially including review and analysis of existing data, susceptibility analysis, reliability assessment and coping analysis. An important activity of this pilot application will be to specify each of these analyses in detail necessary for evaluation of an integrated RPS and/or ESFAS replacement using the risk-informed, graded approach to safety significance. That graded approach allows for a smaller or less-integrated I&C system to be accepted with limited reliability analysis, risk assessment or additional design and operating features to prevent or mitigate an I&C failure. A safety-related I&C system, or one which can affect the likelihood or consequences of a significant event, requires more analysis and potentially design changes.

The project team anticipates that technology gaps will be identified as well as areas with unacceptable uncertainty of results. In such cases, the project will specify the best available approach for use in the pilot study; and, if possible, will identify R&D activities that can improve the process in future applications. Once the evaluation approach for the proposed RPS and/or

ESFAS replacement is specified, it will be subjected to critical review, table top simulations of the process, and detailed analytical assessments of critical parts of the process.

The current NRC position to address uncertainty of software design common cause failures of digital safety-related RPS and ESFAS systems calls for implementation of a diverse analog system. This requirement would be a considerable operational and cost burden for this plant modernization. This use-case will address this important NRC concern during the development of the well-structured, risk-informed, graded assessment approach as well as during the table-top implementation of the process

(4) Short Term Deliverables and Minimum Viable Product

This pilot application is designed to be a MVP. That is, the scope of work is intended to be small enough to be completed quickly and with minimum resources while large enough to demonstrate feasibility and value of the process to the end-user. Furthermore, the scope and individual activities are intended to provide evidence that the pilot application can be scaled up with reasonable cost and effort to other applications at the plant, to other users, and that it can evolve through modular upgrades and enhancements. The proposal to evaluate only a channel-level conceptual design and to validate the chosen evaluation process only as a table-top exercise, with selective deep-dives where appropriate, reflects the fact that thoroughly analyzing the RPS and/or ESFAS is a large and challenging workscope. This smaller scope is intended to demonstrate feasibility and value within, say, one year. Furthermore, the pilot study will be structured as a modeling and simulation application, very likely using the INL RAVEN tool as a controller.

Specifically, the short-term deliverables are intended to be:

- A risk-informed analysis process – specifying steps, methods, and tools – to assess the safety risk and operational cost risk for a digital replacement to RPS and/or ESFAS systems at the chosen 3-loop Westinghouse plant.
- A software application of the process with a controller such as RAVEN and use in the table-top assessments and for project documentation.
- A table-top evaluation of the model and process with critical assessments of the feasibility and value of the process. The use-case will propose solutions where process gaps or unacceptable uncertainties are identified. Limited deep dive analyses in some areas will be considered.
- The next steps in the evolution of the process and tools necessary to support the next stages of the engineering and licensing of the I&C system.

(5) Long Term Objectives

In the discussion of the scope for the MVP, it has been stated that the current work scope considers only a relatively high-level conceptual I&C system design, and it evaluates the analysis process with table-top exercises and limited deeper analytical dives. The long-term vision for this process and tools is to support the I&C model, data, and modular analysis software application, so the process can evolve throughout its design, licensing, implementation, and operation. It should also be transportable to other sites or other systems. Consideration of these long-term objectives will be a factor in the development of the process; the modeling, simulation, and documentation tool; and in the selection of table-top and deep-dive evaluations for demonstration.

(6) Selection Criteria

This use case meets five of the six project selection criteria from the project selection meeting at INL with interested utilities as described in Chapter 1 of this report. The only criterion not met for this Use Case application is criterion 6 (Results of use-case address a critical near-term need of NPPs). It is possible to conclude that the modern implementation is not a critical near term need of US nuclear plants. However, it is essential for any plant considering continued operation through 80 years (i.e. SLR), and it is a critical need for many plants planning to operate to 60 years. The only reason it is not a critical near-term need is the long lead time to get a cost-effective modification licensed by the regulator. So, it is considered to be a near-term imperative to start now.

4.5 Fuel Enrichment and Burnup Extension to Enable 24 Month PWR Cycles

(1) Industry Issue Statement

Extending the fuel discharge burnup level can present significant economic benefits to the current fleet of operating LWRs. It allows for longer cycles and improved resource utilization. The major economic gain of longer cycles is due to the increased capacity factor resulting from decreased refueling times as a fraction of total operating time, as well as fewer assemblies to be discharged for a given amount of produced energy. Significant progress has been achieved in the past to increase fuel discharge burnup. This has given the utilities considerable reductions of fuel cycle costs. Further burnup increase would incentivize the utilities to achieve additional fuel cycle cost reduction. Previous studies conducted by EPRI found that fuel costs decrease with increasing discharge burnups, with the use of fuel enrichment less than the current limit of 5 w/o [20]. Additional studies also showed that enhancements of fuel enrichment greater than 5 w/o (up to 6 w/o) can result in additional decreases in fuel costs and further increases in discharge burnups for both BWRs and PWRs [21].

(2) Problem Statement

Increasing the fuel assembly discharge burnup is the most efficient means to achieve the fuel cycle cost reduction. Advanced fuel assembly designs offer sufficient margins to be used with higher enrichments in smaller fuel reload batch sizes and with increasingly heterogeneous core loading schemes. However, there are many technological challenges posed by the increased burnup such as the corrosion and hydrogen pickup of the clad, fuel thermal conductivity degradation, dimensional changes of the fuel assembly structure, the rim effect of the pellet, and the potential for increase of fission gas release. Additionally, increased discharge burnup results in increased loads and more demanding requirements for the fuel assemblies, which could raise the risk of fuel failures. These issues would be exacerbated considering the current industry trend of adopting flexible operation strategies to maximize the revenue of the NPPs.

In the United States the main licensing challenges for high burnup fuel are design basis accident condition analyses, especially for LOCA and RIA. (Note that for international applications, analyses related to beyond design basis accident (BDBA) conditions or Design Extension Conditions (DEC) would provide an additional licensing challenge.) The design basis Large Break LOCA sequence can be divided into three phases: blowdown, refill and reflood. During the blowdown phase, ballooning and burst of the cladding occur since the rod internal pressure becomes much higher than the system pressure of the reactor pressure vessel and the strength of the fuel cladding decreases as the temperature increases. During the refill phase, the cladding is severely oxidized by steam and it becomes embrittled. During the reflood phase, the embrittled cladding may rupture by thermal shock caused by rapid cooling. Under RIA conditions, the fuel clad local conditions such as oxide layer thickness, oxide spalling and local hydrides have strong influence on fuel rod safety and the fuel rod local conditions are a strong function of the burnup level. Another obstacle is that there is no internationally accepted RIA failure limit at high burnup. Fuel rod burst, fuel pellet fragmentation, relocation, and dispersal during these transient conditions are the main obstacles for fuel discharge burnup to be extended above the current limit of 62 GWD/MTU. A major open question is how far experimental data for accident conditions can be extrapolated above the burnups covered by the currently available data. The current enrichment limit of 5 w/o U-235 represents a world-wide established limit for fabrication, transport and storage of nuclear fuel for light water reactors. It is anticipated that considerable effort would be necessary to obtain regulatory approvals to extend either the current enrichment or burnup limits associated with nuclear fuel.

(3) Technical Approach

Evaluation of burnup extension involves multiple disciplines to address the challenging licensing issues under transient conditions. The risk-informed multi-physics best estimate plus uncertainty (RI-MP-BEPU) framework provides the approach needed to accelerate the licensing and deployment of this technology. Core design will be performed for a four-loop Westinghouse design PWR with increased enrichment up to 6 w/o to achieve a twenty-four month cycle and around 75 GWD/MTU discharge burnup. The VERA-CS code will be used to provide pin-resolved power distributions for the core design followed by detailed fuel performance calculations for individual fuel rods in the core using the FRAPCON and BISON fuel performance analysis codes. The risk-informed transient safety calculations will subsequently be performed to address the challenging issues of burst potential evaluation under LOCA conditions and fuel fragmentation, axial relocation, pulverization and dispersal issues during LOCA and RIA events. The analyses will apply both deterministic (VERA-CS, FRAPCON/FRAPTRAN, BISON, RELAP5-3D, MELCOR) and probabilistic (SAPHIRE, RAVEN) methods using the LOTUS controller. Tightly coupled calculations between RELAP5-3D and BISON, and RELAP5-3D and FRAPTRAN during LOCA and RIA conditions are required to provide detailed assessment of the fuel rod burst potential, fuel fragmentation, relocation and dispersal. The tightly coupled calculation capability for RELAP5-3D/BISON and RELAP5-3D/FRAPTRAN will be developed as part of this demonstration pilot project. Rigorous Uncertainty Quantification and Sensitivity Analysis techniques will be integrated into the RI-

MP-BEPU framework to alleviate concerns (to the extent practicable) on extrapolating experimental data.

(4) Short Term Deliverables and Minimum Viable Product

Because all operating US NPPs have been consistently increasing the fuel discharge burnup in response to the economic challenge to reduce costs associated with nuclear power, the methodology developed in this Use Case application to evaluate further increased burnup will be directly transferable across the industry. The MVP for this project will be the conduct of evaluations of the challenging licensing issues associated with increased enrichment (above 5 w/o and up to 6 w/o) and fuel discharge burnup (from the current limit of 62 GWD/MTU to 75 GWD/MTU) such that fuel cycle length can be extended to twenty-four months for large 4-loop PWR NPPs. Economic analyses will also be performed to provide the cost and benefit tradeoff studies to find the optimal level of enrichment, fuel discharge burnup and fuel cycle length. The outcome of these assessments will be the capability to evaluate the degree to which the combination of the optimal level of enrichment, burnup and cycle length will provide the greatest benefits in terms of plant safety and economics.

The short-term deliverables for this application are as follows:

- Conduct evaluations of non-burst potential evaluations of high discharge burnup fuel (up to 75 GWD/MTU rod averaged burnup).
- Collaborate with the ongoing Nuclear Science User Facility (NSUF) project to provide comprehensive uncertainty quantification and uncertainty analysis to inform the experiments that will be conducted at the TREAT reactor for high burnup fuel.

(5) Long Term Vision

This Use Case application is intended to work with industry partners (including EPRI and industry lead utilities conducting evaluation and testing of fuel enrichment and burnup extensions) to address the challenging licensing issues of fuel fragmentation, relocation and dispersal and evaluate the economic improvements from the adoption of enhanced fuel technology.

(6) Selection Criteria

This use case meets five of the six project selection criteria from the project selection meeting at INL (described in Chapter 1) with an interested utility outside those that attended the INL meeting. The only criterion not met for this Use Case application is criterion 6 (Results of Use Case that addresses a critical near-term need of NPPs). It is possible to conclude that the burnup extension is not a critical near term need of US nuclear plants. However, it is essential for any plant considering further improving plant economics to stay competitive, and it is a critical need for many plants planning to operate to 60 years and to 80 years. The primary reason that it is not a critical near-term need is the long lead time to get this technology licensed by the regulator (which would require NRC rule making potentially supported by extensive experimental testing). Because such experimental testing and licensing activities will require significant time, it is considered a near-term imperative to start now.

4.6 Strategic Risk-Informed Enhancements

(1) Industry Issue Statement

As an outcome of the 2011 Fukushima accident, considerable effort has been placed on enhancing plant resilience via strategic design and operational modifications. Examples of such technologies as ATF, FLEX equipment, passive cooling systems, and digital I&C are either being developed or have been implemented. However, many of these technological enhancements are being pursued as individual (i.e., “stand alone”) applications. There exists a critical need to evaluate combinations of these technologies to determine to what extent each contributes to enhanced resiliency so that limited capital resources can be allocated in a manner that provides the greatest benefits for the least expenditure.

(2) Problem Statement

The current fleet of commercial NPPs is facing significant challenges related to having comparatively high operating costs (particularly with respect to current natural gas prices) while being required to implement measures to enhance plant safety. There are a number of strategic initiatives within the nuclear industry to enhance the safety and improve the economic competiveness of these existing plants. Examples of these initiatives include efforts on development and deployment of ATF concepts [22, 23], implementing FLEX [24] to provide additional mitigation capability in the unlikely occurrence of a beyond design basis event, and an industry-wide initiative entitled, “Delivering the Nuclear Promise: Advancing Safety, Reliability, and Economic Performance” [25]. The collective changes resulting from these initiatives are intended to contribute to NPPs that are more efficient while simultaneously being more resilient to events that could challenge the integrity of the fuel or containment systems [26].

(3) Technical Approach

The use of modeling and simulation provides a well-established technological approach to address this issue which essentially is an optimization problem. Although this approach has been used in diverse applications in both government and industrial sectors, it has not penetrated to a great extent into the commercial nuclear sector. One extremely successful application of this approach was evaluation of the Containment Protection and Release Reduction (CPRR) efforts conducted in the US in the aftermath of the Fukushima Daiichi accident in Japan. This work, documented in references [27, 28], provided detailed technical assessments and results that were used by industry and the US NRC to determine whether sufficient benefit would be derived that would justify the very high capital costs associated with installation of filtered vent systems on Mark-I and Mark-II BWR containments.

This Use Case application is designed to evaluate the potential safety and economic benefits that can be achieved by the deployment of strategic investments, either individually or in combination. In this Use Case application, work will focus on near term ATF concepts combined with optimization of FLEX equipment and development / possible deployment of new passive cooling systems. The combinations of ATF concepts shown in Table 4-1 will be evaluated:

Table 4-1. Near-Term and Long-Term ATF Concepts.

	ATF Cladding		Fuel	
Near-term	Coated Cladding	FeCrAl	Doped UO_2	-
Long-term	SiC	-	U_3Si_2	Metallic Fuel

This initial application will concentrate on evaluation of potential enhancements in combination with deployment of ATF concepts to determine which potential enhancements provide the greatest safety, risk, and economic benefits. The analyses will apply both deterministic (RELAP5-3D, TRACE, MELCOR, MAAP) and probabilistic (SAPHIRE, HUNTER) methods using LOTUS and RAVEN controllers. Since all US NPPs have deployed FLEX equipment and developed processes and procedures for their use to enhance plants' resiliency to cope with a BDBA, how to optimize the utilization and credit of the FLEX equipment in plant risk assessments, especially in the human reliability area, will be studied to provide quantification of the enhanced resiliency of NPPs with the introduction of these new technologies. In parallel, augmented cooling systems such as extending the Reactor Core Isolation Cooling (RCIC) system operating band in BWRs or installation of new passive cooling systems in PWRs will be evaluated. It should be noted that since incorporation of these changes may require plant modifications or retrofitting of plant equipment, obtaining an integrated understanding of the potential benefits that can be obtained will be an essential element to determine if the benefits justify the costs associated with these changes.

(4) Short Term Deliverables and Minimum Viable Product

Because all operating US NPPs have programs to assess cost / benefit tradeoffs associated with large capital expenditures, the technology developed in this Use Case application will be directly transferable across the industry. The MVP for this project will be the conduct of evaluations of a portfolio of technical enhancements that are proposed and are under active development for implementation to improve plant safety. The outcome of these assessments will be the capability to evaluate the degree to which the different improvements can enhance plant safety or reduce risk which can be used to more efficiently allocate limited research and capital expenditures to where they will provide the greatest benefits.

The short-term deliverables for this application are as follows:

- Conduct evaluations of benefits of ATF concepts combined with FLEX and passive cooling approaches.

(5) Long Term Vision

In reference [26] a plan was developed that is intended to be conducted in collaboration with work being performed as part of broader industry efforts to develop, mature, license, and deploy ATF / ERP Systems. This Use Case application is intended to work with industry partners (including EPRI and industry lead utilities conducting evaluation and testing of ATF) to evaluate combinations of ATF with other strategic investments to enhance safety while simultaneously obtaining economic improvements from margin enhancements that are achieved from the adoption of advanced technologies.

(6) Selection Criteria

This Use Case application represents a challenge, as it does not currently have an identified utility sponsor. Thus this application does not meet selection Criterion 3 described in Chapter 1. This is due, at least in part, to the composition of the utility group that participated in the May 15th meeting at INL. During these discussions, none of the utility participants were NPP fuel management experts (all of the participants were specialists in asset management, ER, or PRA) or had been involved to a significant extent with the strategic enhancements described above. Because the development and possible deployment of the identified strategic enhancements (e.g. ATF, passive cooling systems) is a priority for both the DOE and industry, it is believed that collaboration with EPRI and industry utilities supporting these efforts will result in identification of one or more lead utilities to provide sponsorship for this application.

4.7 Terry Turbine Extended Operating Band Research

(1) Industry Issue Statement

The typical nuclear application of Terry turbines attaches them to pumps, such as the reactor core isolation cooling (RCIC) system for boiling water reactors (BWRs), and turbine driven auxiliary feedwater (TDAFW) system for pressurized water reactors (PWRs). Notably, the RCIC systems employed at Fukushima Daiichi (Units 2 and 3) operated for far longer than existing analyses suggested they would. Instead of failing within a 4 to12 hour timeframe following battery depletion as is normally assumed in plant probabilistic risk assessment, the RCIC system of Unit 2, for example, provided cooling water to the reactor for nearly three days following the earthquake and tsunami of March 11, 2011, and did so in the absence of electrical power to its controller or manual control. From the industry viewpoint, gaining knowledge on the true operating limits of these systems will allow utilities to take credit for extended emergency core cooling via these systems, thus providing margin on the distribution of scarce plant resources to where they are most urgently needed, and providing more time to transition to other core cooling equipment such as FLEX in order to prevent core damage.

(2) Problem Statement

Prior to the accidents at Fukushima Daiichi, assumptions and modeling of the performance of Terry turbopumps were based mostly on generic vendor’s use of service guidance (i.e., NEMA SM23 *Steam Turbine for Mechanical Drive Service*). However, RCIC system performance under beyond design basis event (BDBE) conditions is poorly known and largely based on conservative assumptions used in probabilistic risk assessment (PRA) applications. For example, common PRA practice holds that battery power (DC) is required for RCIC operation to control the vessel water level, and that loss of DC power results in RCIC flooding of the steam lines and an assumed subsequent failure of the RCIC turbopump system. This assumption for accident analysis implies that RCIC operation should terminate on battery depletion which can range from 4 to 12 hours. In contrast, real-world observation from Fukushima Daiichi Unit 2

(1F2) shows that RCIC function was affected but not terminated by uncontrolled steam line flooding, and in fact provided coolant injection for nearly three days [29 - 32].

Use of conservative assumptions regarding equipment functioning as found in PRA applications may limit the anticipated mitigation options considered for normal and emergency operations. Improved understanding of expanded operations of Terry turbopumps can be realized through a combined and iterative process of advanced modeling methods and full-scale experimental testing. Towards that end, the overall Terry turbine expanded operating band (TTEXOB) project creates the technical basis to:

- Reduce and defer additional utility costs
  - Associated with post-Fukushima actions
  - Prevent the need of non-reactor grade water sources required during FLEX events
  - Extend the interval between preventive maintenance actions
- Simplify plant operations, and
  - Provide guidance to operators for expanded RCIC or TDAFW operations
- Provide a better understanding of the true margin which could reduce overall risk of operations.

(3) Technical Approach

The TTEXOB Project is investigating the operation of Terry turbines from the component level to the system level both computationally and experimentally [33]. Work completed through the TTEXOB Project is via a phased approach; i.e., the first step (completed in 2015) was to identify the principles and phenomenology, which provided valuable input for full-scale component testing and basic science experiments. Experimental testing is currently underway, with future plans calling for integral full-scale experiments for long-term low-pressure operations and scaled high pressure experiments replicating the self-regulating feedback observed during the Fukushima Daiichi Unit 2 accident.

In addition, individual components of a Terry turbine are being tested under single- and two-phase conditions, while first-of-a-kind experimental visualization of two-phase supersonic jets is planned for future experiments. These activities will satisfy the basic modeling needs that are required to model BDBA Terry turbine performance and the full range of anticipated emergency conditions. In addition, both the lubrication oil and turbine's bearings will be examined under extreme conditions in order to provide the utilities guidance on maintenance and testing requirements to ensure operation during these extreme conditions can be maintained. To date, no known testing has been conducted on these systems or components over the range of conditions that may be encountered during a BDBA.

(4) Short Term Deliverables and Minimum Viable Product

The short term deliverables for this project are as follows:

- Obtain flow loss coefficient data on governor and trip/throttle valves as a function of valve position to support modeling efforts and to provide operators the information needed to successfully perform a RCIC/TDAFW system 'black start' (i.e., without instruments) operation in the event of an emergency.

- Obtain data on oil and bearing operations under prolonged elevated temperature operations to provide a technical basis for specifying appropriate maintenance requirements.
- Obtain data on Terry turbine performance under two-phase water ingression conditions to support modeling of RCIC/TDAFW under off-normal conditions.

This information is considered the Minimum Viable Product from this activity, and should provide the technical basis for utilities to take some level of credit for extended and degraded (two-phase flow across the Terry turbine) RCIC/TDAFW operation during an emergency thereby supporting PRA applications, as well as supporting efforts to reduce maintenance requirements for these systems.

(5) Long Term Objective

The long-term vision for this work is to provide the technical basis, data, and tools that achieve the following objectives:

- Protect utility assets by using the Terry turbopump under a broader range of conditions,
- Delay or prevent the need to use less preferred non-reactor grade water sources required during FLEX events,
- Extend the interval between preventive maintenance actions,
- Provide an avenue for qualification of obsolescent parts,
- Provides a potential for regulatory avoidance, and
- Specific to BWRs;
    - Extend the time to get residual heat removal (RHR) system back online,
    - Extend the time for RPV depressurization, and
    - Reduce outage time.

(6) Selection Criteria

This Use Case application meets all six of the project selection criteria from the project selection meeting at INL with interested utilities that was described in Chapter 1. This project directly interfaces with all utilities operating BWRs through the TTEXOB subcommittee of the BWROG. The BWROG cost shares 1/3 of the project. The modeling and testing being carried out to understand Terry turbine performance under beyond design basis conditions is first-of-a-kind work and will provide the technical basis for increasing plant safety margins and so will inform plant margin management decisions. The TTEXOB project has conducted supporting scaling analyses to ensure that the test results and supporting models are applicable to all plants operating RCIC and TDAFW systems in their plants. The results of this Use Case study address a critical near-term need identified by the industry in response to the reactor accidents at Fukushima and provides an avenue for utilities to preclude implementing FLEX with non-reactor grade water.

5. Industry Adoption of RISA

The primary objective of the RISA Pathway is for operating NPPs to successfully adopt and apply LWRS developed technologies to address issues of critical importance to plant safety and economics. As described in previous sections, the use of utility Use Case applications serves as a primary vehicle to support the development and initial application of these technologies. Because at least one host utility will provide sponsorship for each application, there will be direct NPP involvement throughout the entire project life cycle. This involvement will be essential to ensuring the technologies that are developed and applied meet the needs of the host utility and that a MVP is available at the completion of the Use Case application that can be transferred to industry for additional development to support industry wide adoption.

However, experience indicates that transfer and adoption of new technologies (including obtaining any needed regulatory acceptance for use) across the nuclear industry is a significant challenge. This chapter describes the additional actions that the RISA Pathway will take to support these transitions. First, at the completion of each Use Case application the MVP that is developed will most likely require additional development and maturation before it is accepted and broadly adopted. To support this additional development and maturation an industry working group will be assembled to provide direct feedback. This working group is described in Section 5.1. A second critical element of RISA Pathway success will be the capability to deploy the technologies developed within a timeframe that supports industry use to address critical issues and support current operational needs. To support meeting these needs, a significant effort to provide technology transfer will be a critical element to achieving success. The plans for supporting this technology transfer are presented in Section 5.2.

5.1 Industry Engagement, Input, and Review

A critical element of the RISA pathway is the formation of an industry working group that consists of key industry experts to provide technical and programmatic feedback, as well as participation in pilot demonstrations of the RISA technology. This working group includes a broad array of experts from across the industry with representation from utilities (NPP owner/operators), reactor vendors, engineering service providers, NEI, and EPRI. In addition to providing feedback to the RISA pathway, this group will serve as a communication vehicle to report on progress, key results, and technological maturity of methods and tools across the industry.

5.2 Technology Transfer Plan

As described in Chapter 1, the objectives of the US DOE LWRS Program are to (1) maintain operation of the current US NPP fleet to provide reliable, economic, carbon-free electricity production, and (2) provide a pathway for transition to deployment of advanced reactor technologies. In alignment with these objectives, a fundamental outcome of the RISA pathway is to provide risk-informed methods and tools that are capable of enhancing plant safety and economics of the current fleet of NPPs in the near term. Due to the economic challenges faced by the current fleet of NPPs, RISA Use Case applications are being conducted in partnerships with host utilities to apply critical resources in order to develop solutions to critical issues that are being faced by operating NPPs. As described in Chapter 1, these Use Case applications are structured so that the methods and tools developed are in place and providing value to solve the issue within the next 5 years. Thus, the Use Case applications are being performed on accelerated schedules that target development of applicable methods and tools to a state where they are usable within the next 2 – 3 years. This will permit application across the entire industry over the following 2 – 3 years.

It is clear that for the RISA pathway to provide a meaningful contribution within the timeframes discussed, transfer of the technologies that are developed will be an essential part of the RISA program. As a result the RISA pathway is implementing a comprehensive approach to work with industry to ensure effective and efficient transfer of technology is accomplished. Many of these elements have been discussed previously throughout this report; however they will be reiterated in this section to provide a convenient consolidated discussion.

The first element of the RISA pathway that will facilitate effective technology transfer is the structure of the utility Use Case applications themselves. As indicated throughout this report, each Use Case application will be conducted with a utility sponsor on an issue that is of significance to the industry as a whole. This structure provides a direct mechanism for utility interaction to ensure the methods and tools developed can provide near term benefit and value in addressing the particular issue. The second element of the RISA pathway that will support technology transfer is the industry working group discussed in the previous section.

Because many of the Use Cases have regulatory implications (see, for example, the Digital I&C application discussed in Section 4.4), interfacing with NRC will become an important element needed to successfully deploy the technologies developed in the RISA pathway. The RISA pathway plans a multipronged approach to engage NRC. First, the RISA pathway will communicate with NRC in periodic information sessions that occur as part of governmental interagency communications (i.e. scheduled interactions between NRC and the DOE LWRS program). Second, as the specific technologies mature to the point where they are capable of supporting regulatory applications by licensees, the RISA pathway will provide technical support to the industry organizations (NEI, EPRI, owners groups, etc.) that are interacting with NRC to develop approaches that can achieve regulatory approval.

Finally, the RISA pathway will continue to provide broad dissemination of research plans and status with executive level industry stakeholders via communication paths that have already been established under the LWRS program. Examples include programmatic communications with industry executives through their memberships in NEI and EPRI.

6. Conclusions

The value of application of RISA methods and tools to Use Case applications is expected to be significant to both the sponsoring utilities and to the overall commercial NPP fleet. The applications have been developed with direct utility participation and are designed to address current and near term issues that are being faced. The Use Case applications also have been designed to be accomplished within a timeframe that can provide economic value to the sponsoring utility and host NPP and subsequently be applied to provide significant value across the fleet. Additionally, these applications will be pursued in a manner such that the methods and tools can be developed and matured in a manner that supports issue resolution in a timeframe that accrues economic value to support continued plant operation and decision making for extended plant life (e.g. second license renewal decisions).

Because experience indicates that transfer and adoption of new technologies (including obtaining any needed regulatory acceptance for use) across the nuclear industry is a significant challenge, significant emphasis is being placed on supporting effective technology transfer during both the conduct of the Use Case applications and in subsequent transfer to the broad industry. Two particular specific technology transfer activities will be pursued to meet this challenge. First, it is anticipated that the MVPs that are developed during the conduct of the utility sponsored Use Case applications will likely require additional development and maturation before they can effectively be applied across the entire industry. To support this additional development and maturation, an industry working group will be assembled to provide direct feedback to the RISA Pathway. This working group will provide a direct mechanism for utility input to ensure the methods and tools developed can provide near term benefit and value and that industry needs for successful technology transfer and adoption are addressed.

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