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Development of the LWRS Program Innovation Portal to Support Nuclear Innovation

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The nuclear industry recognizes the need to innovate across key functional areas, and is working to effectively identify, select, and implement beneficial technologies. The traditional sociotechnical infrastructure of the existing U.S. nuclear fleet that once required large workforces and was part of a regulated market now greatly challenges the economical sustainability of these plants. Indeed, the nuclear industry recognizes the need to innovate across key functional areas, and is working to effectively identify, select, implement, and sustain meaningful change. A vital question that is being considered across the nuclear industry entails how to effectively manage innovation to improve the economic viability of the U.S. nuclear fleet.

The Light Water Reactor Sustainability (LWRS) Program Plant Modernization Pathway is addressing this question through a business-driven approach to innovation. The perceived risks of and need for change by an industry, influences how innovation is managed and executed. Consequently, these two drivers typically influence

Continued on next page

Table of Contents

U.S. DEPARTMENT OF ENERGY

Continued from previous page

innovation to be incremental or drastic. In the nuclear industry, characteristics that challenge such change include a strong nuclear-safety culture, a high degree of regulation, and a culture averse to perceived risks. Changes at or to a nuclear power plant—whether it be technology- or process-focused—must be evaluated and determined not to adversely affect safety. Changes must also be evaluated to confirm regulatory compliance, and they must be introduced in a way that will overcome perceived risks. Innovation leaders within the nuclear industry routinely face two forces: (1) the need to change; and (2) organizational resistance to change.

The Plant Modernization Pathway hosted a Nuclear Innovation Workshop in June 2019 to engage innovation leaders across the industry, providing them new insight and tools to help manage innovation. This workshop included facilitated discussions and industry presentations within the context of a four-phased approach to nuclear innovation. These phases include innovation identification, selection, implementation, and evaluation. (See Figure 1)

One of the most difficult parts of managing innovation is selecting and implementing innovation. The Plant Modernization Pathway recognizes to effectively select and implement innovation, both a top-down and bottom-up approach is needed. This approach ensures strong alignment between the leadership's vision and the organization's implementation of that vision. Top-down refers to senior leadership developing strategic objectives for the organization to deliver safe, reliable and cost competitive operations. These objectives are used by the organization through a bottom-up analysis to select innovative solutions and develop implementation plans that will meet these strategic objectives.

These ideas were shared with the industry and three initiatives were identified from the workshop. These initiatives are being actively pursued by the Plant Modernization Pathway. First, developing an Innovation Portal to provide industry, researchers, and vendors with a resource for listing relevant technologies and demonstrating how those technologies interrelate for business-driven innovation that addresses a specific functional area. Second, initating and establishing an innovation group to routinely convene and discuss lessons-learned and any innovation progress for the industry. Finally, facilitating open discussion with industry about nuclear innovation; industry participants will be contacted by Plant Modernization Pathway researchers through phone or email. These discussions are meant to share lessons-learned through recurrent meetings with utilities, vendors, and research organizations.

The Innovation Portal will support these initiatives by faciliating business-driven innovation across the industry through key functions, including: (1) the ability to provide detailed information that enables the identification and

Figure. 1 Four-phase approach to nuclear innovation.

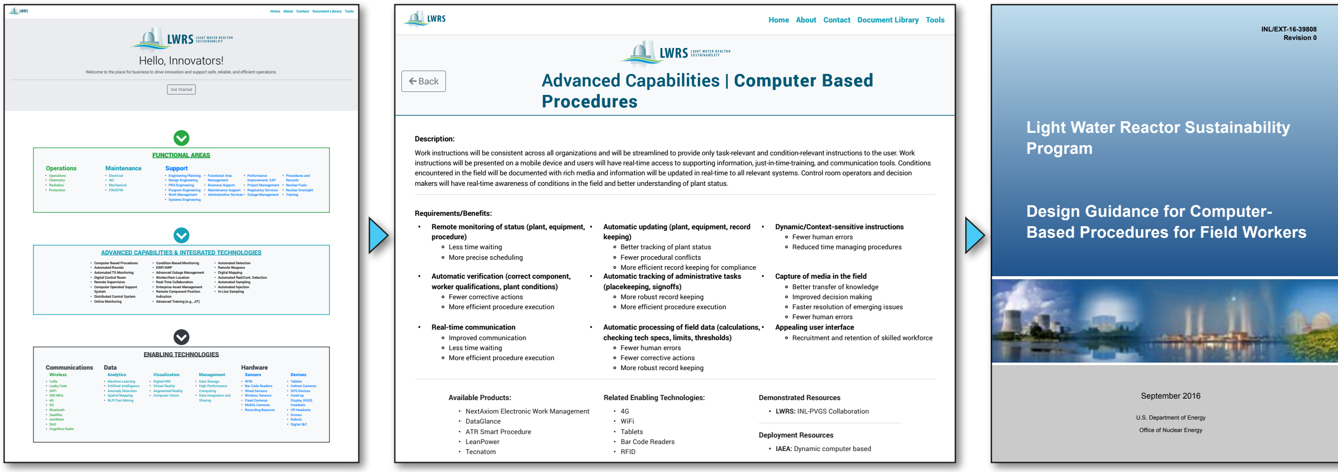

Figure 2. Advanced capabilities and technologies.

selection of technology and capabilities, (2) an interface to help identify, select, and implement advanced capabilities and technologies, and (3) the ability to perform 'what-if' evaluations using enabling technologies, advanced capabilities, and processes for specific utilities. Using this unique innovation mapping, users are provided with insight as to how technology maps to business needs (See Figure 2). Further, this tool will support cost-benefit analyses and work function analyses for the strategic integration of technologies to support capabilities and key work functions.

The Plant Modernization Pathway researchers and developers welcome input from industry, including utilities, vendors, and universities to develop and improve the Innovation Portal. If you are interested in participating in the Innovation Portal development or becoming a member of the innovation group, please contact Casey Kovesdi at casey.kovesdi@inl.gov for more information.

How decades of work at Argonne led to a pivotal moment for U.S. nuclear plants

Following the 2011 Fukushima disaster, where an earthquake and tsunami touched off a series of fuel failures resulting in radioactive leaks, U.S. regulators considered a series of safety enhancements on nuclear power plants. But for many boiling water reactor operators, these new prospective requirements would have meant either closure due to noncompliance or massive retrofitting costs to keep operating. Eventually, a third path emerged, informed by research conducted at the U.S. Department of Energy's Argonne National Laboratory. Data from years of tests at Argonne supported an approach that could both preserve safety and avoid a crippling $1 billion in expenses for plant operators.

Nuclear reactors are protected by a steel-lined containment building reinforced with concrete both inside and out. In an accident, the challenge is to prevent corium—the lava-like material formed when uranium fuel rods in the reactor core melt, along with their protective metal cladding—from entering the environment if the corium escapes the reactor vessel and erodes the concrete floor below.

As a response to the 1979 partial meltdown at Pennsylvania's Three Mile Island power plant, Argonne researchers had been simulating the process of a reactor core melting to see how the resulting corium interacts with concrete, and how that interaction can be halted by flooding with water. The experiments were some of the largest of their kind in the world, and nuclear energy companies co-sponsored them to support safety improvements at their plants. Argonne's research effectively demonstrated that if corium were to migrate outside the reactor vessel, it could effectively be cooled by injecting water through the vessel while keeping the radioactive material inside the containment building—an approach that wouldn't require new equipment or expensive plant modifications.

For more information, please navigate to: [How decades of work at Argonne led to a pivotal moment for U.S. nuclear plants]().

HERON: A New Code for Optimal Dispatch of Nuclear Power

Paul W. Talbot, Cristian Rabiti, and Richard D. Boardman
Flexible Plant Operation and Generation Pathway

The LWRS Program is developing a computer code that will help utilities evaluate future operating options for nuclear power plants. With electricity grid operations undergoing rapid but far-reaching changes, nuclear power plant owners and utility companies need to understand the lifetime financial benefits of LWR plant operations that involve switching between electricity production for the grid or directly providing thermal and electrical energy to an industrial. For example, the nuclear plant could apportion electricity between the grid and an electrolysis plant that produces hydrogen or a water desalination plant that produces fresh water.

Due to the expansion of wind and solar energy and the rapid growth of natural gas power plants, nuclear power plants in some regions may not always operate as baseload plants, but may need to dispatch power to the grid to make up the difference between electricity grid demand and supply provided by other sources, including renewable energy. With flexible operation and generation, nuclear power plants may distribute energy to an industrial process in a dynamic manner that optimizes the revenue of nuclear power plant owners. Some type of energy storage may be required to satisfy the time-of-day needs of the electricity grid and the industry user. A computational code that is capable of projecting and analyzing the integrated system capital and operating costs and cash flow is needed to help optimize the revenue to each of the partners.

A new code, named HERON for Holistic Energy Resource Optimization Network, is being developed as a plugin to RAVEN (Risk Analysis Virtual ENvironment)—a model that was developed to optimize the performance of a complex system. Together, HERON and RAVEN make it possible to account for the increasing random behavior of electricity markets when evaluating key nuclear power plant operating decisions or capital projects. The code characterizes key stochastic trends that account for variables such as solar cycle and weather correlations with variable renewable energy generation, electricity demand, and market pricing. The code creates synthetic time histories for grid hourly pricing for the projected life of a given LWR flexible plant operation and generation system, which may be up to 30 or 40 years. This allows meaningful decisions to be made relative to the economic viability of hybrid LWR configurations and operations under conditions specific to a region and grid.

A detailed technical description of the joint RAVEN/HERON code can be found at the LWRS Program reports webpage for Flexible Plant Operation and Generation [1]. The iterative workflow is represented in Figure 3. The inner loop generates stochastic behaviors and synthetic time histories for dispatch schedules relative to capacity additions and LWR hybrid plant operating boundaries and response limits. The outer loop manages the physical size of the flexible plant operation and generation system components. This can be executed by two modes: sweep mode and optimization mode. In sweep mode, various combinations of component capacities are sampled in order to obtain an understanding of how economic metrics change with respect to changes in the component capacities. This can yield differential economic proforma or sensitivity results. In optimization mode, the outer loop seeks the cost-minimizing or profit-maximizing component capacities by exploring the variable space made up of the component capacities.

As an example, HERON/RAVEN was recently employed in a Cooperative Research and Development Agreement (CRADA) [2] study with Exelon and FuelCell Energy to analyze an integrated LWR electrical power and hydrogen production facility in the Midwest. The code was used to assess the NPV of the systems as a function of the size of the hydrogen plant, the optimal schedule for producing hydrogen or sending electricity to the grid, and the size of hydrogen storage that is needed to ensure a constant supply of hydrogen to industrial users. This optimized system was used to identify attributes of profitability for the affiliated partners under a range of market conditions.

LWRS Program researchers are currently testing the RAVEN/HERON code for regulated and deregulated market conditions. The goal is to make this computer code available to LWR owners and utilities interested in evaluating flexible plant operation and generation alternatives early in 2021. New integrated system configurations will be added to the code to expand the capability of the model beyond hydrogen production. Future capabilities may include new electrochemical processes for polymers or chemicals production, wastewater treatment, or plastics recycling. The code will help evaluate these alternatives to help guide nuclear plant owners in making strategic decisions relative to the best markets and optimal modes of plant operations.

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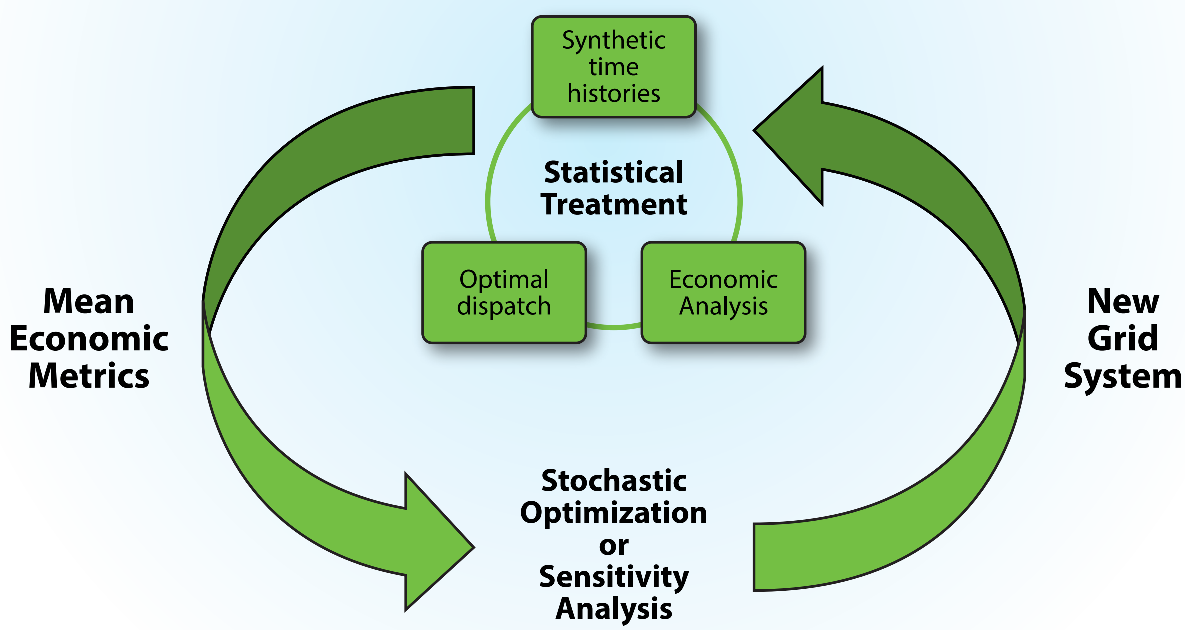
2. The CRADA was cost shared among the industrial partners and Department of Energy Office of Nuclear Energy Crosscutting Technology Development Integrated Energy Systems program and DOE office of Energy efficiency and Renewable Energy Fuel Cell Technology Office.

Figure 3. RAVEN/HERON model workflow.



Toward the Development of a Nuclear Power Enterprise Risk-Analysis Framework

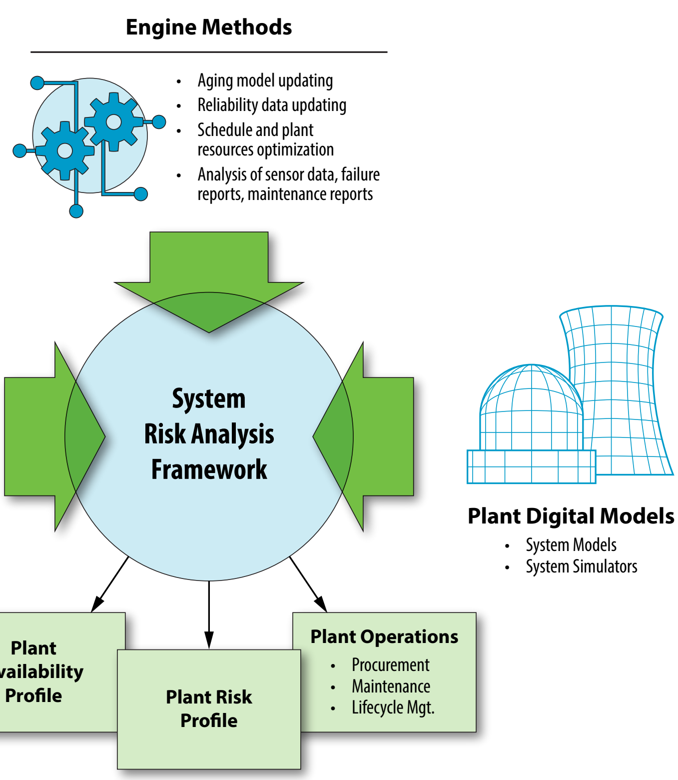
Diego Mandelli, Congjian Wang, David P. Morton, Ivilina T. Popova, Stephen M. Hess
Risk-Informed Systems Analysis Pathway

Industry equipment reliability and asset management programs are essential to help ensure the safe and economical operation of nuclear power plants. The effectiveness of these programs is addressed in several regulatory and industry-developed programs, such as the U.S. Nuclear Regulatory Commission (NRC) Maintenance Rule 10 CFR 50.65 and the Mitigating Systems Performance Index programs [1]. These programs are labor intensive and expensive; therefore, the goal is to reduce cost and improve operational effectiveness by applying risk-informed based tools and methods. To do this, two work scopes are set: (1) automation of equipment reliability and asset management programs; and (2) development of an integrated computational framework that can reduce plant operational costs while maintaining adequate safety margins and satisfying regulatory requirements

A Framework to be Deployed across the Nuclear Industry

The Risk-Informed Systems Analysis Pathway provides efficient analytical methods and tools to support risk-informed decisions for nuclear power plants equipment reliability and asset management programs. The outcome of this project will be an Enterprise Risk-Analysis Framework, as shown in Figure 4, which can be deployed

Figure 4. RISA Pathway Enterprise Risk Analysis Framework.



across the nuclear industry. This framework will combine data analytics tools with risk-informed methods to manage plant assets over years of operation—including periods of subsequent license renewal—in a manner that is significantly less labor-intensive and more cost-effective than is currently performed.

Initial work has started using the LWRS Program-developed RAVEN code, which provides advanced capabilities in terms of uncertainty quantification, sensitivity analysis, data mining, and model optimization. These capabilities are used to evaluate the impact of different equipment reliability and asset management strategies—such as different maintenance policies or the deployment of new technologies—from a reliability and economic perspective. The distinguishing feature of this kind of analysis is that it permits the simultaneous evaluation of coupled economic and risk impacts.

As an example, the evaluation of the impact of new maintenance strategies at the system/plant level incorporates maintenance cost and reliability data into a model that describes how they are related when the time between Preventive Maintenance (PM) actions changes. Similarly, the same maintenance model can be used to capture corrective maintenance (CM) costs and identify the optimal interval between PM actions as labeled T_PM in Figure 5, which minimizes maintenance costs while achieving targeted system/plant availability goals.

Another development of the Enterprise Risk-Analysis Framework is targeting a class of optimization methods explicitly designed to address subsequent license renewal issues. Sample questions that can be answered with this system are:

- Which set of projects maximizes the financial return on investment under budget constraints on capital improvements, operations and maintenance, and funding availability?
- What is the best time window to complete each project to maximize the return on investment given aspirations to minimize and smooth expenditures (i.e., small cost variability from year to year), while limiting risk to unexpected costs?

The answers to these and other long-term asset management investment questions can be obtained by applying the methods developed in this research program and using them to optimally schedule component replacement and refurbishment. These methods integrate both risk, reliability, and cost models into a single decision-making tool that helps to address questions at the nexus between safety and economics.

Reference

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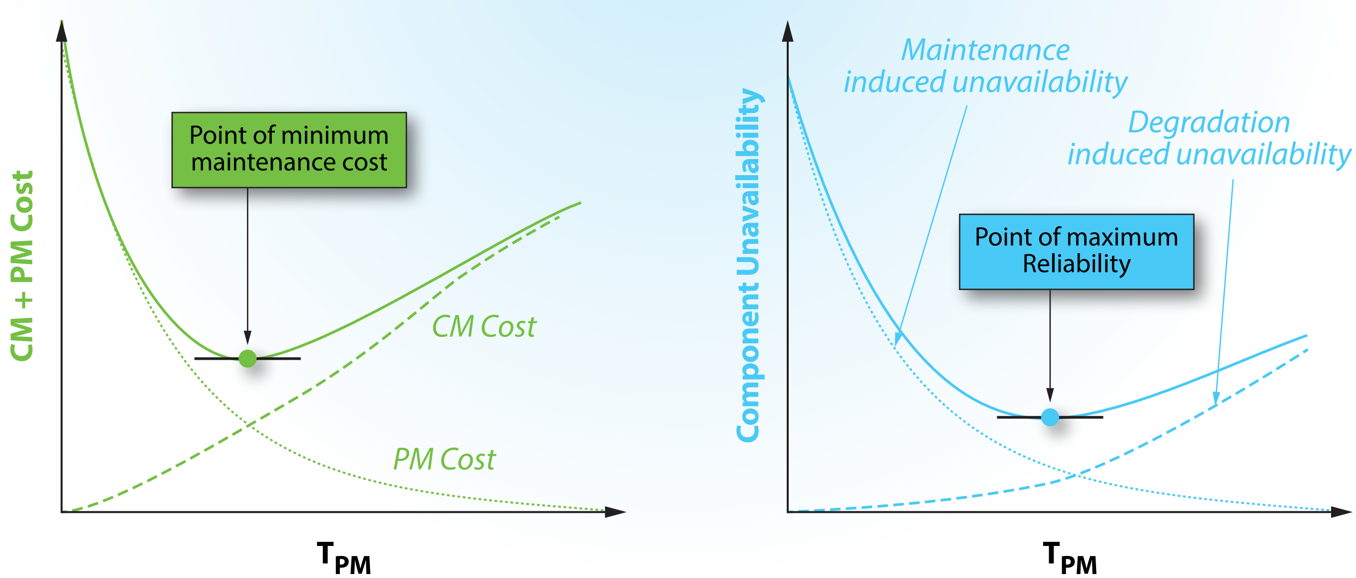
Figure 5 Balancing costs and reliability: preventive maintenance use case.



Improving Force-on-Force Modeling and Simulation to Support Physical Security Optimization



Robby Christian, Steven R. Prescott, Vaibhav Yadav
Physical Security Pathway

The goal of the LWRS Program Physical Security Pathway is to develop tools, methods, and technologies, and to provide the technical basis for an optimized physical security posture at nuclear power plants [1]. Force-on-Force (FOF) simulation models are used by facilities to compare and evaluate their protection strategies. This research paves way for risk-informed physical security optimization by incorporating dynamic scenarios, operator actions, FLEX portable equipment, and thermo-hydraulics analysis with the plant FOF models.

Dynamic FOF modeling is performed using the SCRIBE3D computer simulation tool developed by Sandia National Laboratories and integrating it with the dynamic assessment tool EMRALD developed at Idaho National Laboratory (INL). These FOF models are powerful tools to perform quantitative assessment of a plant's physical security performance effectiveness under simulated scenarios. These models enable the analysis of current postures, perform sensitivity analyses of variables and elements of physical security, identify strengths and weaknesses in the current strategy, explore different strategies by simulating variables and outcomes in a given sabotage scenario, and derive potential approaches to optimize a plant's physical security posture.

The current effort utilizes the following computational tools:

1. SCRIBE-3D Tabletop Recorder [2], a software tool that allows users to visually record and play-back FOF scenarios during a tabletop exercise. It offers a set of tools to visualize, organize, and record data reflecting their decisions while users develop scenarios.
2. AVERT Physical Security [3], which is 3-dimensional (3D) simulation software that analyzes the effectiveness of a physical protection system by using Monte Carlo simulations of adversarial pathways. These simulations provide analysts with an improved understanding of vulnerabilities at a facility.
3. EMRALD [4] is a dynamic risk assessment tool that is based on three-phase discrete event simulation, where the next events in time are sampled. Traditional aspects of risk assessments such as components with basic events, fault trees, and event trees are represented in a dynamic framework of state diagrams and are displayed. The user interface allows for quick and easy-to-understand modeling of scenarios, as well as the means to represent system, component, and operator actions.

EMRALD is used to manage the different FOF simulation tools and supplement the simulation capabilities with dynamic uncertainties, as shown in Figure 6. This framework allows a security analyst to relax the conservatism in their security posture and gain further insight on optimizing the posture for protection effectiveness and associated costs. The following analyses have been performed using this framework:

1. Analyzing the change in security effectiveness using randomized shift breaks.
2. Comparing the security effectiveness and cost between different physical protection configurations.
3. Analyzing operator actions to mitigate sabotage attacks, such as:
    a. The likelihood and possible pathway for control room operators to evacuate to a backup control room under certain circumstances.

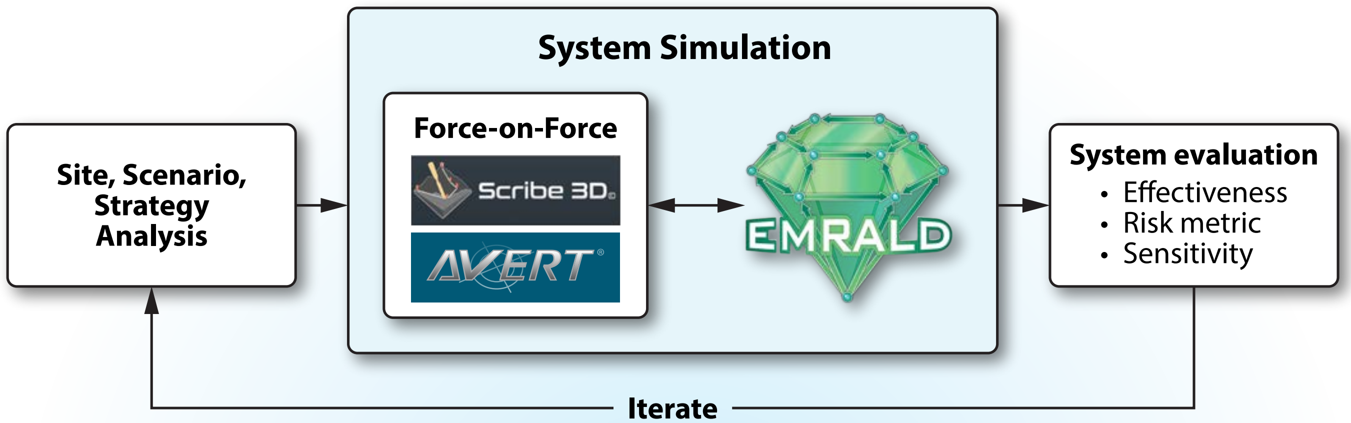


Figure 6. Dynamic FOF simulation framework

b. Timeline evaluation of diverse and flexible coping (FLEX) mitigation strategies and their success probabilities [5].

The Physical Security Pathway is also collaborating with South Texas Project Electric Generating Station and ARES Security on using dynamic modeling and simulation to: 1) obtain the most effective and economically efficient physical security posture for a future capital investment in plant security, and 2) provide technical basis for incorporating FLEX portable equipment into plant security plans and procedures.

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Using Automated J-R Curve Analysis Software to Simplify Testing and Save Time

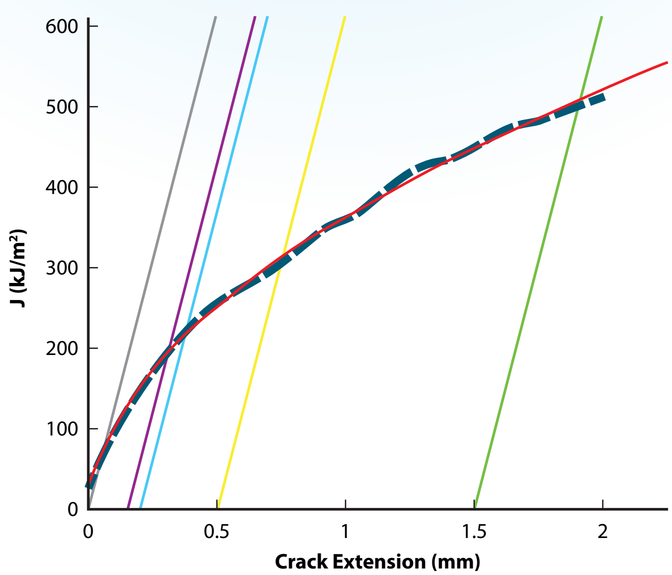
ASTM International, one of the world's largest associations of materials-centric engineers and scientists, has selected an article authored by LWRS Program researchers — Xiang (Frank) Chen, Alberto Esteban Linares, Logan Clowers, Mikhail A. Sokolov, and Randy K. Nanstad — for inclusion in the 2020 ASTM E1820 standard. The article titled, "Using Automated J-R Curve Analysis Software to Simplify Testing and Save Time," discusses newly developed automated software based on the ASTM standard E1820-18 normalization method, which is a useful tool for evaluating material fracture toughness in the ductile region. The software is user-friendly, and yields results that match the manual analysis method. Source codes were written in MATLAB and the compiled software in the form of a standalone executable and is readily compatible with modern Windows operating systems. Read more here: ASTM International selects AM&P article for inclusion in 2020 ASTM standard.

Development of Automated J-R Curve Analysis Software to Simplify Fracture Toughness Testing and Analysis

Xiang Chen, Logan Clowers, Alberto Esteban-Linares, Mikhail Sokolov, Randy Nanstad
Materials Research Pathway

The Materials Research Pathway developed open-source software to perform the automated J-integral versus crack growth resistance curve (J-R curve) analysis. The J-R curve is a useful tool for evaluating materials fracture toughness and has been widely used in both academia and industry [1], such as assessing the fracture resistance behavior of reactor vessels and the irradiation embrittlement of reactor internal materials. A widely accepted practice for conducting J-R curve testing is American Society for Testing and Materials (ASTM) Standard E1820 [2], which includes the normalization method and the conventional elastic unloading compliance (EUC) method. The normalization method significantly simplifies the testing procedure because it does not require compliance measurements during testing, unlike the EUC method, but it does require very complicated analysis procedures. Because of this, the Materials Research Pathway researchers recently developed an open-source J-R curve analysis software to automate the analysis procedures. The source codes were written in MATLAB® and the compiled executable software has a user-friendly graphical interface that is readily compatible with Windows® operating systems. The software provides a convenient tool for evaluating the long-term aging effect on materials fracture toughness properties to support the safe operation of existing nuclear power plants. Figure 7 shows the startup window for the software.

Figure 7. Startup window of the normalization analysis software (automated J-R curve analysis based on the ASTM E1820-18 normalization method).



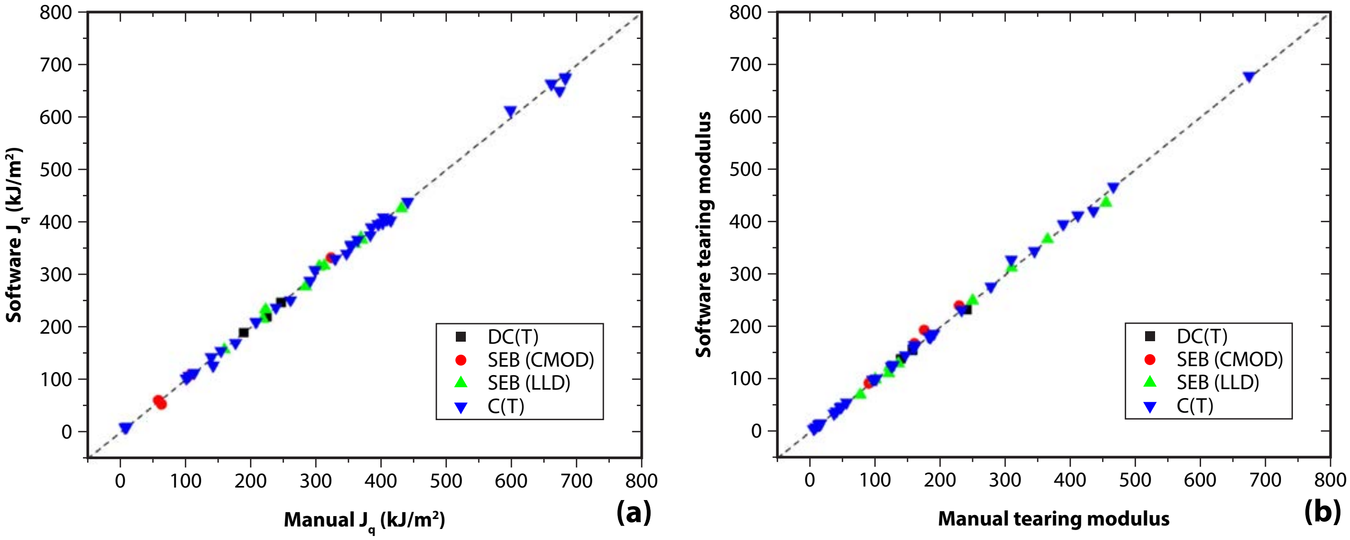
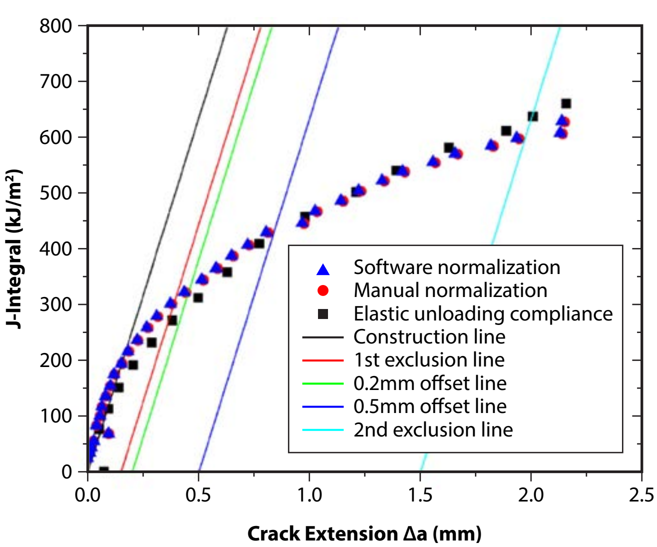


Figure 8. The close match of the J-R curve derived Jq results in (a) and the tearing modulus results in (b) between the software and the manual analysis.

The software is capable of analyzing the four most commonly used fracture toughness specimen geometries (i.e., compact tension [C(T)], disk compact tension [DC(T)], single edge bend with load line displacement measurement [SEB(LLD)], and single edge bend with crack mouth opening displacement measurement [SEB (CMOD)]). To verify that the J-R curve analysis software yields valid J-R curves, the software results were compared with the results from the manual analysis based on the normalized method. The sampling dataset for the comparison included 50 tests covering all four different specimen geometries; a wide testing temperature range from 23°C to 700°C; and materials including stainless steels, nickel-based alloys, ferritic-martensitic steels. The comparisons for fracture toughness Jq and tearing modulus results derived from the J-R curves are shown in Figure 8 [3]. The software yields essentially identical results as the manual analysis method. The small differences observed between two analysis routes are due to the different criteria used in terminating the iterative calculation process. Further, Figure 9 shows the same specimen J-R curve results derived from three different analysis routes [3], namely the software normalization analysis, the manual normalization analysis, and the EUC method. The J-R curve results from the software and manual normalization analyses overlap with each other while small differences are observed between the normalization method and the EUC method due to the differences in the calculation of crack sizes between the two methods.

Figure 9. Comparison of J-R curves from three different analysis routes for the same specimen.



The reference for the analysis software has been balloted and added to the ASTM E1820 standard. Both source codes and the compiled executable file are available to download at code.ornl.gov/xc8/ANJR.

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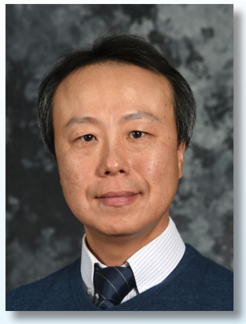
Technical Capability Assessment of RAVEN (Risk Analysis Virtual Environment)



Yong-Joon Choi and Curtis L. Smith
Risk-Informed Systems Analysis Pathway

The LWRS Program has developed software tools that need to achieve a high technical maturity in order to be utilized by the nuclear industry. Therefore, the software needs a comprehensive capability assessment based on their potential use.

The Risk-Informed Systems Analysis (RISA) Pathway performed an assessment of software to be used in risk-informed margin management. The assessment process includes three items:

1. Developing the software capability requirements;
2. Evaluating the importance (i.e., high, medium, or low) of the requirements; and
3. Assessing the Technology Readiness Level (TRL) of each requirement.

Technical Capability Assessment of RAVEN

Developed by the U.S. National Aeronautics and Space Administration, the TRL is a method for estimating the maturity of technologies during the development and acquisition phase of technology deployment as shown in Figure 10. A total of nine levels are set from low level (1 to 4) to high level (5 to 9), which represents a range from research and development status to readiness for industrial use.

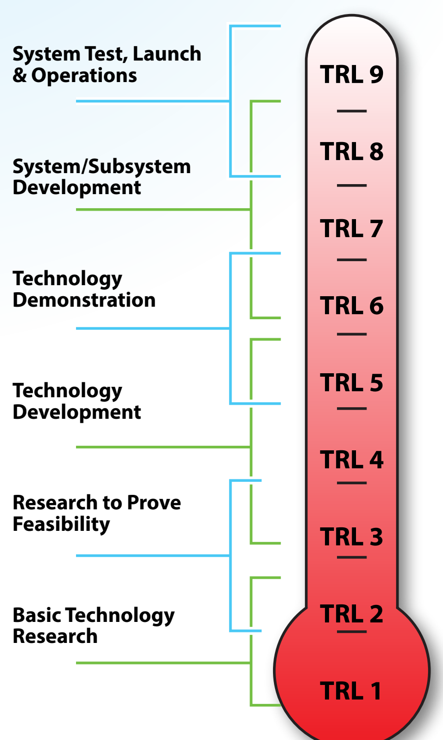
The RAVEN software developed by LWRS Program researchers at INL [2] is used by the RISA Pathway for uncertainty quantification, regression analysis, probabilistic risk assessment, data analysis, and model optimization. One of the purposes of RAVEN is to support system-analysis code application for risk-informed analysis.

The RAVEN development philosophy is to construct a capability of analysis from calculation flow to interpreting the user-defined instructions and then assembling the different analysis tasks following a user specified scheme. The Python programming language was used to maximize flexibility and accelerate development. Flexible code coupling capability is one of the strong features found in RAVEN. It was designed to couple many of the computer codes in the field of thermal-hydraulics, safety analysis, neutronics, probabilistic risk assessment, and Multiphysics Object Oriented Simulation Environment (MOOSE) based-applications. This coupling works even with code generated with different program languages such as FORTRAN, C++, and Python.

RAVEN was designed as a non-physics application (it does not solve partial differential equations for example); therefore, no specific validation is necessary. However, RAVEN automatically performs a regression test to confirm that the code works correctly. A total of 733 regression tests are available in the RAVEN framework and tests are continuously added as needed.

During the assessment, 14 requirements were considered, including: the code development level, capability and features, quality assurance program, developer/independent verification and validation (V&V) record, separate/integral tests history, user documents, and user feedback. Table 1 summarizes the result of the assessment, including the importance of each requirement and the assessed TRL. RAVEN has been used for uncertainty quantification, dynamic probabilistic risk analysis, automated sensitivity studies, and extensive data mining. It has a strong capability of coupling with various computer software packages used in the nuclear industry. An open source policy, its plotting capability, and detailed output

Figure 10. Technology Readiness Levels (TRL) [1].



Requirements	Level of Importance	Results	TRL
Code development level	High	Fundamental development for RAVEN technology is mostly finalized. Coupling capability with external software is fully demonstrated. Need platform for VERA-CS, FRAPCON/FRAPTRAN, CFAST, FDS, and GOTHIC. More industrial use and V&V is needed.	7
Use of proven technology	High	Python used. No specific issue was found.	9
Probabilistic Risk Assessment capability/applicability	High	Demonstrated for classical and dynamic probabilistic risk assessment purpose. Risk-weighted optimization method could improve quality.	8
Documentation	Medium	Set of manual includes theories, user guide, and verification activities. Thorough revision and proof reading is necessary.	6
System requirements	Low	Linux, Windows, and Mac OsX with various versions are tested. Operating system comparison study was not performed.	7
Easy installation	Medium	Installation method is well described in software package.	9
Graphic user interface (GUI)	Medium	No official GUI is currently available. Plotting capability is included. GUI will facilitate coupling capability.	5
Version control	Medium	New version includes all features of previous version and updates. Developer's version is also available. No version comparison study.	7
V&V history	Low	No validation activity is needed for RAVEN. Verification is extensive.	9
Quality Assurance (QA) program	High	Follows development company's QA program (NQA-1 compliance).	9
Web page	High	Both GitHub and conventional style web pages are functioning. However, general information should be updated.	7
User support	High	GitHub web page is main method for user support. Reported issues management is well controlled. However, sustainable resource is necessary for continuous support to RAVEN development team.	7
Training program	Medium	Training program is organized by development team as needed.	8
License	Medium	RAVEN is open source. Contributor license agreement is needed for participating development.	9

Table 1. Results of the technical capability assessment of RAVEN.

data management are also notable features. As an element of the RISA Toolkit, RAVEN has proven capable of generating various dynamic probabilistic risk assessments and coupling capability with the RELAP5-3D thermal-hydraulics software. In addition, new capabilities are added as needed, extending this framework to support LWRS Program projects.

The RISA Pathway evaluated both RAVEN and RELAP5-3D in 2019. From these analyses, we identified areas for future focus. In summary for RAVEN, the TRL is quite high indicating a mature software package. Next, we will evaluate the INL-developed HUNTER (human reliability simulation) and EMRALD (dynamic risk simulation) using this assessment approach.

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Sustainable Energy Economy Workshop: Light Water Reactor and Hydrogen Hybrids

Eric Williams
Flexible Plant Operation and Generation Pathway

From Richard Boardman's perspective, "We're transitioning from a hammer looking for a nail, to a carpenter looking for a nail." Boardman, LWRS Program Pathway Lead, cites Abraham Maslow's Law of the Instrument – "I suppose it is tempting, if the only tool you have is a hammer, to treat everything as if it were a nail" – in describing the transformation nuclear energy is undergoing.

Boardman credits the University of Toledo (UToledo) for convening a diverse group of carpenters more interested in crafting innovative products than in pounding away at the same old nails. This past January, UToledo hosted the Sustainable Energy Economy Workshop: Research & Development of Light Water Reactors and Hydrogen Hybrids. As the follow-up report explains, central to the workshop was to "explore opportunities in repurposing light water nuclear reactors for hydrogen production through a hybrid systems design," with Energy Harbor's Davis-Besse Nuclear Power Station serving as the laboratory.

"We found a gold mine of experts at the workshop," said Boardman, Flexible Plant Operation and Generation Pathway Lead for the LWRS Program.

"It wasn't an arbitrary decision that the University of Toledo was the host," agreed Constance Schall, a chemical engineering professor at the school. "There's a spirit of community in the Toledo region that supports diverse partnerships." "There is a considerable existing market for hydrogen and a lot of promise and potential in this region," said Alan Scheanwald, with Energy Harbor who is the company's project manager for this effort.

Indeed, the report backs up Scheanwald's assertion, noting that Davis-Besse is within 150 miles of major, existing hydrogen consumers. As the report put it, Ohio already has "a strong base of fuel cell component and material suppliers and has demonstrated hydrogen use in public buses. Dayton is a major producer of hydrogen forklift vehicles and Ohio has numerous large warehouses where such vehicles can be used. Trucking is an important Ohio industry that will benefit by hydrogen-powered fuel cell trucks and Ohio is close to major automotive centers."

Hydrogen has long held a substantial-but-elusive promise for the nuclear energy industry. Scheanwald believes that potential is on the precipice of becoming reality, with Davis-Besse's primary role being to demonstrate and deploy a 1- to 3-MW low-temperature electrolysis unit to produce commercial quantities of hydrogen.

"The main objective is to boost the revenue of struggling nuke power plants that are competing with cheap natural gas and renewables," Scheanwald said. He echoed the words of INL's Bruce Hallbert, director of Department of Energy (DOE's) Light Water Reactor Sustainability Technical Integration Office, who described when Davis-Besse was selected to anchor the project.

"This first-of-a-kind project represents significant advances for improving the long-term economic competitiveness of the light water reactor industry," Hallbert said. "This project also accelerates the transition to a national hydrogen economy by contributing to the use of hydrogen as a storage medium for production of electricity, as a zero-emitting transportation fuel, or as a replacement for industrial processes that currently use carbon-emitting sources in hydrogen production."

Producing hydrogen is an inverted solution to the notion that nuclear power plants need to ramp up and down with demand and to integrate with renewables. Instead, the plants will produce hydrogen during low-demand times – say, when the wind is blowing, or the sun is shining – and thus continue to provide baseload and operate at an extremely high capacity level.

Along with INL and Energy Harbor, partners in the two-year DOE project include Xcel Energy, which owns and operates two nuclear power plants in Minnesota, and Arizona Public Service, which operates the nation's largest nuclear plant, the Palo Verde Generating Station in Arizona.

Scheanwald, Boardman and others also marveled at how the workshop brought otherwise disparate worlds together and not only revealed the overlap between those spheres, but also geographic and industrial diversity.

Alongside representatives of large industrial companies such as Air Liquide (France-based supplier of industrial gases) and Cummins (the Indiana-based manufacturer best known for its engines that is now developing fuel cells) were companies few people are aware of, including:

Figure 11. A Stark Area Regional Transport Authority (SARTA) hydrogen fuel cell bus was available for attendees at the University of Toledo's Sustainable Energy Economy Workshop. (Photo courtesy of University of Toledo).

- OCO – An Oregon-based company that uses captured carbon dioxide to make formic acid, displacing fossil-fuel-derived feedstocks. Formic acid has a broad array of uses, from preserving silage (cattle feed) to airplane de-icer.
- Midrex Technologies – The Charlotte, North Carolina, direct-reduction ironmaking technology and services company that is a central player in the rebirth of iron and steelmaking in the American Midwest.
- Nikola Motor – The Arizona company that makes hydrogen-powered fuel cell trucks. Nikola made a splash late in 2019 when it completed what was called the first-ever emissions-free beer delivery, part of its agreement to build 800 trucks for Anheuser-Busch.

The workshop also made Boardman a disciple of what Michael Heben, professor of physics and director of UToledo's Wright Center for Photovoltaics Innovation and Commercialization, calls "transactive energy," meaning actions or transactions that imply some sort of agreement. "The synergy is everyone gets higher value for their electricity – the producer and the buyer. It's a whole new business structure."

"The little-known fact is that hydrogen is already used at nuclear plants," he said, pointing out that boiling water reactors use hydrogen for water chemistry and pressurized water reactors like Davis-Besse deploy hydrogen in cooling applications. "Our industry places nuclear, personal and industrial safety first and foremost in everything we do."

See the full version of this article: Sustainable Energy Economy Workshop: Light Water Reactor and Hydrogen Hybrids.

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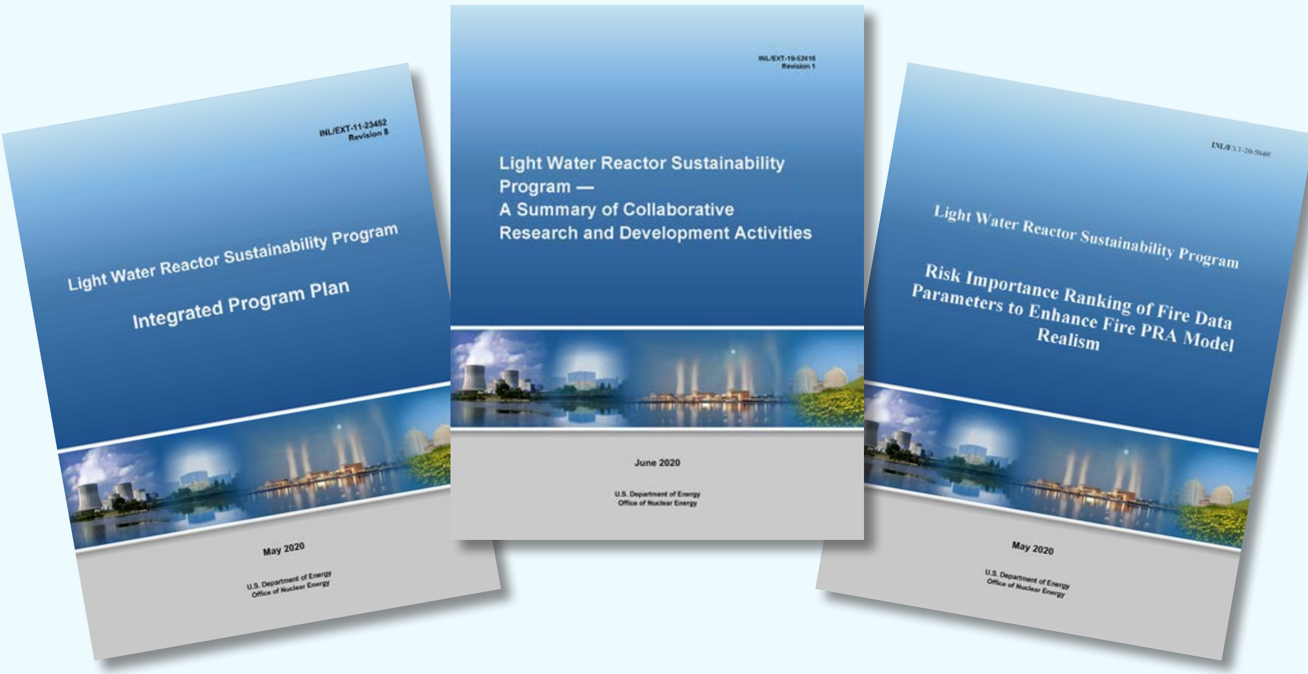

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