Nuclear News

September 2021

PROBABILISTIC RISK ASSESSMENT

In This Issue:

The origins of *The Reactor Safety Study*

Helping solve the plant safety riddle: An overview of probabilistic risk assessment

September 2021
Volume 64, Number 10

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How risky is it to cross the street?

If I walk across a street, what are the chances that something bad will happen to me? I don't know the answer to that, but I suspect that there are a lot of variables that should be considered. Is it a busy street? Am I crossing where there are traffic lights or a stop sign? Is it daytime or nighttime? Are there trees around that could fall on me? Am I paying attention to my surroundings or looking at my phone as I cross? Then, there is my physical condition to be added to the equation: How old am I? What is my health status? At what pace can I be expected to cross the street?

There is risk in everything in life. This issue of *Nuclear News* is devoted to risk, specifically focusing on the science of how likely something of consequence can happen at a nuclear power plant. That's where probabilistic risk assessment comes in. PRA is an analytic tool that is flexible enough to tie in a plant's neutronics, thermal hydraulics, systems analysis, chemistry, and other parameters as input to a cost-benefit and optimization analysis. PRA is about taking objective information and combining it with subjective information to make educated decisions.

In addition to articles on the origins of the Reactor Safety Study by Nuclear Regulatory Commission historian Thomas Wellock and an overview of PRA by a team of authors, another feature in this issue is an interview with Matt Denman (page 54), chair of the ANS/ASME Joint Committee on Nuclear Risk Management's Subcommittee on Standards Development. As Denman notes in the interview, PRA is a living science, because as objective information changes, it will change the subjective understanding of what to do and how to move forward.

"That's just part of the process, because humanity as a whole has not agreed on what 'safe enough' means," Denman commented. What "safe enough" means in the United States could differ from what it means in other parts of the world. As such, it will push risk assessment technologies in different directions and will require an evolving understanding of risk acceptability.

"Regarding physical science," Denman said, "I can measure gravity's constant and know that there's only so far I can go in refining that information. For risk assessment, however, because it always harkens back to the philosophical ideas of what we can accept as 'safe enough' and what we should do as a company or a society, those ideas will be constantly changing, because humanity is constantly changing."

A lot of people might view PRA as a design optimization tool—"I'm going to design the safest reactor possible"—but that's not how Denman views its benefits. He explained that nuclear power is a carbon-free energy source that doesn't have the particulates of fossil fuels and doesn't take up land like wind and solar installments do, which are positive attributes for nuclear's PRA. "You don't get those benefits by designing the minimized risk reactor," he said. "You get those benefits by *building* nuclear power plants. They need to be safe and acceptable to the public, but that's a pass/fail piece of information. I think that the PRA technology is at its best when it's treated that way."

For now, it's lunchtime, and I think I will walk to the sandwich shop, across the street.—*Rick Michal, Editor-in-Chief (rmichal@ans.org)* framatome

What’s buried can
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The rationale behind drip shields for the Yucca Mountain Project

(*Editor's note: We are including in this* NN *issue the following letter that references an article in ANS's* Radwaste Solutions *magazine because we feel that* NN *readers will be interested in the topic.*)

I was impressed with the excellent recent review by Dennis W. O'Leary on the geology of the Yucca Mountain area (*Radwaste Solutions*, Spring 2021, p. 36). However, he did not discuss the details of or the perceived need for the titanium drip shields. Many Yucca Mountain Project (YMP) engineers, including Kevin McCoy in his Readers Write letter, "Remembering Yucca Mountain" (*NN*, July 2021, p. 6), were not proponents of their use. However, a little background might provide the rationale.

I joined the YMP in 1987 and sometime later was made the lead for the development of waste package materials. At that time, the design of the waste package had not been finalized. Thus, it was necessary for the long-term, large-tank corrosion studies, which early on were conducted by Lawrence Livermore National Laboratory, to include a broad range of materials (carbon steels, stainless steels, copper alloys, and a limited number of high-nickel alloys) and a broad range of pH (2.7 to 12) and temperature (~80°F to 200°F). In addition, short-term, desktop-localized corrosion studies were conducted.

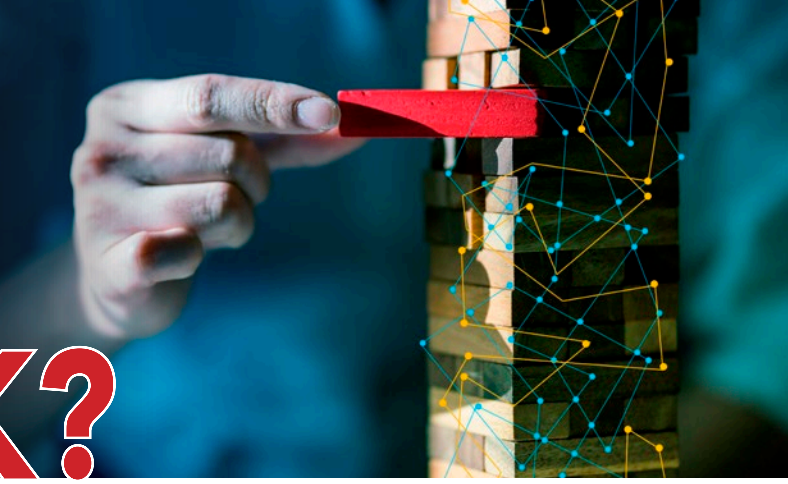
At the same time, YMP geochemists were developing a better understanding of the chemistry of the water that might drip on the waste packages through the use of models and *in situ* heater tests. These efforts helped us dramatically narrow the pH range of concern, to about 5.6 to 8. The corrosion testing, particularly the localized corrosion tests, showed that the high-nickel alloys would perform best under the expected conditions. Because of the higher cost of the high-nickel alloys, the waste package design team, under Tom Doering, developed a design that had an outer shell of the nickel alloy for corrosion resistance and an inner shell of stainless steel for strength. Based on the need to meet the corrosion and mechanical requirements, I selected, and the Department of Energy approved, the use of Alloy 22 as the outer shell material.

However, some uncertainties arose. For example, could localized corrosion, particularly stress-corrosion cracking, cause early failures? This was mitigated by the development of laser peening of the closure welds to eliminate tensile stresses in the welds. Also, there was some uncertainty in the concentration of chlorides, nitrates, and sulfates in potentially dripping water. Tests by the microbiology department at the University of Nevada–Las Vegas indicated that the high-nickel alloys were resistant to microbial attack by sulfate reduction and other bacterial activity, but that the titanium alloys were basically immune to that attack.

Hence, that led to the current design that includes both the Alloy 22 outer shell and titanium alloy drip shields. The latter would be placed over the waste packages just prior to closure. The period between insertion of waste packages and closure of the repository could be as long as 40 to 100 years. During this period, testing on the geochemistry would be conducted, to better ascertain the water chemistry, as would additional corrosion testing, to confirm the resistance of the Alloy 22 to degradation. If the results were benign, the drip shields could be made of stainless steel and would function only as rock fall protection and not as the additional corrosion barrier that would be provided by the more expensive titanium alloys. Thus, the titanium alloy drip shields were viewed as an insurance policy that, if needed, could greatly increase waste package life.

David Stahl
Las Vegas, Nev.

ATOMS



What's the RISK?

Risk. It's about what can go wrong and how bad it could be. But risk assessment is more than just a pessimist's idea of a good time. Optimists and realists alike bet on the application of math, science, and computing to reduce the chance of dicey outcomes.

Blaise Pascal

Pierre de Fermat

Pierre-Simon Laplace

Probabilistic past

French mathematicians are among the historical figures credited with formalizing probability theory. In 1654, Blaise Pascal and Pierre de Fermat began writing letters to one another in which they worked out a mathematical treatment of dice games and some fundamental principles of probability theory. In 1812, Pierre-Simon Laplace introduced new techniques and applied probabilistic ideas to scientific and practical problems in his book *Théorie Analytique des Probabilités*.

Climate RISK

The unmatched safety record of nuclear power generation is built on risk awareness. Yet the risk posed by a low-carbon nuclear plant is dwarfed by the risk of climate inaction. The World Economic Forum's Global Risks Report 2021 identified climate action failure as the most impactful and second most likely long-term risk facing the world, and there is good money to be made in advising companies of all sizes on climate risk management.

According to data presented by the National Oceanic and Atmospheric Administration, the United States saw nearly $550 billion in losses in severe weather disasters in the 10 years from 2004 to 2013.

Data source: NOAA, https://health2016.globalchange.gov/extreme-events

Billion Dollar Losses from Disasters

2004 to 2013

$392 billion
Hurricanes

$46 billion
Tornadoes/Severe Storms

$78 billion
Heat Waves/Droughts

$30 billion
Flooding/Severe Storms

Computational RISK analysis

While theory will get you pretty far, real-world physics determines what will melt, break, crack, shake, or flood. Computational risk analysis combines physics-based computational models with probabilistic analysis and lets researchers simulate disasters and gather a huge amount of data representing movement within space and time.

The MOOSE simulation platform developed at Idaho National Laboratory can be used to model nuclear fuel rod behavior, as shown here, and supports risk assessment applications.

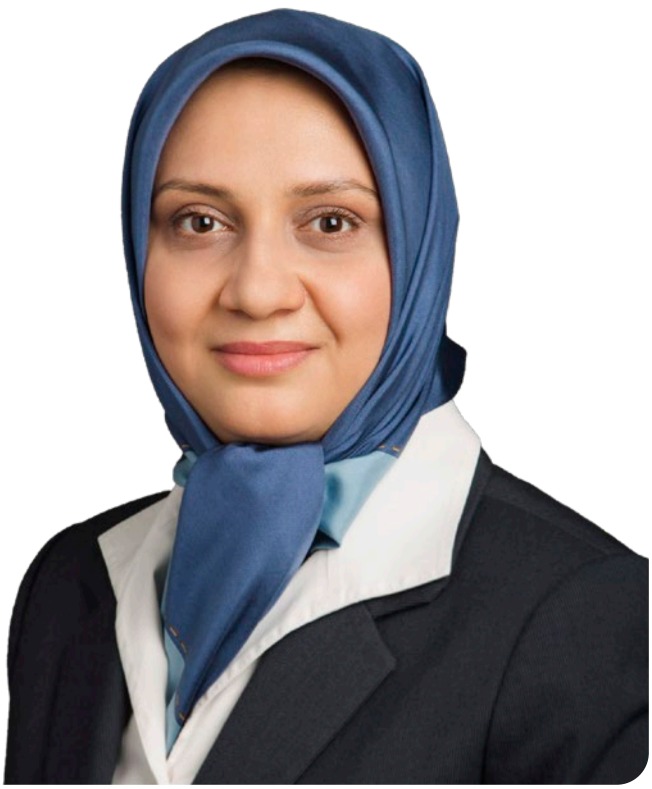
Photo: INL

Lighting the path for next-generation PRA leaders in nuclear engineering

By Zahra Mohaghegh

Our next-generation leaders must begin to think more creatively, using risk-informed solutions to ensure safe, resilient, sustainable, and socially responsible technological advancements to usher in an era void of technological accidents. Probabilistic risk assessment (PRA) research and education provide nuclear engineering students with the scientific expertise and viable skill sets essential for meeting the growing demand for risk analysts in nuclear energy domains.

Since the *WASH-1400 Reactor Safety Study* in 1975, PRA has played a vital role in policy and decision-making for nuclear power plants; however, there is currently a large gap in the U.S. between the demand for risk-informed analysis of nuclear technologies and PRA research and education in nuclear engineering. This gap is mainly due to (1) the lack of hiring PRA junior faculty for nearly two decades in university nuclear engineering programs and (2) the ever-increasing need for risk-informed analysis to address emergent safety concerns; improve operational efficiencies in existing plants; and promote the design, licensing, and operationalization of advanced reactors.



Zahra Mohaghegh is an associate professor in the NPRE department at UIUC and is director of the SoTeRiA Research Laboratory.

In 2013, the Department of Nuclear, Plasma, and Radiological Engineering at the University of Illinois–Urbana-Champaign (UIUC) took the lead and established the Socio-Technical Risk Analysis Research Laboratory (SoTeRiA lab) to advance PRA science and applications.

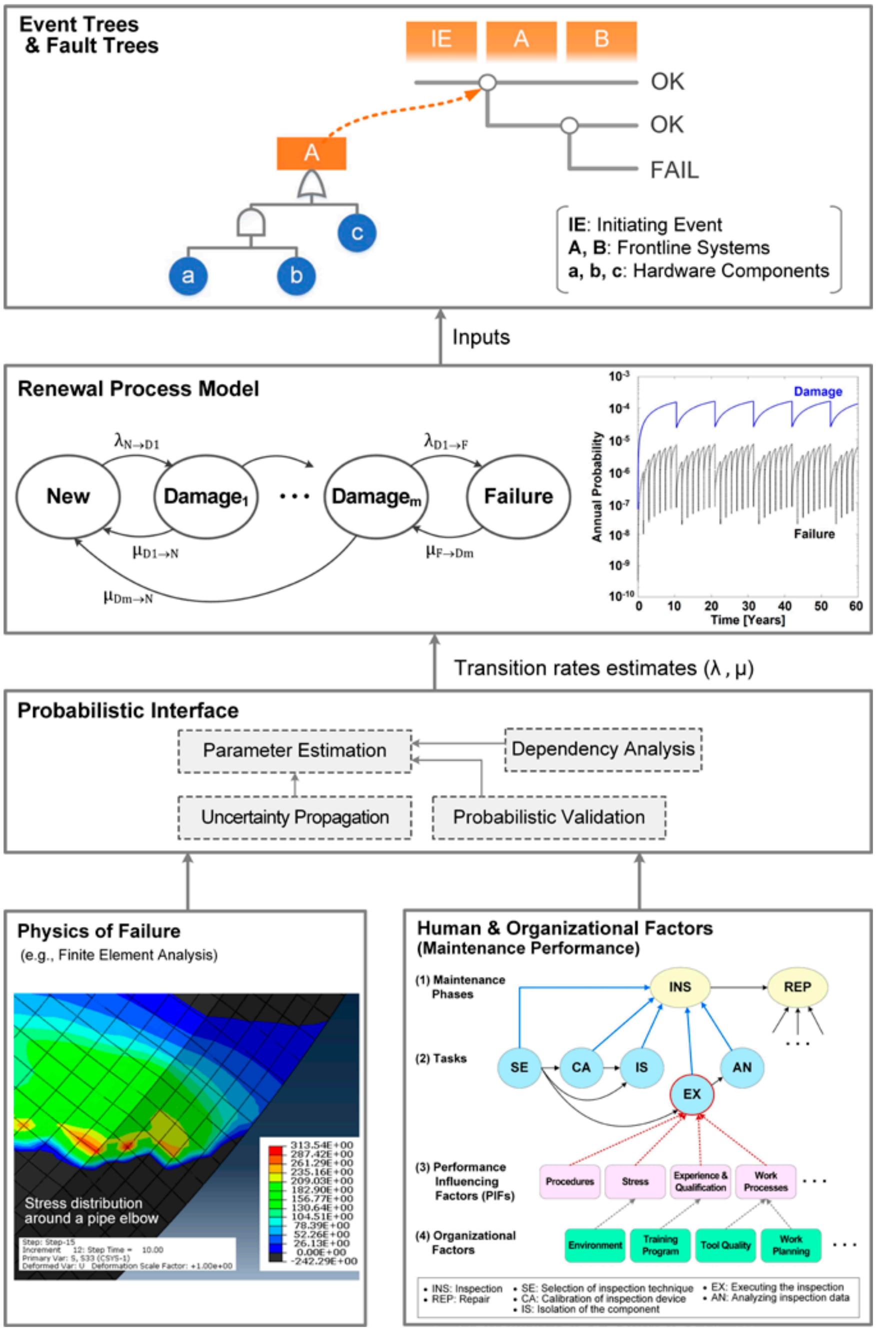
Following the success of the SoTeRiA lab, a few other U.S. university nuclear engineering departments have hired junior PRA faculty. However, to meet short- and long-term goals for nuclear energy, critical PRA educational and research needs and gaps still require urgent attention.

From the educational perspective, only one U.S. nuclear engineering department that has a stand-alone PRA course in its required curriculum, 17 out of 34 nuclear engineering departments/programs[1] offer PRA courses as electives, and the rest have no PRA courses. Even though a few departments have included a limited number of lectures on PRA in their required courses, this does not equip nuclear engineering students with enough knowledge about PRA and may not motivate them to take an elective PRA course; thus, a

1. Based on the *U.S. Nuclear Science and Engineering Education Sourcebook 2020.*

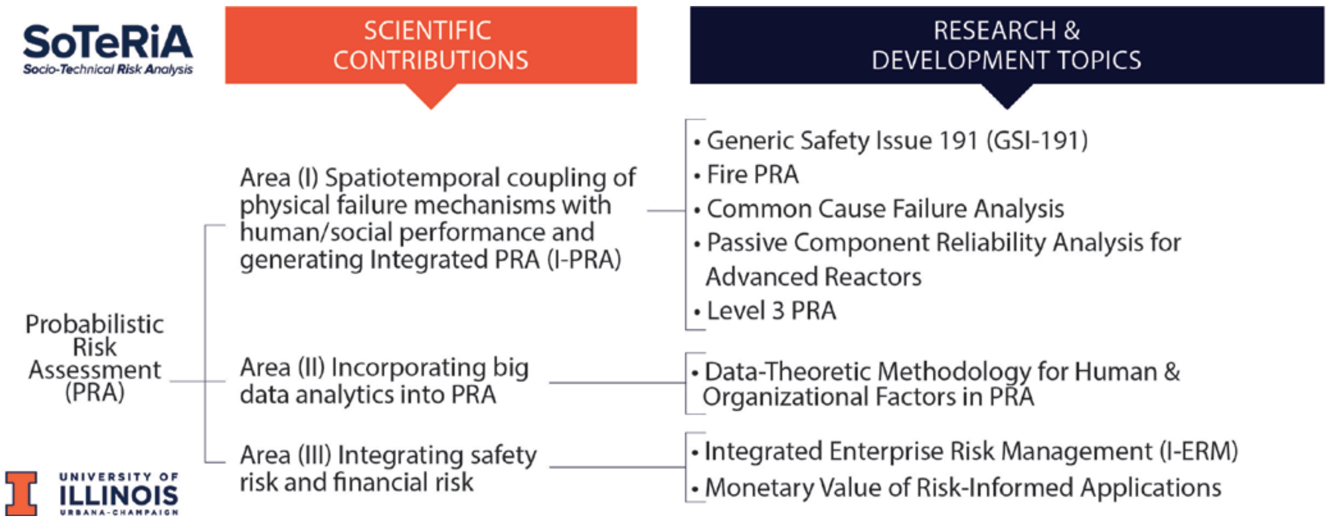
high percentage of nuclear engineering graduates are joining academia, national laboratories, the Nuclear Regulatory Commission, or industry workforces with only a limited PRA background. This fails to satisfy the demand for risk-informed analysis and impedes effective collaboration between PRA experts and those in other areas of nuclear engineering. From the participation of the SoTeRiA lab in the risk-informed resolution of Generic Safety Issue 191, as well as participation in Fire PRA advancement in partnership with the nuclear industry and national laboratories, I have witnessed firsthand how the collaboration among experts from PRA and other areas of nuclear engineering plays a key role in the effectiveness of large-scale nuclear energy projects.

From the research perspective, one of the aspects needing immediate attention is PRA for advanced reactors. It is time-critical to focus on risk-informed analysis of advanced reactors prior to, or in parallel with, technology developments, but the research funding designated for generating technology-inclusive PRA methodologies for advanced reactors is very limited. In recent years, major efforts in PRA development for advanced reactors and its use in risk-informed decision-making include the Licensing Modernization Project, development of 10 CFR Part 53 and other regulatory guidance by the NRC, as well as issuance of *Probabilistic Risk Assessment Standard for Advanced Non-Light Water Reactor Nuclear Power Plants* (ASME/ANS RA-S-1.4-2021); however, significant research needs for methodology developments still exist. One of the key methodological challenges is that a design-specific experiential database is often limited or not available for



Spatiotemporal Coupling of Physics of Degradation Phenomena with Maintenance Human/Organizational Factors and Generating an Integrated PRA Methodological & Computational Platform. Created by the SoTeRiA lab at the University of Illinois–Urbana-Champaign; supported by the U.S. Department of Energy, Office of Science, Office of Nuclear Energy University Program (NEUP), Reactor Concepts Research Development and Demonstration (RCRD&D) under Award #17-12614.

Leaders continues



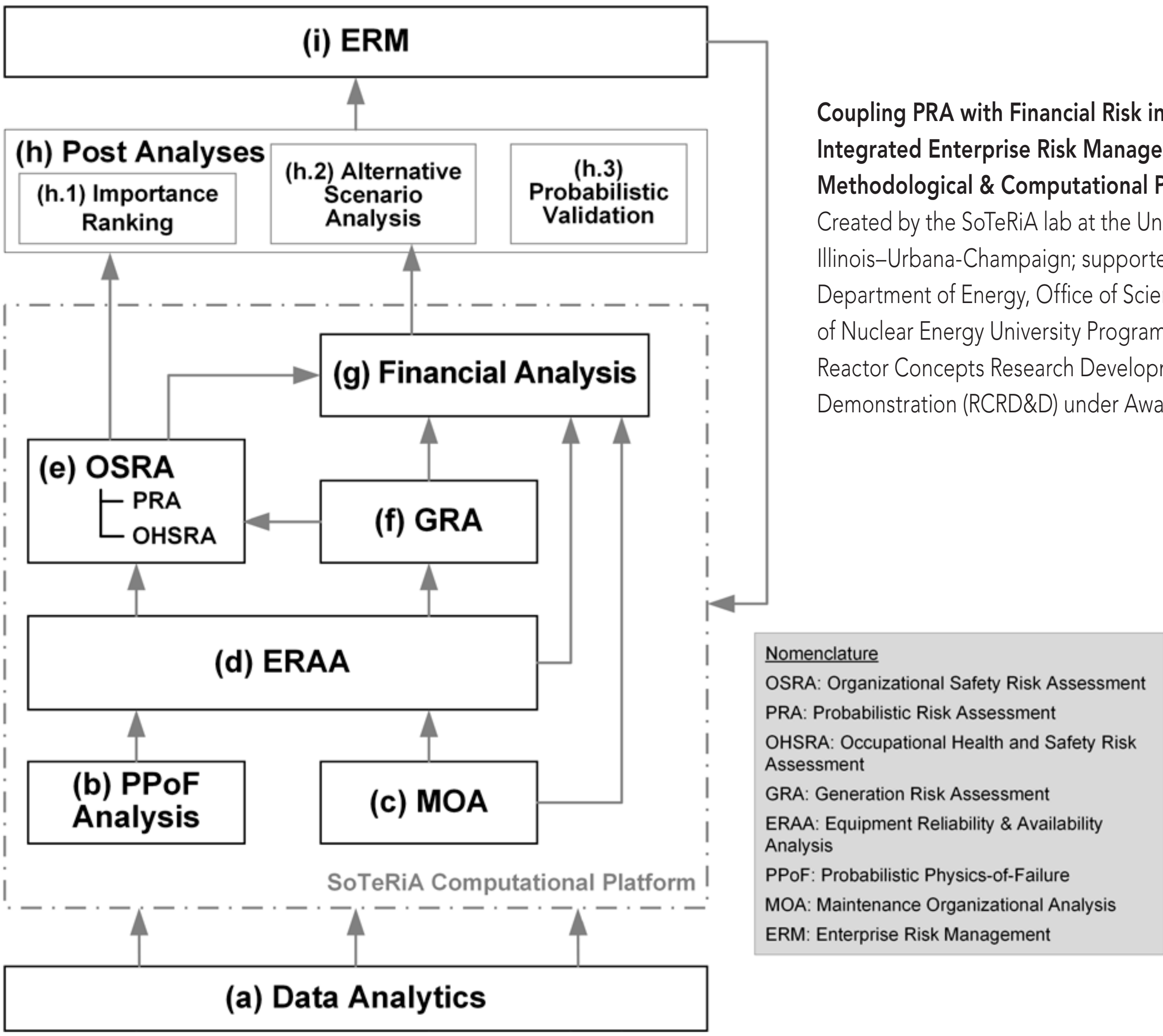
Scientific and Practical Advancements to PRA. Created by the SoTeRiA lab at the University of Illinois–Urbana-Champaign.

advanced reactors, while the applicability and relevancy of the experiential data from the existing fleet to advanced reactors may be questionable due to differences in design principles, physical conditions, and operation and maintenance procedures. A possible path to alleviate this challenge is to incorporate into PRA the simulation of underlying causality, including the interactions of physics of phenomena with human and organizational factors that drive the performance of structures, systems, and components. As an example of this research direction, the SoTeRiA lab, under the International Atomic Energy Agency project that focuses on risk-informed methodology generation for advanced reactors, has created an integrated methodological platform to couple physics of degradation phenomena with models of maintenance work processes (e.g., in-service inspection and repair) and has incorporated this coupling into PRA. Examples of my observations from this project include the following:

■ As the modeling and simulation of physical phenomena and human contributing factors become more explicit in PRA, the spatial and temporal resolution of PRA increases; however, to address the trade-off between PRA realism and the resources required for PRA implementation, the spatial and temporal resolution should be gradually refined depending on the phases of analysis (e.g., design, licensing, construction, and operation) and the relative importance of the PRA elements. Under an ongoing Department of Energy project, the SoTeRiA lab is developing a risk-informed decision-making algorithm for the deployment of new technologies in the existing fleet, while future research is required to extend this algorithm for advanced reactors to guide the gradual refinements of the PRA model for advanced reactors.

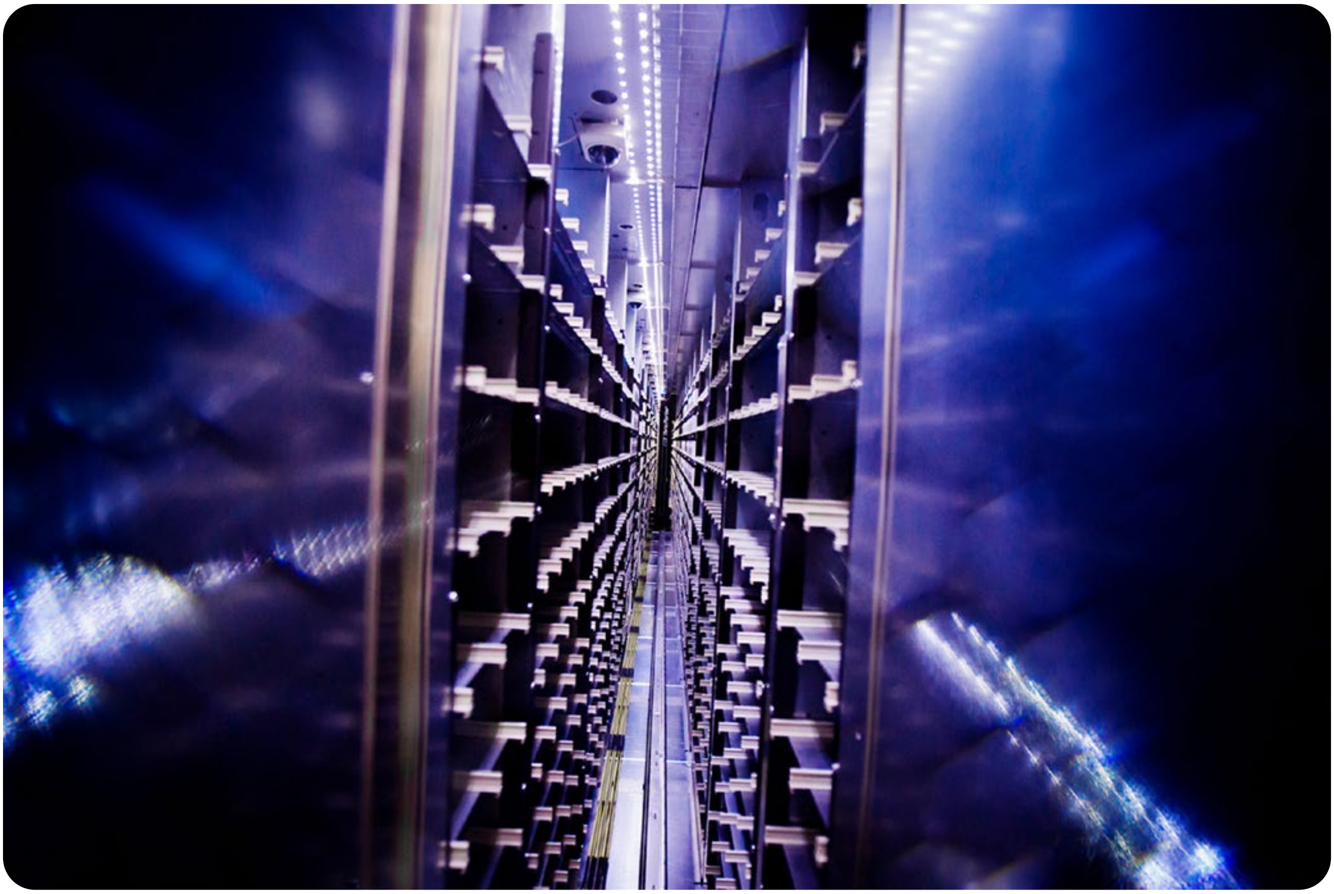
■ For the materials and phenomena that do not exist in operating reactors, no consensus model that has been validated or peer reviewed is available. In addition, the use of artificial intelligence (AI)–based automation has been actively evaluated for advanced reactors to improve the efficiency of operation and maintenance, while validation of AI-based automation technologies remains challenging. The absence of validated models, combined with the lack of relevant experiential data, can significantly increase the uncertainty of the PRA outputs for advanced reactors. This highlights the urgent need for advancing methodologies of uncertainty analysis and management as well as for the automation trustworthiness evaluation in the risk-informed analysis of advanced reactors. In an ongoing NRC project, the SoTeRiA lab is examining how uncertainty analysis in risk-informed regulation should be upgraded to accommodate the need for advanced modeling and simulation. The SoTeRiA lab has also recently been awarded a DOE project to develop a risk-informed methodology for evaluating and improving the trustworthiness and transparency of AI-based automation technologies in the existing fleet. The outcomes from these projects can provide the initial seeds for the expansion of PRA research to address these areas of need for advanced reactors.

- Advanced PRA methodologies are needed for enterprise risk management to facilitate an integration of safety risk with the financial risk associated with the operation and maintenance of advanced reactors. These methodologies should consider severe accident scenarios as well as those that do not generate catastrophic accidents but can lead to financial losses due to plant shutdowns. While several research organizations, including the SoTeRiA lab (under a DOE grant), have focused on extending the scope of PRA for the existing fleet to integrate financial and safety risk, further research is required to establish this integration for advanced reactors.
- Other important areas of research, under PRA for advanced reactors, include the effective use of risk information for determination of the site-specific emergency planning zone, multi-unit/multi-module dependency analysis, common cause failure analysis, and risk-informed security analysis.



Coupling PRA with Financial Risk in an Integrated Enterprise Risk Management Methodological & Computational Platform. Created by the SoTeRiA lab at the University of Illinois–Urbana-Champaign; supported by the U.S. Department of Energy, Office of Science, Office of Nuclear Energy University Program (NEUP), Reactor Concepts Research Development and Demonstration (RCRD&D) under Award #17-12614.

Leaders continues



The National Center for Supercomputing Facility at the University of Illinois–Urbana-Champaign, supporting integrated PRA computational platforms created by the SoTeRiA lab. (Photo by UI Public Affairs: Stauffer)

Educational and research gaps must be addressed to enable next-generation PRA leaders to meet nuclear energy goals; therefore, immediate action is needed on the following:

- Nuclear engineering departments need to develop strategies to lead PRA education and research by hiring more PRA faculty and by enriching their core curriculums with robust PRA courses, while national laboratories, consulting companies, and the nuclear industry maintain their crucial roles in PRA development and implementation. Academia should advance PRA knowledge sharing with industry and government agencies to help nuclear engineering students conduct PRA research on the real-world problems of nuclear energy. Academia also needs to foster an open scientific environment, enabling next-generation PRA leaders to contribute to international nuclear safety through risk analysis and risk communication.
- Government agencies are asked to allocate adequate research funding for the creation of technology-inclusive PRA methodologies for advanced reactors. These methodologies can support the risk-informed design, licensing, operation, and maintenance of advanced reactors and help evaluate and compare diverse advanced reactor designs with respect to safety, security, and profitability. Results of these risk-informed comparative studies can provide valuable insights for the DOE and other stakeholders as they prioritize investments in advanced reactor technologies.

Nuclear Station Beyond-Design-Basis Electrical Power Supply Coping System

An innovative, rapidly deployable battery power supply system that enhances operator flexibility, improves stations' probalistic risk assessment (PRA) profile, and augments FLEX response.

By Benjamin P. Youman, BlackStarTech Strategic Implementation Director

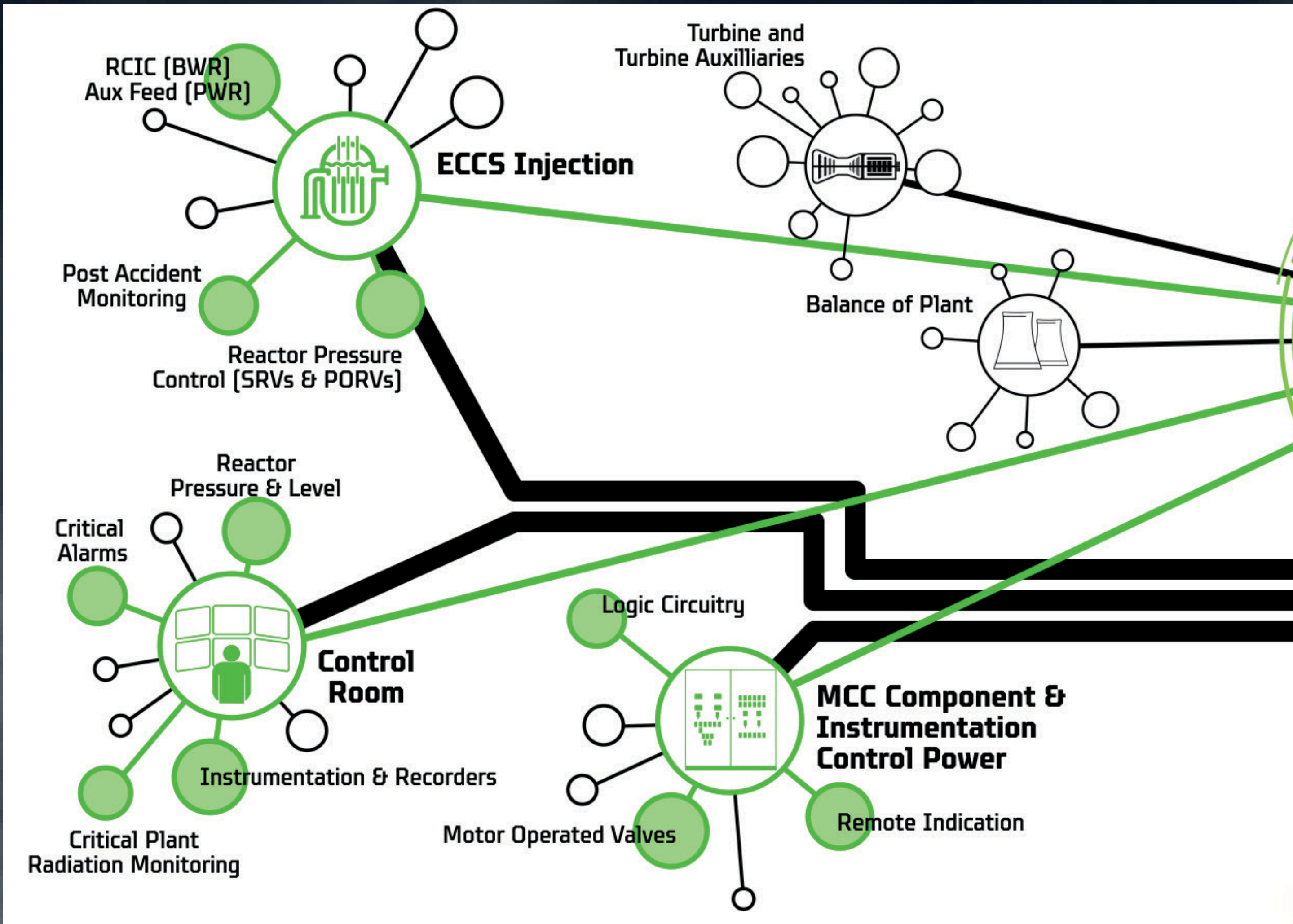
BlackStarTech® Innovation Group asked one simple question:

How do we further improve the response times of our FLEX strategies?

That question led to a second question:

Can we add defense in depth to U.S. FLEX response, enhance safety margins, and strategically provide critical power rapidly and reliably in under 30 minutes for up to 30 days?

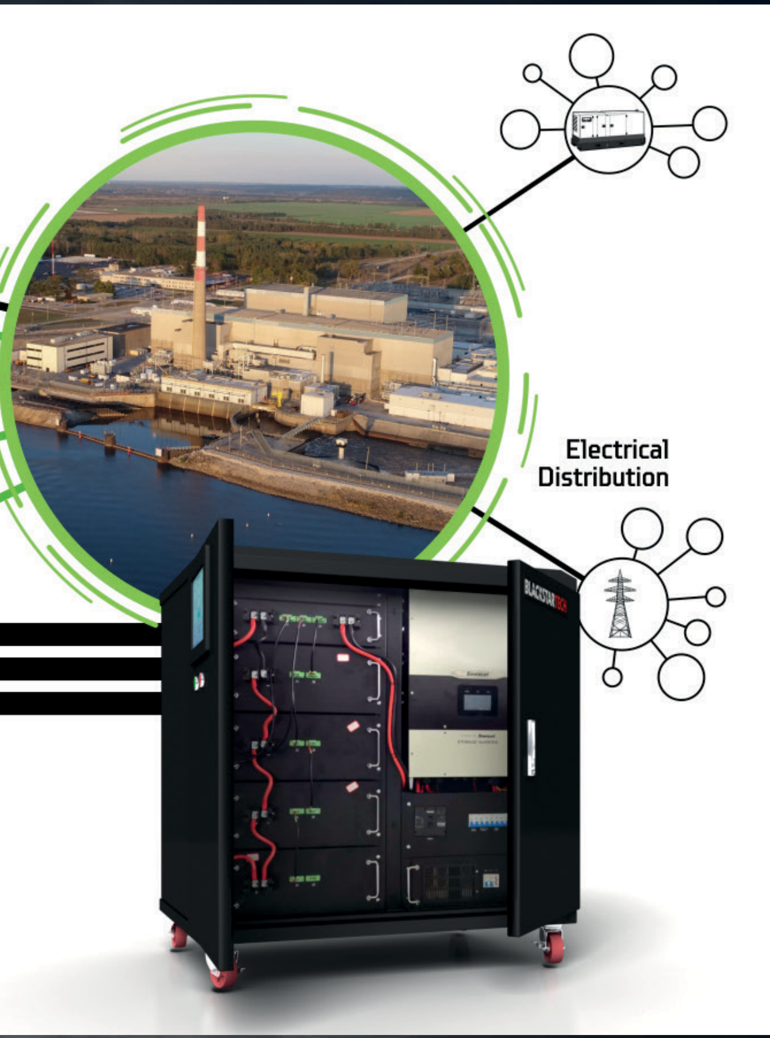
The response and resultant innovative journey led to the development of a rapidly deployable and portable battery-powered energy delivery system transforming how the nuclear industry can provide critical DC and AC power to the most essential components and control systems. The BlackStarTech methodology utilizes compact and portable power supplies to further enhance essential equipment availability, as well as providing defense in depth to FLEX and B.5.b response. The portable battery power technology provides an alternative means of electrical power delivery solutions, expanding operator flexibility and optimizing station risk reduction strategies.



The technology utilizes state-of-the-art lithium iron phosphate batteries and integrates specialized inverters and rectifiers to provide targeted instrumentation and control power, as well as a wide range of DC and AC direct-drive supply power (including 3-phase 480VAC). The specialized system can be used for critical control room indications, plant controls, and many essential emergency system components. The system rapidly deploys (within 30 minutes) and powers targeted loads until the integrated long-term backup propane generator supply is connected. By using the portable integrated propane generators, it is possible to keep the BlackStarTech system powered for at least 30 days.

Quad Cities Generating Station successfully piloted and fully deployed the BlackStarTech Basic system in 2019. Based on a successful outcome, Exelon Generation chose to implement BlackStarTech Basic across its entire nuclear fleet to augment FLEX implementation strategies and enhance response capabilities to various postulated extended loss of AC power (ELAP) situations caused by a beyond-design-basis event. Overall, the BlackStarTech Basic system delivers three specific mission-critical strategies:

- Provide rapidly deployable power to key critical main control room indications, control systems, and critical sub-components.
- Support reactor vessel core cooling.
- Augment reactor vessel pressure control.



The Innovation Back Story

Dave Heilman, a Quad Cities Generating Station reactor operator, envisioned BlackStarTech as a far quicker means for operators to obtain the needed electrical power in a Fukushima-type loss of all power beyond-design-basis event. The underlining design mission remained to simplify operator response and provide additional flexibility to the many redundant capabilities and backup systems already at nuclear power stations while further diversifying critical power solutions for at least 30 days.

Inspired by his vision, Heilman initially created a handheld portable 125V DC power supply to energize critical equipment and instrumentation in the main control room. As a result of his inventions, senior leadership encouraged him to further develop and expand his innovative portable power methodology. Through a series of continued developments and refinement steps, Heilman came up with the preliminary concepts for the BlackStarTech Basic portable power response system to provide Quad Cities Station with solutions for an extended ELAP and other beyond-design-basis loss of power events.

With the growing capabilities, Exelon Generation formed the BlackStarTech Innovation Group to further expand the design and drive the development and deployment of the new portable power technology. The BlackStarTech system evolved to expeditiously deploy battery power to critical equipment by "surgically" applying targeted power within 30 minutes right at the point where it is needed most. The approach augments the existing FLEX strategies that often require powering entire electrical distribution buses with large and somewhat cumbersome power sources that can typically take between six to 12 hours to fully deploy and require extensive fuel deliveries for longer-term response.


Dave Heilman, BlackStarTech inventor

The BlackStarTech Basic system relies on establishing rapid connection points that power critical components right at the motor control centers or directly at the critical loads, simplifying response and eliminating extensive engineering evaluations or modifications. The portable power system, paired with a long-term diverse fuel supply system (utilizing propane generators), is specifically integrated with the portable battery energy delivery system. The combined battery generator system functions as an uninterruptable power supply (UPS) system, carrying the critical electrical loads while simultaneously recharging the core battery system. If the portable AC generator supply power is lost, the integrated system automatically switches to battery backup without dropping the critical electrical loads.

125VDC/250VDC Power Cart & Integrated Propane Generator
18kWh – 25kWh DC Control Power Carts to rapidly provide critical DC Loads such as RCIC or Isolation Condenser system DC valves when the essential station battery is challenged. Long term power and UPS function can be realized when connected to the dual fuel propane generator system.

The propane fuel source provides a diverse fuel supply with an indefinite shelf life that is stored safely at the nuclear facilities to provide 30 days or more of extended operation for the most essential electrical loads. By diversifying the on-site fuel source, this provides an alternative to diesel fuel deliveries and adds emergency capability if there is ever a wide-ranging regional event or natural disaster. These smaller generators can be quickly deployed and will also run on gasoline if the need arises — further expanding resiliency and flexibility of response.

Quad Cities Pilot and Fleet Implementation Details:

Exelon Generation launched two BlackStarTech fleet projects in the 2nd quarter of 2019:

BlackStarTech Basic Fleet Implementation

- Deploy BlackStarTech equipment to provide FLEX augmentation and minimize impacts of postulated beyond-design-basis loss of AC power.
- Enhance Station PRA profile achieving upward of 10-25% reduction in overall risk margins from typical nuclear station industry averages.

BlackStarTech Risk Informed

- Utilize BlackStarTech methodologies and strategies to achieve further industry PRA safety margins to aid in facility 50.69 classifications and provide additional safety factors for risk-informed completion times and actions.
- Provide additional safety factor improvements to industry margins in postulated fire, full power internal events, and external event categories.

Quad Cities Generating Station piloted the BlackStarTech Basic system, deploying and staging the equipment throughout the plant to augment reactor operator response for beyond-design-basis ELAP events. As part of the implementation, station reactor and equipment operators received extensive hands-on instruction. The BlackStarTech Portable Power System was deployed in strategically predetermined locations with protective Electromagnet Pulse barrier storage covers. BlackStarTech Basic system consisted of seven pieces of response equipment, each being easily deployed by one station operator, and included the following:

1 | BlackStarTech Control Room Nano-Grid

5kWh cart with integrated 24V/48V/125V DC and 120V AC power supplies with rapid connection system to power critical control room components and displays for several instrumentation loops including reactor power, reactor or steam generator level, coolant temperature, and reactor or steam generator pressure.

2 | BlackStarTech 125VDC/250VDC Power Cart

18kWh – 25kWh DC control power carts to rapidly provide critical DC loads such as RCIC or isolation condenser system DC valves.

3 | BlackStarTech 3-Phase 480VAC Power Cart

20kWh – 30 kWh 3-Phase 480V AC power cart to rapidly provide power to critical AC valve loads.

4 | BlackStarTech Rapid Deployment Kit

Battery/inverter system with patented rapid electrical connector system to remotely connect temporary 125VDC or 120VAC power to affected critical components and instrumentation.

5 | BlackStarTech Integrated Generator Systems

3.5kW – 9.5kW integrated dual fuel propane/gasoline generator systems for long term auto transfer UPS operations and battery charging capabilities.

6 | BlackStarTech 3-Phase 480V MOV Power Case

Portable Integrated MOV power pack with both drive and control power functions to remotely operate critical MOVs and components.

7 | BlackStarTech 125VDC Portapower Power Case

Portable 125VDC and 120VAC power to remotely operate critical 125VDC or 120VAC components, such as reactor safety relief valve solenoids for reactor pressure control.

Utilization of the BlackStarTech technologies also augmented station FLEX response by providing rapidly deployable portable power systems to respond to a series of extreme postulated loss of power events. During the initial pilot, Pat Boyle, former plant manager at Quad Cities Station, stated: “The BlackStarTech solution revolutionizes the approach to provide critical power by supplying an additional completely separate rapid power source during a FLEX event that adds a new safety layer of protection for nuclear plant assets.” The BlackStarTech system rapidly targets main control room critical instrumentation and controls, emergency core cooling assets, and pressure control to further minimize the effects of any extreme postulated event. Boyle, now plant manager at Dresden, also supported site BlackStarTech Basic deployment activities in 2020. To date, Exelon has completed four BlackStarTech site deployments, with the remaining fleet to fully implement by the end of 2022.

Realizing Improved Safety Enhancement Contributes to Significant PRA Benefits

Due to the rapid nature that the BlackStarTech Power system deploys, it also provides vital power solutions to critical loads often much faster than current industry FLEX strategies. The rapid response (typically <30 minutes) provides quantifiable improvements in nuclear stations’ risk profiles, which adds additional safety margins above industry standards for our facilities. These safety enhancements translate to direct improvements in the Significance Determination Process response providing enhanced benefits to both postulated internal and external event risk profiles. Additionally, these enhancements provide supplementary capabilities with risk-informed improvement processes across many, if not most, nuclear stations, realizing significant quantifiable improvements of anywhere between 10% and 25% in baseline risk improvements. In fact, additional applications of risk-informed improvement processes identified new strategies with BlackStarTech to potentially improve significantly specific internal and external event risk profiles.

The BlackStarTech technology provides capability for improved regulatory margin and potential advances in:

- 50.69 categorization and component classification.
- Risk-informed completion time program backstops.
- Broad FLEX and B.5.b augmentation.
- Improvements in the Significance Determination Process response that can reduce the significance of regulatory findings and mitigate liability in SDP enforcement cases.

Based on the initial results with Quad Cities, Exelon continues assessing new strategic options to utilize BlackStarTech to obtain new potential benefits in “risk-informed” classifications and PRA margin for Peach Bottom, Nine Mile Point-1, and FitzPatrick throughout 2021 and 2022.

Nano-Grid Cart

Control Room Nano-Grid 5kWh Cart with integrated 24V/48V/125V DC and 120V AC Power Supplies and rapid connection system to power critical control room components and displays for several instrumentation loops including reactor power, reactor or steam generator level, coolant temperature, and reactor or steam generator pressure.

3-Phase 480V MOV Portable Power Pack
Integrated MOV power pack with both drive and control power functions to remotely operate critical MOVs and components.

Rapid Deployment Kit
Battery/Inverter system with patented rapid electrical connector system to remotely connect temporary 125VDC or 120VAC power to affected critical components and instrumentation.

Table 1: Quad Cities PRA Profile Benefits from BlackStarTech

Integration Scenarios/Components of Opportunity	Estimated Improvement in Baseline Risk
RCIC BlackStarTech	At least a 10%
BlackStarTech DC Instrumentation Support	Up to 5%
Improved Hardened Containment System Response	20% –25%

The Innovation Impact

Implementation of BlackStarTech technology clearly provides augmented capability to Exelon Generation's FLEX strategies by providing rapidly deployable targeted power systems to respond to a series of nuclear design and beyond-design-basis events. The integrated systems revolutionize the approach to extended loss of power events by providing rapidly deployable portable battery-powered in an unlikely Fukushima type event that requires extended power back up for essential systems and components. For many scenarios, BlackStarTech provides solutions faster than FLEX, and the rapid capability provides operators enhanced flexibility and significant benefits in station PRA.

Due to the rapid deployment time frame and defense in depth the BlackStarTech system provides, quantifiable improvements in station baseline risk profiles and margins can be achieved at nuclear facilities. Furthermore, by reducing facility risk profiles the BlackStarTech solution yields improvements in the Significance Determination Process, providing additional margins, which in turn can minimize the potential significance of findings.

BlackStarTech battery power technology also inspired the development of a number of battery power supply tooling and lighting innovations that provide industry leading enhancements to industrial and radiological safety as well as productivity methodologies across Exelon Generation's facilities that provide substantial synergies and schedule savings in both online and outage activities.

The BlackStarTech system and specialty equipment is applicable across many industries outside of nuclear and can be used anywhere that rapidly deployable temporary or backup battery power is required.

BlackStarTech Genesis Family of Portable/Emergency Power Systems

ANS Standards Committee responds to the industry's need for PRA and RIPB methodology

By the Standards Committee

For more than two decades, the American Nuclear Society's Standards Committee has recognized the benefit of incorporating risk-informed and performance-based (RIPB) methodology into ANS standards to improve their effectiveness, efficiency, and transparency. In general, standards using RIPB methods with properly identified and structured objectives need less modification and can be expected to remain valid for much longer periods.

Formation of the RISC

In 1999, the ANS Standards Board, a standing committee of the Society, formed the ANS Risk Informed Standards Committee (RISC) in response to industry's need for RIPB methods in voluntary consensus standards. Thus, the RISC became the fourth ANS standards consensus committee, whose defined scope was to develop standards that establish risk criteria and methods for probabilistic risk analysis, risk assessment, and risk management for nuclear facilities.

"The industry recognized that risk-informed applications could not be implemented efficiently without consistency in the requirements for probabilistic risk assessments (PRAs), and so, ANS responded with the formation of the RISC," said Paul Amico, the RISC's first chair. The RISC's first developed standard, ANS-58.21-2003, *External Events in PRA Methodology*, was approved in early 2003. The objectives of this standard were to set forth the requirements for external-event PRAs to support risk-informed decision-making for commercial nuclear power plants and to prescribe the method(s) for applying these requirements to specific applications. This was followed by the issuance of ANS-58.23-2007, *Fire PRA Methodology*, which was used to directly support industry initiatives for RIPB fire protection.

Shortly after the RISC was formed, the ANS Standards Committee began exploring whether existing standards would benefit from the use of RIPB methods or a graded approach to specifying requirements in nuclear technology. Donald Spellman, chair of the ANS Nuclear Facilities Standards Committee (NFSC) and one of the four ANS standards consensus committees at the time, called a special meeting in 2004 with the goal of achieving consensus as to whether approved NFSC standards could be adapted, or new standards should be initiated, to incorporate RIPB methods. An individual integral to this discussion was a well-known expert in industry performance-based regulations, Sheldon Trubatch. Committee members reviewed Trubatch's "Process for Converting Prescriptive Requirements into Performance-Based Regulations" to get a better understanding of how to modify

Spotlight On continues

Seismic-related standards

- ANSI/ANS-2.27-2020, *Criteria for Investigations of Nuclear Materials Facility Sites for Seismic Hazard Assessments* (revision of ANS-2.27-2008)
- ANSI/ANS-2.29-2020, *Probabilistic Seismic Hazard Analysis* (revision of ANS-2.29-2008)
- ANSI/ANS-2.30-2015 (R2020), *Criteria for Assessing Tectonic Surface Fault Rupture and Deformation at Nuclear Facilities* (new standard)
- ASCE/SEI 43-19, *Seismic Design Criteria for Structures, Systems and Components in Nuclear Facilities* (revision of ASCE/SEI-05)

existing standards to incorporate RIPB principles. Spellman said, "The meeting concluded with the decision to launch a pilot to incorporate RIPB insights into a new standard in development." The pilot was successful, resulting in the approval of ANSI/ANS-2.26-2004 (R2017), *Categorization of Nuclear Facility Structures, Systems, and Components for Seismic Design*. This standard provides criteria and guidance for selecting seismic design categories and limit states for the SSCs in a nuclear facility, other than commercial power reactors, whose seismic design requirements are established by other standards and regulations.

The seismic design categories and limit states are to be used in conjunction with the standards shown at left that apply RIPB insights or a graded approach.

A revision of ANSI/ANS-2.26-2004 (R2017) is currently in development.

Standards currently in development by the JCNRM

- ASME/ANS RA-S-1.2-2014, *Severe Accident Progression and Radiological Release (Level 2) PRA Methodology to Support Nuclear Installation Applications* (previously ANS/ASME-58.24) (trial-use standard to be revised and seek ANSI approval)
- ASME/ANS RA-S-1.3-2017, *Standard for Radiological Accident Offsite Consequence Analysis (Level 3 PRA) to Support Nuclear Installation Applications* (previously ANS/ASME-58.25) (trial-use standard to be revised and seek ANSI approval)
- ANSI/ASME/ANS RA-S-1.4-2021, *Probabilistic Risk Assessment Standard for Advanced Non-LWR Nuclear Power Plants* (current standard)
- ASME/ANS RA-S 1.5, *Advanced Light Water Reactor PRA Standard* (proposed new standard)
- ASME/ANS RA-S-1.6 *Requirements for Low Power and Shutdown Probabilistic Risk Assessment* (previously designated ANS/ASME-58.22) (trial-use standard to be revised and seek ANSI approval)
- ASME/ANS RA-S-1.7, *Trial Use Standard for Multi-Unit PRA Standard* (proposed trial-use standard)
- ASME/ANS *Guidance Document for Risk Informing Physical Security and Cyber Security Programs at Nuclear Facilities* (proposed guidance document)

Formation of the JCNRM

In 2011, the RISC merged with an American Society of Mechanical Engineers committee chartered with the same objectives, and together they now operate as the ANS/ASME Joint Committee on Nuclear Risk Management (JCNRM). As a result, ANS-58.21, the RISC's first standard, was revised and incorporated into the joint standard ANSI/ASME/ANS RA-S-2008 (R2019), *Standard for Level 1/Large Early Release Frequency Probabilistic Risk Assessment for Nuclear Power Plant Applications*, with addenda issued in 2008 and 2013. A further revision is expected to be approved and issued later this year.

The box at left indicates some of the additional standards and projects currently in development by the JCNRM and associated with probabilistic risk analysis, risk assessment, and risk management for nuclear facilities.

With the recognition of growing interest in RIPB methods, in 2011, the JCNRM created the Subcommittee on Risk Application (SCoRA) as one of its three subcommittees. SCoRA's charter was and still is to interface with ANS and ASME committees and committees of other nuclear standards development organizations, as requested, that include or plan to include risk assessment and risk management in the development and updating of standards. The objective is to strive for consistency in other nuclear-related standards with risk management principles in general and to work toward consistency with the JCNRM's PRA standards. Part of this interface activity includes an education function, for which SCoRA will avail itself of resources that exist among the broader JCNRM membership.

Formation of RP3C

The Risk-Informed and Performance-Based Principles Policy Committee (RP3C) was commissioned in 2012 as a special committee of the ANS Standards Board responsible for the identification and oversight of approaches, priorities, responsibilities, and schedules for the implementation of RIPB principles into ANS standards. The RP3C interfaces with and provides training to the ANS standards consensus committees, subcommittees, and working groups related to RIPB principles, which ensures consistency across ANS standards on the implementation of these principles.

The need for the RP3C was identified by an ad hoc committee formed to facilitate a reorganization of the Standards Committee's consensus committees. Steven Stamm, who headed up this committee, said, "Our discussions led us to recognize the need for a new high-level committee to establish overall guidance to incorporate risk and performance principles into ANS standards, and the Standards Board agreed."

The RP3C was initially tasked with establishing a plan to provide approaches and procedures to be used by ANS consensus committees to consistently implement RIPB principles into ANS standards. Over the years, the components of this plan have been broadened to be based on the ANS Standards Committee Strategic Plan, which is aligned with the Society's Strategic Plan and incorporates a guidance document to help standards writers. After issuance, the guidance document will need periodic updates as lessons are learned.

What followed was a review by the RP3C of all ANS standards and projects, leading to the creation of a list of 23 ANS standards that were deemed most likely to benefit from incorporating RIPB methods. Of this group of standards, nearly half have already been revised or are currently in development.

In 2019, the RP3C issued a guidance document, *Incorporating Risk-Informed and Performance-Based Approaches/Attributes in ANS Standards*, for interim trial use. The guidance document identifies roles and responsibilities and the process for using RIPB approaches, as appropriate. This guidance document is intended to be used by all eight ANS standards consensus committees during the development of new standards and revisions to existing standards. A training module was also developed to accompany this guidance document. A revision incorporating comments and lessons learned is expected to be released later this year. Once it is completed, the RP3C will build on the guidance by creating a more comprehensive training package that will include presentations to train current ANS working groups on the application of RIPB principles in ANS standards. The RP3C then intends to present its progress and accomplishments to other industry organizations through industry forums.

To further support the private and public sectors, the RP3C launched a RIPB community of practice (CoP) in February 2020. CoPs are groups of people who share knowledge and experience around specific topics, best practices, or professional lessons learned. The purpose of this CoP is to support

Spotlight On continues

An artist's rendering of the NuScale plant. (Image: NuScale)

rapid knowledge sharing on the development and application of RIPB principles and practices within the nuclear industry. CoP presentations have been made by several of the advanced reactor developers, including NuScale and Oklo. Other presentations have focused on voluntary consensus standards or topics such as "RIPB in ALARA." The RP3C's CoP events are open to anyone interested. Presentations and recordings are available on the RP3C's webpage.

It is known that RIPB methods are not necessarily applicable in the same way to all standards developed by the ANS Standards Committee. Some standards may need to remain deterministic for practical reasons. Others, such as standards developed by the Nuclear Criticality Safety Consensus Committee (NCSCC) and its series of ANS-8 nuclear criticality safety standards, present special challenges for RIPB concepts and will likely maintain long-standing practice. The NCSCC is responsible

Standards using RIPB principles that have been issued to date

- ANSI/ANS-2.8-2019, *Probabilistic Evaluation of External Flood Hazards for Nuclear Facilities* (current standard)
- ANSI/ANS-2.26-2004 (R2017), *Categorization of Nuclear Facility Structures, Systems, and Components for Seismic Design* (current standard)
- ANSI/ANS-2.27-2020, *Criteria for Investigations of Nuclear Facility Sites for Seismic Hazard Assessments* (current standard)
- ANSI/ANS-2.29-2020, *Probabilistic Seismic Hazard Analysis* (current standard)
- ANSI/ANS-2.30-2015 (R2020), *Criteria for Assessing Tectonic Surface Fault Rupture and Deformation at Nuclear Facilities* (current standard)
- ANSI/ANS-53.1-2011 (R2016), *Nuclear Safety Design Process for Modular Helium-Cooled Reactor Plants* (current standard)
- ANSI/ANS-54.1-2020, *Nuclear Safety Criteria and Design Process for Sodium Fast Reactor Nuclear Power Plants* (current standard)
- ANSI/ANS-57.3-2018, *Design Requirements for New Fuel Storage Facilities at Light Water Reactor Plants* (current standard)
- ANSI/ANS-58.8-2019, *Time Response Criteria for Manual Actions at Nuclear Power Plants* (current standard)
- ANSI/ANS-58.14-2011 (R2017), *Safety and Pressure Integrity Classification Criteria for Light Water Reactors* (current standard)
- ANS-58.21-2007, *External-Events PRA Methodology* (superseded by ASME/ANS RA-S-2008)
- ANS/ASME-58.22-2014, *Requirements for Low Power and Shutdown Probabilistic Risk Assessment* (trial-use standard)
- ANS-58.23-2007, *Fire PRA Methodology* (superseded by ASME/ANS RA-S-2008)

for maintaining 18 current standards for the control of criticality risks associated with processing fissionable materials outside reactors.

Thirteen standards using RIPB principles or graded approaches to varying degrees have been issued, and another 15 standards are currently in development. Standards issued with RIPB principles are listed in the box on the previous page.

"While much progress has been made in developing RIPB standards," said RP3C chair N. Prasad Kadambi, "much work remains to take full advantage of the benefits of the RIPB approach." Kadambi encourages anyone interested in joining this effort to become an active member of the RP3C.

Advanced reactors and RIPB

With the increased industry activity supporting advanced reactors, including advanced light water reactors and non-LWRs, RIPB methods are central to the licensing efforts. Under the existing licensing approach using 10 CFR Part 50 or 52, non-LWRs are applying the Licensing Modernization Project (LMP) process described in NEI 18-04 (Rev. 1), *Risk-Informed Performance-Based Technology Inclusive Guidance for Non-Light Water Reactor Licensing Basis Development*, and endorsed by the U.S. Nuclear Regulatory Commission's Regulatory Guide 1.233, *Guidance for a Technology-Inclusive, Risk-Informed, and Performance-based Methodology to Inform the Licensing Basis and Content of Applications for Licenses, Certifications, and Approvals for Non-Light Water Reactors.*

In addition, a Part 53 licensing approach is being developed under the "Rulemaking Plan on 'Risk-Informed, Technology-Inclusive Regulatory Framework for Advanced Reactors,'" as required by the Nuclear Energy Innovation and Modernization Act, signed in January 2019. Use of either the LMP or Part 53 licensing approach for an advanced reactor will require the development and use of a PRA that meets the applicable requirements of JCNRM standards, such as ANSI/ASME/ANS RA-S-1.4-2021, *Probabilistic Risk Assessment Standard for Advanced Non-LWR Nuclear Power Plants*, for a non-LWR applying the LMP.

"PRA has moved from an analysis that confirms acceptable risk levels for the existing nuclear plants to analysis that is central to the design and licensing of advanced plants," said Dennis Henneke, the current ANS JCNRM chair. "This is key to ensuring that very low-risk nuclear plants can be built quickly and for a much lower cost."

Final word

Standards Board chair Donald Eggett recognizes the nuclear industry's need for standards incorporating RIPB methods, especially in the advanced reactor community. "One of my top priorities as Standards Board chair is to listen and to act accordingly in support of the entire community and its needs," Eggett said. "Without question, RIPB methodology, along with its benefits and approaches, is just one of them."

Anyone with questions or interest in getting involved with the ANS Standards Committee is encouraged to contact standards@ans.org.

Taishan spent three days in the spotlight: What can we learn?

By Susan Gallier

The facts, once known, were not complicated. At Taishan-1 in China—the first Framatome EPR to be commissioned—operators detected an increase of fission product gases within the primary coolant circuit sometime after the reactor's first refueling outage in October 2020. The cladding on a handful of the more than 60,000 fuel rods in the reactor had been breached, posing an operational issue—but not a public safety issue—for the plant.

Taishan operates on the north shore of the South China Sea in Guangdong Province. The region has become a hub for technology and business, and, with a population of about 113 million, Guangdong has a clear need for the combined 3,320 net MWe provided by the two largest operating power reactors in the world: Taishan-1, which entered commercial operation in December 2018, and its twin, Taishan-2, which followed in September 2019.

Both units remained at full power in mid-June as Framatome—the French reactor designer and fuel supplier contracted to provide operating support services at Taishan, which is majority owned by China General Nuclear Power Group (CGN)—continued to assess the fuel failure. The company's efforts caught the attention of a CNN reporter, and a widely circulated article—"Exclusive: US assessing reported leak at Chinese nuclear power facility"—was published on the morning of Monday, June 14, setting off a short-lived storm of media attention.

Taishan-1 was the world's first EPR to be connected to the grid. (Photo: CGN)

While the reporting from other media outlets proved to be more measured than CNN's own speculative report, articles shared online bore attention-grabbing headlines suggesting a radiological disaster and international cover-up: "China Nuclear Plant Leak Response Evokes Chernobyl as Taishan Facility Insists It's Safe" (*Newsweek*), "China Denies Radiation Leak at Nuclear Reactor but Admits Fuel Rod Damage" (*New York Times*), "After lab-leak suspicion of Covid-19 virus, radiation-leak scare at Chinese nuclear plant" (*India Narrative*), "China's Nuclear Leak Is No Chernobyl, But We Should Still Worry" (*Bloomberg*).

The French and Chinese partners issued brief media statements but details were scarce, and online speculation swirled as pressure to fill the information void drew comments from international organizations, nuclear experts, and the concerned public.

As ANS President Steven Nesbit observed nearly one month later, "Although the complete story may never be public, it appears to have been a molehill that looked a bit like a mountain because the Taishan plant operator was not particularly forthcoming with information."

It all happened at the whiplash pace of the online news cycle, and while the media moved on after just three days—once China's nuclear regulator issued a detailed press statement—fear and skepticism were being shared on social media even after it became clear that the issue had been overblown. Now that Taishan-1 has been shut down to remove and assess the damaged fuel, it's time to take a more measured look at both what happened and what didn't, and how facts, shared honestly and when needed, can counterbalance hype.

"[The event] appears to have been a molehill that looked a bit like a mountain because the Taishan plant operator was not particularly forthcoming with information."

The story broke

CNN's June 14 report was based on a memo obtained by a CNN reporter that had been sent by Framatome to the U.S. Department of Energy on June 8. According to CNN, it warned of an "imminent radiological threat" at the Taishan plant and included a claim that the Chinese safety authority was raising the acceptable limits for radiation detection outside the plant to avoid shutting it down.

CNN reported that Framatome first informed the DOE of a potential issue at Taishan in late May and followed up with an operational safety assistance request on June 3 that formally requested a waiver to address "an urgent safety matter." The June 8 memo asked for an expedited review of that request, according to CNN.

Reporter Zachary Cohen took a speculative approach to the information he had received, calling the notification "alarming," adding that "it is unusual that a foreign company would unilaterally reach out to the American government for help when its Chinese state-owned partner is yet to acknowledge a problem exists. The scenario could put the U.S. in a complicated situation should the leak continue or become more severe without being fixed."

Initial response

Framatome acknowledged in a June 14 press release that it was "supporting resolution of a performance issue" at Taishan, where it has a long-term contract for support operations, outage and maintenance work, and spare parts supply and engineering services. "According to the data available, the

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plant is operating within the safety parameters. Our team is working with relevant experts to assess the situation and propose solutions to address any potential issue."

The brief statement stood in contrast to the significant claims reportedly made in the company's June 8 memo and drew criticism from some observers. CNN reportedly asked for comment and received a similar reply on June 11. While Framatome may have been unable or unwilling to make additional public comments about its Chinese customer, CNN's initial query did give the company a few days to prepare a public response.

Electricité de France (EDF), a French state-owned company, owns 75.5 percent of Framatome. EDF is also 30 percent owner of the Taishan Nuclear Power JVC (TNPJVC), the joint venture company that owns and operates the Taishan plant. CGN is the majority owner of TNPJVC, at 51 percent, and the remaining 19 percent is held by the Chinese utility Guangdong Energy Group. CGN has been on the U.S. Commerce Department's Entity List of foreign companies that U.S. firms have been forbidden to do business with since 2019, which compelled Framatome to get an exemption from strict U.S. export control policies on China to consult with U.S. experts.

While China was celebrating a three-day national holiday from June 12th to the 14th, TNPJVC reportedly published a statement on its website on June 13 stating that environmental readings for the plant and its surroundings were normal, and that both units met all regulations and technical specifications. For its part, EDF announced on June 14 that it had been informed of the increase in the concentration of certain gases in the primary circuit of the reactor and noted that it had called for a special meeting of the board of the joint venture "to present all the data and the necessary decisions."

Filling an information void

Accessing information about the operation of a plant in a country with strong central control is a challenge for reporters, especially those on the other side of the globe. As the media and concerned members of the public searched for more information, others, including the French Nuclear Society and the American Nuclear Society, offered what facts they could.

> "Both [Taishan] events were Level 0 deviations and did not affect the safe operation of the unit, the health of the workers, the communities in the vicinity, or the environment."

The next official statement on the condition of the plant came from a Chinese Foreign Ministry spokesperson, who said in a June 15 media report that "China attaches great importance to nuclear safety and has established a nuclear safety regulatory system that is up to international standards and in line with national conditions. . . . The Taishan nuclear power plant performs to the requirements of the technical specifications with [a] normal level of environmental radiation in the surrounding areas of the nuclear power plant, the safety of which is guaranteed."

Hong Kong, formally recognized as a Chinese "special administrative region," is located about 85 miles from Taishan, and its observatory monitors and publishes real-time background gamma radiation levels. On June 15, the Hong Kong Security Bureau, which receives communications from the Nuclear Emergency Committee Office of Guangdong Province, added its voice to those asserting that the Taishan plant posed no emergent hazard: "In 2021, we have so far received two notifications regarding [Taishan], which are about the operational events that occurred on February 21 and April 5 respectively. Both events were Level 0 deviations and did not affect the safe operation of the unit, the health of the workers, the communities in the vicinity, or the environment. The current situation at TNPS does not trigger the relevant notification mechanisms."

ANS member Katie Mummah—Student Sections Committee chair, University of Wisconsin Ph.D. student, and Twitter's @nuclearkatie—drew on her own education and experience as an intern to untangle the event with a thread that probed the facts and encouraged clear nuclear communication. She and other nuclear community members who are active online helped interpret the available information and pointed out that the situation at Taishan did not, in fact, merit the attention it was receiving.

Tweets on June 16 summed up Mummah's perspective: "This is a repeating event in the nuclear industry. When an event is truly non-safety related, the industry doesn't think they need to respond. But the media and the public panic even more when there is no forceful, honest, and timely response clarifying the situation"; "the end result is that small and boring events from an engineering perspective can and have led to large, and in this case global, panics from the media, and on social media where information travels in a split second."

ANS focuses on facts

As a professional society, ANS can and does provide needed context on nuclear science and technology without wading into speculation. Immediately after the CNN article began to circulate, ANS activated its own Rapid Response Team of technical experts and communications specialists to monitor the event. Executive Director/CEO Craig Piercy issued a press statement emphasizing that "it is premature to speculate about the exact nature of the situation, but it does underscore the value of international collaboration on nuclear safety issues, consistent with IAEA guidelines."

One month later, Piercy reflected on the incident. "At its core, this is a story about a well-understood and manageable condition that sometimes occurs with light water reactors, but it's also a lesson about the click-hungry media ecosystem we all live in today," he said. "Internal government documents ended up in the hands of a reporter without the benefit of accurate technical context, making a minor issue seem like an emergency. It's the kind of thing that keeps nuclear engineers up at night."

"At its core, this is a story about a well-understood and manageable condition that sometimes occurs with light water reactors."

ANS Fellow Jacopo Buongiorno, professor of nuclear science and engineering at the Massachusetts Institute of Technology and a member of ANS's Rapid Response Team, said, "We will remember this as a significant PR blunder that could have been easily avoided with more careful coordination among the actors involved." He added, "I hope Framatome and its Chinese partners together can find a better way to communicate that doesn't entail using alarming language like 'immediate radiological threat' when such alarm is not minimally justified."

Sometimes it is important to acknowledge that the details of a situation are unclear, Buongiorno said. "We need to learn to say 'I don't know' more often. Professing ignorance in the face of information scarcity is honest and ultimately a more effective communication approach than speculating."

ANS President Steven Nesbit agrees. "Technical experts like to try to solve puzzles even when we don't have enough of the pieces," he said. "Our first rule is to distinguish rigorously between what we know and what we don't."

A Critical Look continues

U.S. expertise in demand

A French firm alerting the U.S. government to a problem at a Chinese power reactor left the media grasping for context, and an assumption that the United States had no experience with the EPR may have fueled the perception that a truly significant incident was underway, leaving Framatome with no recourse but to seek help from the highest levels of government.

It is important to recognize that the United States has extensive experience from decades of operating the world's largest fleet of LWRs, and that some U.S. reactors use fuel very similar to that used at Taishan. The United States has also developed advanced technologies to assess fuel failures using fission product information.

Given that worldwide EPR operating experience is thus far limited to a few years at Taishan and that U.S. expertise at the DOE and national laboratories, domestic fuel technology and manufacturing companies (including subsidiaries of Framatome), and operating power reactors is substantial, the company's request for assistance is not unusual.

And while technical assistance was Framatome's likely aim, the United States can also share hard-earned lessons about communications with nuclear operators around the world.

"In the nuclear field, it is always best when the responsible authority is accessible and forthcoming with information. Then organizations like ANS don't have to fill in the gaps with explanations of what might or might not be happening," Nesbit said. "This was one of the many lessons learned from the Three Mile Island accident in the U.S. in 1979. It's second nature now for U.S. utilities, but much more challenging for plant operators in countries like China with more centralized control and less media freedom."

Regulators come forward

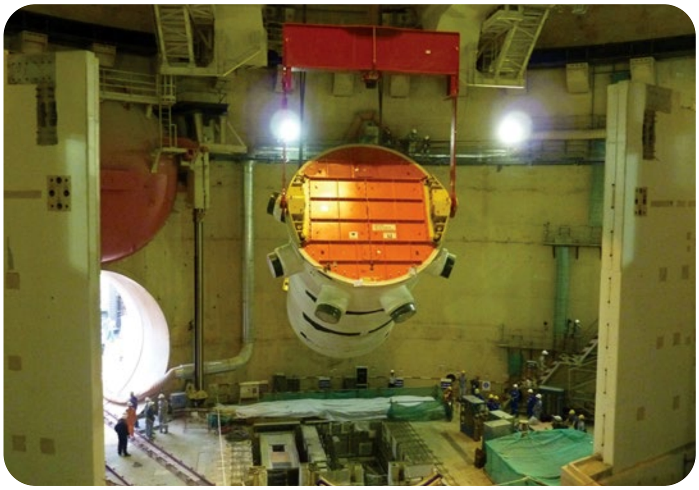
On June 16, the third day of media attention, the National Nuclear Safety Administration (NNSA) of the Chinese Ministry of Ecology and Environment issued a press release with more details than previously offered. Acknowledging that the cladding on about five of the reactor's fuel rods had been damaged, the NNSA pushed back firmly on CNN's report of a leak of radioactive gas to the environment, saying, "This report is not true. The [NNSA] has not approved an increase in the acceptable limit of radiation detection outside the Taishan Nuclear Power Plant. The [NNSA] reviewed and approved the relevant limits for the specific activity of the reactor coolant inert gas in the Taishan Nuclear Power Plant's primary circuit chemistry and radiochemistry technical specifications. This limit is used for operation management and has nothing to do with the external radiation detection of the nuclear power plant."

"At present, it is estimated that the number of damaged fuel rod claddings is about five, and the proportion of damaged fuel rods is less than 0.01 percent of the total, which is much lower than the maximum damage of the fuel assembly assumed in the design," the NNSA said, attributing the damage to "uncontrollable factors" such as manufacturing, transportation, and loading.

While the French regulator, the Autorité de Sûreté Nucléaire (ASN), issued no public statement before the NNSA's June 16 statement, in a June 17 press release, ASN said that it had reached out to its Chinese counterpart on June 12 to open a technical dialogue on the reactor's performance.

"ASN has proposed this interchange in order to examine to what extent the feedback from the current operating situation in Taishan can be taken into account in the ongoing examination of the commissioning application for the Flamanville EPR in France," the regulator said, reporting that the NNSA had responded favorably.

Fuel failures in context



The reactor pressure vessel is lowered into place at Taishan-1 in June 2012. (Photo: TNPJVC)

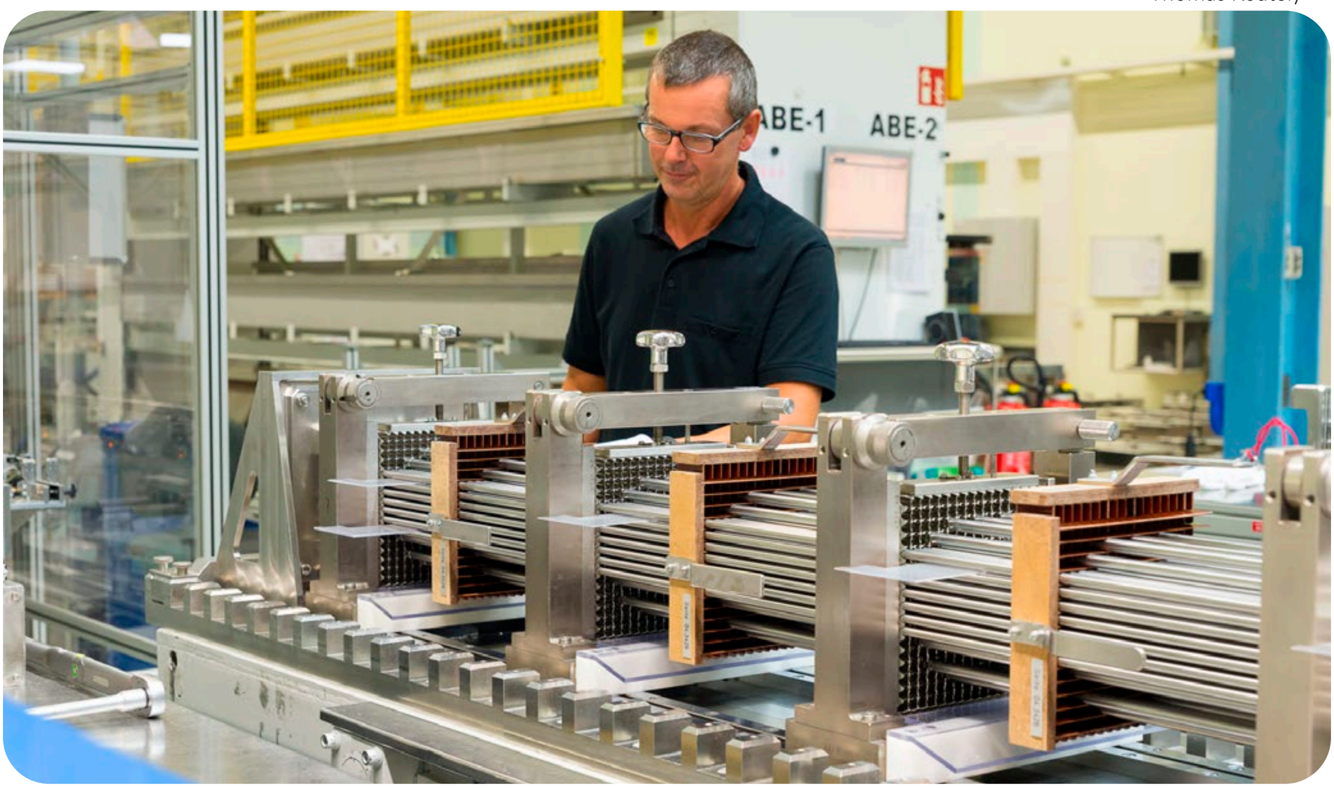
EDF described fuel cladding failures in a June 14 statement as “a known phenomenon.” Indeed, before China acknowledged that fuel failures had occurred, nuclear experts commenting online had noted that the failure was the likely source of the fission gas increase in Taishan’s primary coolant loop.

The core of an EPR reactor is made up of 241 fuel assemblies, each with 265 zirconium-cladded fuel rods. The uranium dioxide fuel pellets in Taishan, and in most LWRs, are stacked within a sealed metallic tube—the fuel’s cladding. Fission products created within the fuel pellets of an operating reactor are contained within the cladding, which serves as the first of three barriers to prevent a release of radiation. If the cladding is breached, any fission products released circulate within the reactor’s primary coolant system—the second of three barriers—where they can be monitored and managed. The third barrier is the reactor containment itself.

Reactor operators are quickly alerted to fuel failures by an increase in gamma activity associated with specific radioactive fission products in the reactor coolant. Regular monitoring of the relative concentration of isotopes of the noble gases xenon and krypton, as well as iodine and cesium, allows operators to determine—with the help of computer modeling—when a failure has occurred, where it is located, when the affected fuel should be removed, and the cause of the failure. Gases can be stored until their radioactivity is reduced and then vented into the atmosphere. A reactor’s license typically permits such small releases—at levels that are a fraction of background radiation and with no safety

A Critical Look continues

Framatome fuel assembly hall in Lingen, Germany. (Photo: Framatome/ Thomas Keuter)



significance—during normal operation. Two such releases from Taishan during 2021 were documented by Hong Kong, as described earlier.

Fuel failures can be the result of several causes under normal operation conditions, including wear due to grid-to-rod fretting (friction between rods and the spacer grid that holds them in place), debris fretting, or corrosion.

Just how common is such fuel rod damage? Considerably less common than in the past. According to International Atomic Energy Agency (IAEA) figures described in IAEA Nuclear Energy Series No. NF-T-2.1, *Review of Fuel Failures in Water Cooled Reactors,* published in June 2010, the nuclear industry reduced LWR fuel failure rates between 1987 and 2006 (the latest year for which data are available) by about 60 percent, to an average of about 14 leaks per million rods loaded. IAEA data also indicate that about 78 percent of pressurized water reactors undergoing refueling outages worldwide in 2006 were free of fuel defects.

The same IAEA report notes that "it is a general goal of modern nuclear utilities to operate with a core free of defects," in part because increased radiation from fuel failures can impact planned outages and increase workers' exposure. The report goes on to state that "fuel failure statistics appear to reveal a balance between incentives to operate fuels under more challenging conditions, which may increase failure probability, and the aspiration to have fully reliable fuels with 'zero failure rates.' This balance varies from country to country, and is dependent both on the achieved level of technological maturity and on the local perception of economically and publicly acceptable risk."

Action taken

EDF's most pointed public statement on Taishan's operation emphasized that country-level variance in fuel failure tolerance, and it came more than a month after the most intense media pressure. In a July 22 press release issued after a meeting of the board of directors of TNPJVC, EDF announced that it would shut down Taishan-1 for assessment if it were operating in France.

EDF stated that "analysis of the data available to EDF on fuel rod loss of sealing indicates that the situation is evolving," and concluded, "On the basis of the analyses carried out, EDF's operating procedures for the French nuclear fleet would lead EDF, in France, to shut down the reactor in order to accurately assess the situation in progress and stop its development. In Taishan, the corresponding decisions belong to TNPJVC."

That decision was announced about one week later, on July 30, when CGN reported that Taishan-1 would be shut down to examine fuel rod damage and conduct maintenance. "After full communication between Chinese and French technical personnel, [TNPJVC] insists on safety first and conservative decision-making in accordance with nuclear safety regulations and nuclear power plant operating procedures," CGN stated in its announcement. "The unit will be shut down for maintenance, find the cause of fuel damage, and replace the damaged fuel."

Up next for the EPR

With other EPRs approaching commissioning, Framatome has a major stake in how Taishan's problem is resolved, and how it is portrayed. While fuel cladding failures are manageable and not completely unexpected in a new plant with minimal operating experience, they have complicated the first years of EPR operation at Taishan and will be carefully studied by operators and regulators of other EPRs under construction.

While Taishan-1 and -2 were, respectively, the third and fourth EPR reactors to begin construction—construction began at Finland's Olkiluoto-3 in 2005 and at France's Flamanville-3 in 2007—they were the first to reach commercial operation, and both have completed their first refueling cycle.

In 2010, at the height of the "nuclear renaissance," Framatome (then Areva) anticipated building more than 20 EPRs, including four in the United States (at Bell Bend, Callaway, Calvert Cliffs, and Nine Mile Point). Now, just four are currently under construction worldwide—Olkiluoto-3 in Finland, Flamanville-3 in France, and two units at Hinkley Point C in the United Kingdom. In 2022, Olkiluoto will likely be the next EPR to reach commercial operation—about 13 years after the original target date of 2009.

Fuel loading was completed at southern Finland's Olkiluoto-3 in March 2021. Hot functional testing is underway, and reactor startup is expected soon. (Photo: TVO)

Lessons learned from the initial operation of new designs are not uncommon. Fuel vendors often consider detailed insights on fuel performance to be proprietary, but more information about what caused cladding failures at Taishan could eventually become known through Finnish, French, and U.K. regulatory reviews.

What have we learned?

CNN uncovered hitches in the operation of a first-of-a-kind reactor—and not an incipient radiological disaster. Yet the incident could have value for the nuclear community if it is recognized as another reminder that what happens anywhere can affect operations everywhere.

Nuclear fission reactors are now being developed in a wide range of sizes, and a reactor to rival the size of the EPR might not be built for decades—if ever. But nuclear communication matters whether the reactor in question is a 1,660-MWe powerhouse or a 20-MWt research reactor like that at the NIST Center for Neutron Research, which prioritized early and open communication to build trust with the community near Gaithersburg, Md., after it experienced a fuel failure in February of this year.

During Taishan's three days in the spotlight, public fear focused on the potential that significant information was being concealed. The rapid dissipation of media attention after China's NNSA issued a detailed statement is evidence of the near-universal value placed on such complete communication. China's approach to nuclear communication matters—the country generates more than 10 percent of the world's nuclear power and is responsible for about one-third of all new reactors under construction worldwide. As the nuclear community learned following both the Chernobyl and Fukushima disasters, nuclear safety depends on an operating and regulatory culture that addresses any issue with maximum transparency.

Without transparency, speculation will expand to fill the available space in today's connected media world. Truth and clarity can flush out the lines of communication, displace speculation, and moderate—or even prevent—the next media storm.

Susan Gallier is an NN *staff writer.*

ANS revises two position statements

ANS recently revised two position statements: one regarding the transportation of radioactive materials and another regarding U.S. global leadership in nuclear.

The American Nuclear Society recently revised Position Statement #18: *Transportation of Radioactive Materials* and Position Statement #83: *Assuring U.S. Global Nuclear Leadership*. Both were posted on the ANS website in July after being approved by the Board of Directors.

The revised Position Statement #18 now reads, "ANS supports the continued safe transportation of radioactive materials under the current regulatory structure." The statement further says that transportation of radioactive materials worldwide has been conducted with an excellent safety record for decades. The regulations currently in place adequately protect the health and safety of the public as well as the environment, and current practices and procedures enable the continued safe transportation of radioactive materials.

In the revised Position Statement #83, ANS urges the U.S. government to increase its support for expanding the peaceful use of nuclear energy by promoting the export of U.S. nuclear

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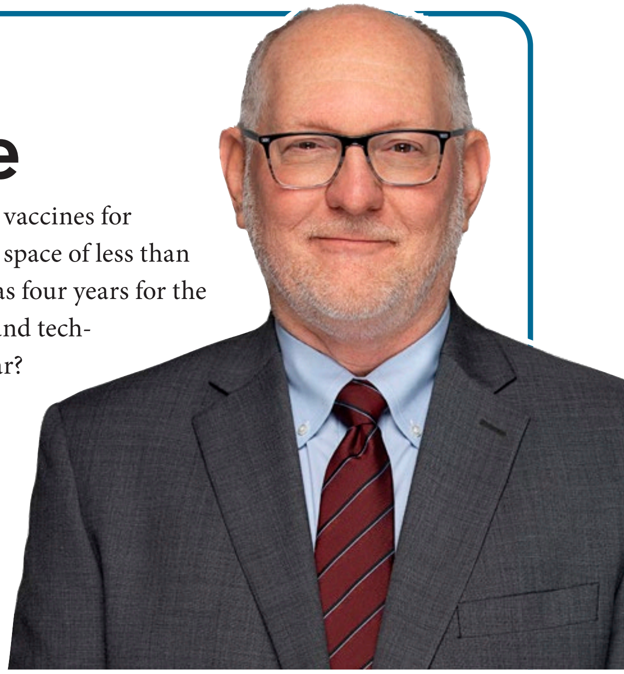
Lessons from medicine



Steven P. Nesbit
president@ans.org

I stand in awe of the pharmaceutical professionals who developed effective vaccines for COVID-19 and obtained emergency approval for their widespread use in the space of less than a year. Normally, vaccines take 10 to 15 years to develop; the previous best was four years for the mumps vaccine. The accomplishment is a testament to the ability of science and technology to work to the betterment of the human race. Does that sound familiar? The American Nuclear Society's vision statement is "Nuclear technology is embraced for its vital contributions to improving peoples' lives and preserving our planet."

Why was the COVID-19 vaccine effort so successful? There are many reasons, I'm sure, but I'll posit a few:

- A universally acknowledged need.
- A clear definition of success.
- A public/private partnership (Operation Warp Speed) that harnessed the abilities of industry and government.
- Ample resources.
- Relatively recent technological advances such as genomic sequencing and messenger ribonucleic acid vaccines.
- Regulatory bodies capable of weighing risks posed by vaccines against benefits offered.

Those of us in the nuclear energy field are often frustrated that the population at large doesn't embrace the potential of nuclear technology the way we do. However, consider the following:

- There is a nearly universally acknowledged need for clean, reliable energy.
- We will be successful if we preserve existing nuclear power generation and deploy new units that embrace new technologies and offer more applications than simple baseload electricity generation.
- The Gateway for Accelerated Innovation in Nuclear initiative and other programs enable the U.S. government to assist the nuclear industry.
- The federal government is providing substantial resources for new technology through the Advanced Reactor Demonstration Program and other initiatives.
- Private investors are providing substantial support for the development of new approaches to nuclear energy production.
- Digital technology, advanced manufacturing, supercomputing, and other technological advances support efficient applications of fission and fusion energy.
- The Nuclear Regulatory Commission is developing a risk-informed, performance-based regulatory framework for advanced reactors.

Former NRC commissioner Jeff Merrifield has in the past referred to the "Eeyore mentality" that we too often encounter in the nuclear field. If you don't know what he is talking about, read *Winnie-the-Pooh* by A. A. Milne because, well, everyone needs to read *Winnie-the-Pooh*. Pooh's friend Eeyore is a donkey who embodies the "woe is me" philosophy. Maybe the beer isn't quite overflowing the nuclear energy mug yet, but we're a far sight better off than staring at a half-empty glass.

In dealing with the impacts of COVID-19 and developing effective vaccines against the disease, the medical and pharmaceutical fields accomplished amazing things in a year, to the betterment of humanity. I know that nuclear professionals accomplish amazing things every day in our power plants, manufacturing facilities, laboratories, offices, and classrooms. Let's work together and make it our turn.

Nuclear Trending continues

Continued from page 36

technology, goods, and services and by maintaining the domestic nuclear market base.

To maintain and enhance U.S. leadership in nuclear nonproliferation and security, ANS recommends that the U.S. government:

- Implement bilateral agreements that give U.S. nuclear energy suppliers early access to markets where new or expanded nuclear energy infrastructure is under consideration. In negotiating these agreements, the United States should not demand conditions beyond existing U.S. legal requirements that other nuclear supplier nations do not require.
- Adopt a "whole-of-government" approach to ensure that every U.S. department and agency with a role in U.S. nuclear energy supply is fully engaged in order to make U.S. suppliers competitive by providing financing, training, assured fuel supply, and spent fuel management to foreign nuclear customers for nuclear technology, goods, and services.
- Enact policies that will ensure that U.S. electric generators will preserve existing reactors as vital national assets, as recommended in ANS Position Statement #26, rather than decommissioning them.

It concludes by stating that if U.S. nuclear policies do not promote U.S. nuclear trade and fail to preserve the domestic reactor fleet, the U.S. nuclear industry will lose global market share to foreign companies and reduce U.S. influence in shaping the energy, nuclear safety, and security policies of emerging nuclear countries.

ANS provides statements that reflect the Society's perspectives on issues of public interest that involve various aspects of nuclear science and technology. Position statements are prepared by key members whose relevant experience or publications inform the documents, and then the documents are reviewed by ANS committees and divisions. The final position statements are approved by the Board of Directors.

Nuclear Notables— A timeline of the NRC's risk-informed regulatory programs

U.S.NRC
United States Nuclear Regulatory Commission
Protecting People and the Environment

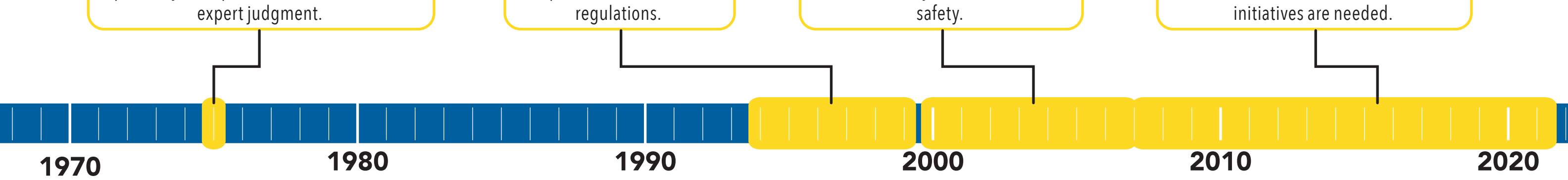
Correction: In last month's Nuclear Notables (*NN* August, page 16), J. Robert Oppenheimer was identified as scientific director of the Manhattan Project. He was in fact the scientific director of Los Alamos National Laboratory for the Manhattan Project.

1975
The Nuclear Regulatory Commission publishes *The Reactor Safety Study* (WASH-1400, NUREG/75-014) on measuring probability for reactor safety. The NRC did not systematically quantify these probabilities until WASH-1400. Previously, the NRC developed many of its regulations without considering numerical estimates of risk, instead developing its prescriptive, deterministic regulatory requirements based primarily on experience, test results, and expert judgment.

1994 to 1999
The NRC develops the Probabilistic Risk Assessment Implementation Plan (RIP) in 1994 to focus the agency's efforts on PRA-related activities. The RIP, and each of the subsequent plans noted in this timeline, has guided the NRC in developing risk-informed, performance-based regulations.

2000 to 2007
In SECY-99-211, the NRC staff advises the commission of its intention to restructure the RIP to more clearly describe the agency's risk-informed activities. Among other things, the new Risk-Informed Regulation Implementation Plan (RIRIP) tracks the three principal areas in the NRC's strategic plan: nuclear reactor safety, nuclear materials safety, and nuclear waste safety.

2007 to present
In June 2006, the NRC directs the staff to improve the RIRIP to help the agency achieve its goal of a holistic, risk-informed, and performance-based regulatory structure. The Risk-Informed and Performance-Based Plan (RPP) is later created. In addition to focusing on the principal areas of the RIRIP, the RPP, among other things, evaluates which initiatives should be continued, which should be retired, and what new initiatives are needed.



LETTER FROM THE CEO

On alpha, flak, and jack

Craig Piercy
cpiercy@ans.org

This month's issue of *Nuclear News* focuses on the role of probabilistic methods in assessing and mitigating the risk of adverse events at nuclear plants and facilities. It's a timely topic as we move to launch a new generation of nuclear technologies, but it is only half of a larger question that is universal to the human condition: Are the rewards of a particular thing worth its attendant risks?

Nuclear engineers use hard technical terms like "probabilistic risk assessment" and "core damage frequency," but other industries have much more colorful ways of describing the holistic risk-reward construct in their world. In finance, it's known simply as "alpha." A zero alpha investment suggests that its returns are commensurate with the associated risks. Negative alphas get pushed to the curb, and "high alpha" deals get Wall Street hedge fund managers their house in the Hamptons.

My favorite shorthand for risk-reward scenarios in the governmental policy arena comes courtesy of current Purdue University president and former Indiana governor Mitch Daniels. He calls it the "flak-to-jack ratio." In essence, how much abuse are you willing to take from the media, interest groups, the Twitterverse, etc., for raising revenue or cutting spending, compared to what you actually reap in dollars? Cutting funding for PBS, for instance, has a high flak-to-jack ratio, as few in Washington want to "kill Big Bird" for a few hundred million in savings. Postponing the start of a somewhat obscure yet important DOE research and test reactor? Flak-to-jack ratio: not so high.

I think it's fair to say that the technical community has done a commendable job of improving the quantification and characterization of nuclear's operational risks, and as a result, it is arguably the safest, cleanest, and most "life-cycle cost-efficient" energy source available in the world today. But it's a two-dial control panel, and we have more work to do in communicating to the public and policymakers about the larger, societal rewards of applied nuclear technology. Today's "domestic clean energy option" narrative is a good starting point, but it is not enough. We also need a cogent, coherent, and loud case for why the U.S. needs to make a long-term commitment to stewarding its nuclear enterprise.

If only we had a Level 2 PRA standard available to assess the risks of insufficient U.S. irradiation capacity on the pace of advanced nuclear innovation, or a Level 3 to understand its impact on American influence on international nuclear safety and nonproliferation norms. Sadly, they don't exist, but whether it's for clean energy, climate change, cancer care, or national security, the "alpha of nuclear" is there for anyone to see if they choose to look. It just may sometimes require a little flak to get the jack.

All the best,

Nuclear Trending continues

The NRC receives a briefing on Human Capital and Equal Employment Opportunity topics from agency officials in 2018. Annie Caputo (in white, left) and Kristine Svinicki (in red, center) have both since resigned from the commission, leaving two vacancies. (Photo: NRC)

ANS urges Biden to quickly fill NRC vacancies

In a July 1 letter to President Biden, ANS President Steven Nesbit and ANS Executive Director/CEO Craig Piercy stated that a full complement of five commissioners is essential to the effectiveness of the Nuclear Regulatory Commission in protecting public health and safety while enabling the deployment and applications of nuclear technology.

Nesbit and Piercy urged Biden to act expeditiously to fill the vacancies created by the departure of Kristine Svinicki in January and Annie Caputo in June, leaving the NRC with only three commissioners. (The NRC requires a quorum of at least three commissioners.) Nesbit and Piercy pointed out that the Energy Reorganization Act of 1974 established a five-person commission to run the NRC, stating, "It is important that the commission operate with its full complement of five members."

NRC commissioners are appointed by the president and confirmed by the Senate for staggered five-year terms, and no more than three may be from the same political party. The current commission consists of one Republican, David Wright, and two Democrats, Jeff Baran and Christopher Hanson. Kristine Svinicki, who had served as chairman from January 2017 to January 2021, and Annie Caputo are both Republicans.

The ANS leaders also pointed out the importance of the next nominees' backgrounds, experience, and qualifications (the backgrounds of the NRC commissioners were discussed in detail in the February issue of *Nuclear News*). They said that with Caputo's departure, the NRC has no remaining commissioners with a strong technical foundation. ANS Position Statement #77 states, "It is not essential that all commissioners be scientists or engineers, but the nature of commission responsibilities makes a technical background a highly desirable trait."

"To restore the needed balance, the White House should seek nominees who are scientists or engineers with significant, recognized accomplishments in their field," Nesbit and Piercy wrote. "Fortunately, the nation has many such qualified candidates, including Ms. Caputo."


Elijah Martin
Plasma Physicist
Big Science.
Big Opportunities.

The origins of *The Reactor Safety Study*

By Thomas R. Wellock

Norman Rasmussen at MIT

In March 1972, Stephen Hanauer, a technical advisor with the Atomic Energy Commission, met with Norman Rasmussen, a nuclear engineering professor at the Massachusetts Institute of Technology. The AEC had recruited Rasmussen to develop a report, *The Reactor Safety Study* (WASH-1400), to estimate the probabilities and consequences of a major nuclear power plant accident. With thousands of safety components in a modern reactor, the task was mind-boggling. Rasmussen proposed a novel approach based on more powerful computers, "fault tree" methodology, and an expanding body of operational data. By calculating and aggregating probabilities for innumerable failure chains of components, he believed he could develop a meaningful estimate of overall accident risk. WASH-1400 would be a first-of-its-kind probabilistic risk assessment (PRA).

Hanauer was persuaded, but troubled. "Do we dare undertake such a study till we really know how?" he wondered.[1] Previous estimates of accident probabilities had produced wildly inconsistent results. The AEC's nuclear power program was mired in controversy, and the report was certain to generate publicity. Proving reactors were safe with an untried methodology might be a fiasco, and it almost was. No regulatory report had a more searing reception than the one that greeted WASH-1400's publication in 1975. Its unsound risk comparisons, incomplete data sets, flawed calculations, and limited use of peer review prompted criticism so intense that the Nuclear Regulatory Commission issued a partial rejection of it in 1979.

Yet, we now know that the AEC's daring paid off. WASH-1400's credibility was restored, prophetically identifying key safety weaknesses that led to the Three Mile Island accident. Today it is remembered as the seminal document of PRA methodology and risk-informed regulation. That happier ending has lent to PRA histories a narrative of inevitability that overshadows the frustrating multi-decade pursuit of accident probabilities that preceded the study and the AEC's fraught debate on moving forward with it. More than the beginning of PRA, WASH-1400 was the culmination of decades of technical and political dilemmas within the nuclear establishment that made a new quantitative approach to safety imperative.

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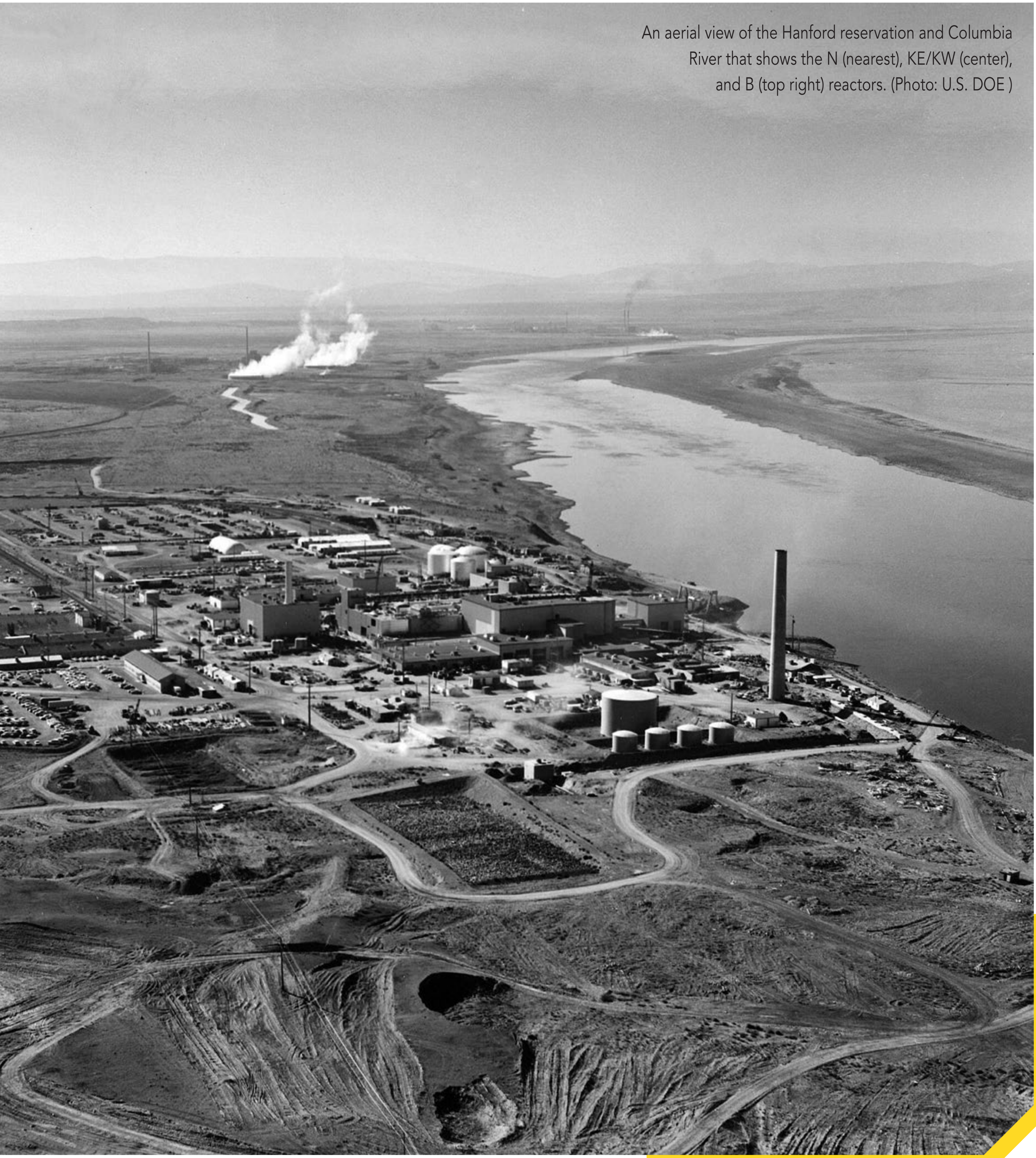


An aerial view of the Hanford reservation and Columbia River that shows the N (nearest), KE/KW (center), and B (top right) reactors. (Photo: U.S. DOE)

The burden of WASH-740

The search for accident probabilities began early in the Cold War era. Reactor safety was grounded in a conservative, qualitative philosophy characterized by the alliterative three D's of safety: design basis accidents, deterministic (conservative) design, and defense in depth. At the AEC's Hanford production reactors in Washington state, experts on the Reactor Safeguards Committee—the predecessor to the Advisory Committee for Reactor Safeguards (ACRS)—were alarmed by emergent hazards that might cause an explosive reactor runaway more powerful than previously imagined. In 1950, the committee noted that probabilistic assessments of risk were the norm in other technologies, and it would dispel the committee's concerns if it could be shown that a reactor disaster was just a one in a million (10^{-6}) probability (ML15113A624). General Electric Company, Hanford's contractor, was confident in the conservatism of its accident consequence estimates, but its forays into probabilistic estimates were foiled by limited operating experience and computing capabilities.

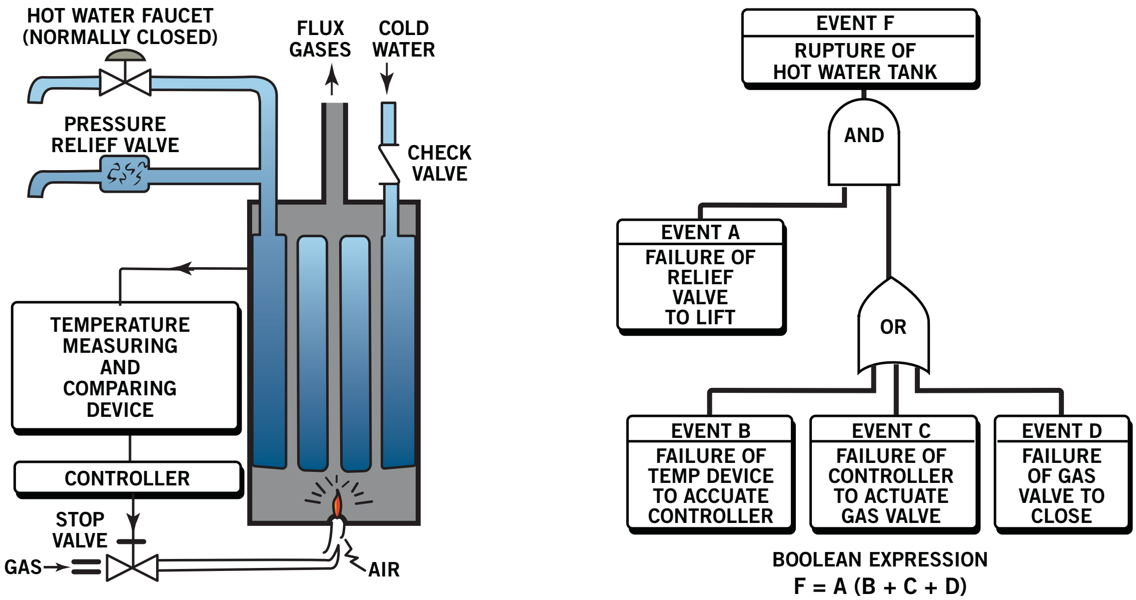
In 1957, Brookhaven National Laboratory came to the same result in its landmark study, WASH-740. Requested by Congress's Joint Committee on Atomic Energy (JCAE) as part of the pending Price-Anderson indemnity legislation, WASH-740's consequence estimates were disturbing. A sudden loss of coolant accident (LOCA) coupled with a failure of the emergency core cooling system (ECCS) and containment could cause 3,400 deaths and $7 billion in property damage. Based on a poll of experts, the AEC maintained that this hypothetical accident had an "exceedingly low" probability, in the range of 10^{-6} per reactor year, but admitted that "no one knows now or will ever know the exact magnitude of this low probability" (ML20086S495).

As the favorite reading of antinuclear critics, WASH-740 was an "albatross around our necks," AEC chairman Dixy Lee Ray later observed.[2] Refuting it became a priority. In 1964, the JCAE tasked the AEC with updating the study. The request was a major mistake. Brookhaven's consequence estimates were even worse than the original study, simply because power reactors were larger and produced more fission products.[3]

The AEC tried to put the update's results in context by contracting a formal probabilistic estimate from Planning Research Corporation. Based on quite limited operating data, Planning Research estimated that a major accident was no more likely than one in 500 years of operation. This was not reassuring. If correct, two major accidents were possible every year in a fleet of 1,000 reactors. A second "quasi-quantitative" estimate relied on a mixture of judgment, failure data, and system block diagrams. It produced very optimistic probabilities, between 10^{-8} and 10^{-16} reactor years of operation. Regulatory staff concluded that the estimates were useless. Even the most pessimistic end of the quasi-quantitative approach meant that a reactor operating since the age of the dinosaurs might have just one accident.[4] The AEC did not publish the results of the update. Unable to quantify risk, the AEC made a virtue of its qualitative safety approach. Over the course of the 1960s, advances in risk assessment methodology, regulatory surprises, and the rise of environmentalism compelled the AEC to attempt probabilities again.

Fault tree methodology: Seeing the forest with trees

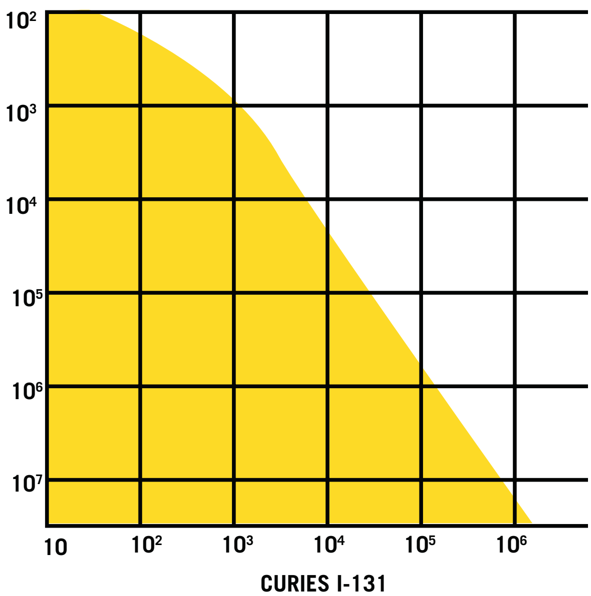
Risk experts needed a universal visual representation of failure chains that could sort out the most important paths to disaster. "Decision trees" came to the rescue, with contributions from the biological sciences, business scholars, and military think tanks. In 1962, Bell Labs adapted decision trees and Boolean algebra to create fault trees for the U.S. ballistic missile program. Fault trees reduced chains of component failures involving power supplies, valves, and pumps to universal symbols—a visual *lingua franca* of catastrophe. Combined with component data, they could compute system failure probabilities. If fluent in fault trees, any analyst could see the likeliest paths to a disaster.[5] The use of fault and decision trees spread to nuclear technology, including satellite SNAP reactors, Hanford's production reactors, and civilian reactor design. Limited data and the possibility of unforeseen mishaps meant that



An example of the simplified illustration Bell presented in 1963 depicting the possible failure paths of a household hot water heater. (Diagram adapted from Boeing Corporation, Ref. 5)

the overall probability estimates from fault trees had a large potential for error, and their application was limited to comparisons of system design variations.

Some risk experts envisioned an ambitious coupling of these bottom-up estimates with top-down quantitative safety goals. In 1967, F. R. Farmer, a British nuclear expert, was dissatisfied with the



The Farmer curve set a maximum radioactive release criterion for an accident based on its probability. (Graph adapted from IAEA Ref. 6, with permission of the IAEA)

arbitrariness of regulation by design basis accidents. In 1967, he proposed to analyze "in a quantity-related manner . . . a spectrum of events with associated probabilities and associated consequences." He established a risk limit curve for reactor design and siting decisions by plotting accident probabilities against international standards for health effects from iodine-131, a radioactive isotope released during an accident. Believing that the public was more averse to one large accident than many small ones, he bent the curve to further reduce the risk of catastrophic accidents. The "Farmer's curve" influenced risk thinking in the United States, too. For example, Ian Wall, a risk expert with GE and a Standards Service Award recipient in 2019 from the American Nuclear Society, incorporated it into a risk methodology he proposed for reactor siting decisions. GE and the rest of the nuclear industry began to develop expertise in probabilistic approaches to safety.[6]

In 1969, Chauncey Starr, a Manhattan Project veteran and dean of engineering at the University of California–Los Angeles, took Farmer's model a step further. He proposed a universal model of acceptable risk and benefits across multiple technologies. Excessive caution by nuclear experts, he believed, produced a generation of "nuclear hypochondriacs" with "irrational anxiety." The key to winning over

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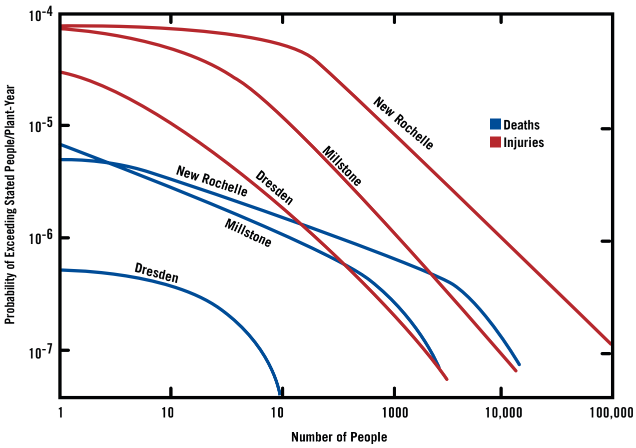
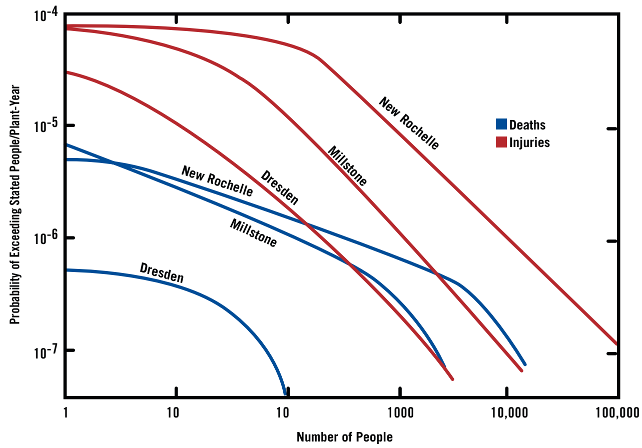
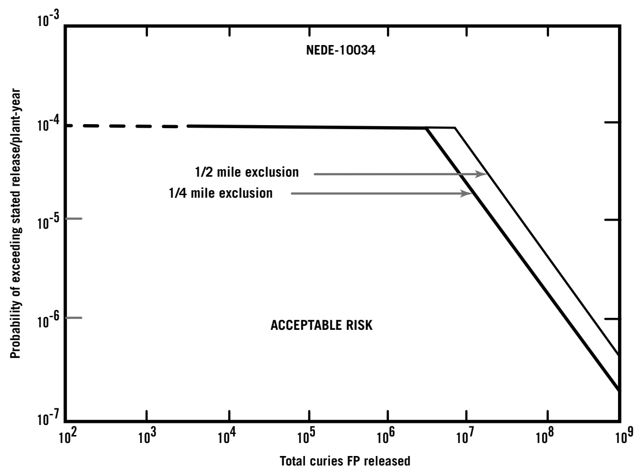




Ian Wall and GE developed a probabilistic approach to nuclear power plant siting decisions based on an analysis of the Dresden and Millstone stations as well as an ill-fated proposal at David's Island near New Rochelle, N.Y. (Graphs adapted from General Electric Ref. 6)



the public was to quantify and compare the risks and benefits of all technologies. He developed acceptable risk curves based on historical accident and disease data, insurance tables on the value of a life lost, and the risks and benefits of various technologies. Starr's calculations showed that nuclear power was safer than almost any other technology. In a clear message to the AEC, Starr wrote, "This approach could give a rough answer to the seemingly simple question, 'How safe is safe enough?' The pertinence of this question to all of us, and particularly to governmental regulatory agencies, is obvious."[7]

Starr's proposal helped inspire a new field of risk analysis. Researchers later identified numerous biases and a lack of trust in experts among the public that made quantification of "safe enough" a task more complex than Starr imagined. Nevertheless, by the late 1960s, the pieces of risk assessment were beginning to coalesce. John Garrick, a future industry leader in PRA, suggested in his 1968 dissertation that experts might soon overcome the obstacles to probabilistic estimates and "arrive at the goal of a figure of merit to quantify safety."[8]

The China syndrome revolution

Developments in risk assessment left AEC officials intrigued but unmoved. Hanauer wrote, "We have not yet arrived at the point where probability analysis techniques give adequate assurance that all failure modes are indeed considered, that the probabilistic model for severe accidents corresponds to the actual failures that will occur, and that adequate failure rate data are available for prediction" (ML20235M908). Defense in depth remained the bedrock of light water reactor safety and containment buildings the last line of defense against catastrophe.

"Then a revolution in LWR safety occurred in 1966," recalled ACRS member David Okrent. During the construction permit review for a General Electric boiling water reactor at Dresden, Ill., and a Westinghouse pressurized water reactor at the Indian Point site in New York, experts recognized that a core meltdown in these large reactors might have sufficient energy to melt through the reactor vessel and breach the containment building. A joke about the molten blob melting all the way to China led to the phenomena's being dubbed "the China syndrome" (ML090630275).

For some ACRS members, the solution was to require safety system diversity and independence with even more robust containment designs. GE advocated an alternative: Make the ECCS so redundant that it would be the lynchpin of defense in depth. Containment design would assume that the ECCS worked sufficiently to prevent major core damage. GE further called for replacing deterministic safety with a probabilistic approach that emphasized the redundancy and reliability of active safety systems over diversity. Presciently, GE argued the AEC's design basis events overlooked small mishaps that could lead to a serious accident. Robert Richards, a GE executive, dismissed the AEC's "almost mystical belief that the containment provided protection" and argued that a core meltdown was only credible during a natural disaster. A careful probabilistic evaluation of a spectrum of accidents could "buy" more safety by optimizing design and providing greater realism to accident analysis (ML20114E664; ML20235C460; ML20114E647).

The AEC did not go along with relaxing containment requirements in exchange for improving ECCS reliability. Clifford Beck, a regulatory technical advisor, responded that GE did not recognize the value of "independent lines of defense which differ in nature and in objective" (ML20118D278). But an AEC task force chaired by William Ergen of Oak Ridge National Laboratory endorsed the industry solution to make ECCS so redundant and reliable that a core meltdown was not credible. The AEC also redirected its safety research program from studies of molten core behavior to focus on tests of ECCS effectiveness. The Atomic Industrial Forum, an industry organization, maintained that research into extreme accidents was unnecessary, since "a major meltdown would not be permitted to occur."[9] That the industry believed it had the power to forbid a meltdown spoke to its confidence that such accidents were not credible.

Alvin Weinberg, the longtime director of Oak Ridge National Laboratory, recognized the "profound repercussions" of the China syndrome debate. "Up to then, we had counted on containment to keep *any* radioactivity from escaping in every case: The consequence of even the worst accident was *zero.* But now . . . we could no longer argue that the widespread damage described in Brookhaven's WASH-740 was impossible. . . . We had to argue that, yes, a severe accident was possible, but the *probability* of its happening was so small that reactors must still be regarded as 'safe.' Otherwise put, reactor safety became 'probabilistic,' not 'deterministic.'"[10]

The AEC's probabilistic turn in 1967 was not manifest in quantitative risk criteria, but the change was evident. Defense in depth incorporated more emphasis on the reliability of active safety systems than static physical barriers, as evidenced in revisions to "General Design Criteria for Nuclear Power Plants" (Appendix A to 10 CFR Part 50). Conceived as a high-level constitution of reactor safety, the initial 1965 draft contained about two dozen criteria, including a requirement that containment would not be breached even during a complete ECCS failure. In the wake of the China syndrome debate, the 1967 draft ballooned to 70 criteria. Containment language was softened to require only a "substantial margin" for ECCS failure. Redundancy and reliability requirements were liberally applied to active systems. The 1965 draft specified single-failure criteria for reactor protection systems and control rod malfunctions. In 1967, it was clearly defined and expanded to electric power systems, decay heat, and core and containment cooling systems (ML090630275, chap. 3).

Probabilistic thinking also influenced debates over a new class of hazards—beyond-design-basis events. The first beyond-design-basis event to receive attention was the failure of the scram system after an anticipated transient, such as a loss of the feedwater system. In 1969, E. P. Epler, a consultant to the ACRS, contended that an anticipated transient without scram (ATWS) was far more likely than previously recognized. "The industry, by not attempting to mitigate the 'China syndrome,'" he argued, "has placed the entire burden of protecting the public

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on the reactor shutdown system." Anticipated transients typically occurred every year at nuclear power plants, and, he estimated, failed scrams occurred about once in a thousand demands. If the United States built 1,000 reactors, an ATWS could happen every year (ML090630275). Epler's estimate included consideration of common-cause failures, such as an electrical fire or a common manufacturing defect that overrode system redundancies. Such a defect had disabled the scram relays at a reactor in West Germany.

ATWSs forced experts to estimate accident probabilities. GE, the most probabilistically minded vendor, claimed that the odds of an ATWS were less than one in 400 trillion. All four reactor vendors argued that an ATWS was not a credible event. Hanauer considered the GE estimate "nonsense" and told his superiors that the vendor was using "fake probabilities." One ACRS consultant criticized GE's analysis. "The AEC staff figures of 10^{-3} [one in 1,000] for the unreliability of reactor scram systems is entirely reasonable. Certainly, the GE value of 2.4×10^{-15} [about one in 400 trillion] is entirely *un*reasonable." Experts in the United States, Canada, and Great Britain estimated an ATWS probability between one in 100 to one in 10,000.[11]

The ATWS issue remained unresolved for the next 15 years, but the debate led the staff to spell out for the first time an informal quantitative safety goal of 10^{-6} for a major accident. Any individual accident scenario, such as an ATWS, LOCA, or damage from a major tornado, should be 10^{-7}, one-tenth of the overall goal. The difficulty with such explicit numerical goals was that they were unverifiable. It would take generations of operating experience to establish with confidence an ATWS probability of 10^{-7} (ML19352A370; ML13073A158). ACRS consultants urged regulators to develop their own capacity for accident modeling and fault tree methodology.

The political necessity for risk assessment

The 1965 update to WASH-740 was not released to the public, but it was not secret. The AEC refused earlier requests from the antinuclear movement to release it. Harder to ignore was Alaska Sen. Mike Gravel's request. The commission turned Gravel down but conceded to "an entirely new revision" of WASH-740. In early 1971, the AEC split the study between the Division of Reactor Development and Technology, which would write a report on the AEC's safety philosophy, and the Office of Regulation, which would attempt a WASH-740 with probabilities to allow for comparisons of nuclear power to other technologies, as Chauncey Starr advocated. While WASH-1400 cost several million dollars and employed nearly 60 experts, the initial study was to be a modest project of a few staffers and a budget of about $200,000. Burdened with dozens of licensing applications, the regulatory staff made no progress on the report (ML20087M293).

Additional prodding followed as the AEC and JCAE confronted new rivals. In January 1970, President Nixon signed the National Environmental Policy Act (NEPA) and later that year established the Environmental Protection Agency. The EPA assumed authority to set public radiation standards, a potential point of conflict with the AEC in regulating licensees. The AEC came under fire for its limited implementation of NEPA requirements in its environmental impact statements (EIS). The AEC excluded major "Class 9" accidents from EIS consideration on the grounds that the probability of such an event, judged to be 10^{-8}, was not credible (ML19263E348). As a regulator of multiple hazardous substances, the EPA was interested in risk assessment, too, and it pressed the AEC to use more than judgment to justify this claim.

More ominously, the AEC suffered a harshly worded legal defeat in 1971 before the D.C. Circuit Court in the Calvert Cliffs decision. The court ordered the AEC to consider a broader range of nuclear and nonnuclear hazards in environmental impact statements. Appearing insensitive to environmental concerns, a change in AEC leadership followed. Nixon appointed to the commission figures outside the nuclear establishment, including chairman James Schlesinger, an economist; William Doub, a Maryland public utilities commission chairman; and

Dixy Lee Ray, a biologist. L. Manning Muntzing, a telephone industry lawyer, was appointed to head the regulatory division. Collectively, the new arrivals were more open to innovative approaches to nuclear safety, including risk assessment.

Environmental turf wars also distracted the JCAE. Until 1970, the Joint Committee was unchallenged in its control over atomic weapons, nuclear energy, and AEC oversight. Environmentalism empowered related congressional committees to challenge its monopoly. The JCAE faced an existential threat from legislative proposals in Congress and by the White House to break up the AEC and roll it into a super energy and resources agency.

Saul Levine

To take back the initiative, Saul Levine, an AEC staffer on loan to the Joint Committee, recommended that the committee request an AEC study of its safety approach and the probabilities and consequences of major accidents—the key elements of the report the AEC had already promised to Gravel. The report would allow the committee to hold hearings and propose its own legislation. In October, the Joint Committee requested that the Reactor Development and Technology Division begin its stalled study on the AEC's approach to safety. In December 1971, committee staff pressed regulatory leadership to get moving on their accident study.[12]

Before the AEC could bring Rasmussen in for his interview in March 1972, the agency took further hits. In January, it began rulemaking hearings to establish performance criteria for emergency core cooling systems (ECCSs). Opponents accused the AEC of stifling the staff witness who disagreed with its position, and the agency appeared as a zealous promoter of nuclear power that lacked a commitment to safety. Even members of the JCAE stated their interest in breaking up the powerful agency. The AEC needed a fresh approach to making the safety case for nuclear power.

The Reactor Safety Study

With its credibility under scrutiny, the AEC sought an outsider to lead the study. In March 1972, Hanauer met with Rasmussen to map out the report's tasks. Several covered the traditional ground of consequence studies like WASH-740—estimates of fission product release, dispersion, and health consequences. The hard part would be two groundbreaking tasks—to construct fault trees and estimate accident probabilities. Rasmussen cautioned, "There will be a significant lack of precision in our final result." Hanauer admitted that the report team might have to "learn by trying," but these new tasks were what the AEC wanted. "We want the whole package," Hanauer wrote. "Doing [accident consequences without probabilities] would be another WASH-740 with the risk still unquantified. We might have to settle for that but want to try to do probabilities."[13]

Rasmussen was hired, but the AEC was not united on what he was hired to do. Tom Murley, a commission staffer who later served in the NRC as the director of the Office of Nuclear Reactor Regulation, was assigned to help Rasmussen in cajoling resources from an overburdened regulatory staff. To history's benefit, he began to keep a notebook that chronicled the hope and foreboding with which AEC leadership approached the report over the next year (ML20087N390).

On the side of hope was AEC general manager R. E. Hollingsworth. He thought the new report would "bury WASH-740," as Murley summarized. In a meeting with industry leaders, Schlesinger seconded the argument that the study would put WASH-740 into perspective for the public, and he was optimistic that a probabilistic study would reveal that current designs were grossly conservative.

Less sanguine was commissioner James Ramey. A former JCAE staff member, Ramey was a New Deal Democrat, a passionate supporter of nuclear power, and perhaps the most influential commissioner in AEC

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Left to right: AEC commissioner James Ramey; AEC chairman Glenn Seaborg; President Lyndon B. Johnson; and AEC commissioner Samuel Nabrit at the Experimental Breeder Reactor-1 in Idaho. (Photo: U.S. DOE)

history. He remembered well the WASH-740 struggle and flawed accident probability results that doomed the 1965 update. He did not want Rasmussen to study accident consequences until he convincingly developed probability estimates. His concerns mirrored those of the nuclear industry. If Rasmussen's analysis confirmed that accident probabilities were low, they asked, why study consequences at all? The commission initially agreed to restrict the investigation of consequences and described WASH-1400 as a study of accident probabilities and an "exploration of implications."

Ramey was also drawn to the study's public relations possibilities. He gave the report a pronuclear tone by adding a Starr-like section that compared nuclear to nonnuclear risks. Of this new section, the staff noted, "The public daily accepts risks to its health and safety when it uses automobiles, airplanes, subways, elevators, and so on. Many of these activities have risks that are precisely known or can be computed. The risks associated with nuclear plants would then be placed in the context of other risks of the modern world" (ML20087M548). This section became the final report's controversial executive summary, which was heavily criticized for comparing well-quantified risks, such as airplane accidents, to Rasmussen's highly uncertain accident probabilities.

"Get Saul Levine full time!" Schlesinger commanded Murley. Rasmussen served the AEC on a part-time basis, and the unwieldy study needed a strong hand. Levine had a temper so ferocious that some staffers summoned to his office remained standing to dodge the desk items he might throw at them. But he possessed navy discipline and attracted loyalty from staffers who adapted to his temper and aim. Levine brought to the study a regulator's perspective on the value of risk assessment that transcended the commission's focus on public relations. Risk assessment, he believed, could solve knotty problems, such as ATWSs, and improve regulatory staff capability. Under Levine's leadership, the AEC later created a group organized around a cadre from the Rasmussen study to explore PRA applications in regulations.

As the study gained coherence in late 1972, it still needed unified commission support to expand it to include probabilities and consequences. Ramey's influence with the JCAE made it difficult to move forward without him, and he micromanaged numerous aspects of the study and staff assignments. Schlesinger urged Rasmussen to "go make peace with Ramey." Ramey held out. At a January 1973 meeting, he said the study might be a "nice theoretical work, but it could be like a successful operation where the patient died." Commissioner Dixy Lee Ray countered that even if Rasmussen did not estimate consequences, someone else could do the same by using WASH-740's results. Ramey quipped, "If it shows just one human life [lost], I'm against it."

Pressure outside the agency grew. In March, the AEC met with representatives of the President's Council on Environmental Quality. CEQ reported that the EPA wanted the AEC to make its case that major Class 9 accidents should be excluded from EIS risk-benefit analysis. "The AEC is telling the world that Class 9 accidents are incredible—they should tell the world why they think so." The EPA could not force the AEC to analyze Class 9 accidents, but it might outflank it. The EPA, the AEC learned, was working on its own study of risk that would include a Farmer's curve as a proposed safety standard.

Myron Cherry, a lawyer for antinuclear groups, threatened a lawsuit to obtain the 1965 update to

WASH-740. AEC leadership concluded that they had no choice but to release it. Despite Ramey's efforts, a worst-case estimate of perhaps 45,000 deaths was about to make headlines anyway. The Rasmussen report began to look more like a solution than a problem.

In a conclusive commission meeting at the end of May 1973, Rasmussen carried the day with a rough probabilistic estimate. Based on reactor vessel failure probabilities, a core-melt accident with serious health consequences was 10^{-6}. A worst-case scenario of 1,400 acute (early) fatalities had a probability of one in 10 billion years. These were limited consequences for such an improbable accident. At last, Ramey agreed. "OK to go ahead!" Murley wrote in this his last journal entry. Ramey even permitted Rasmussen to choose his own staff for low-level team assignments. His term at an end, Ramey left the commission a month later.

Satisfied that WASH-1400 would bury WASH-740 and its update, the commission unleashed Rasmussen. The charismatic professor was deployed to counter the fallout from the release of the WASH-740 update. At a JCAE hearing in September 1973, Rasmussen dismissed WASH-740's "upper-limit" calculations as "far from reality." He expected his report would be "fairly favorable" to nuclear power. Delighted, Congressman Craig Hosmer said the report was "one of the most significant things that we have been presented in a number of years in reactor safety." Holding the EPA at bay, the AEC inserted into its EISs a statement that Class 9 accident probabilities would be addressed by *The Reactor Safety Study* (ML082830088). The industry press reported, "If one thing is clear . . . the Atomic Energy Commission is counting rather heavily on the results of the Rasmussen risk quantification study to confirm . . . that the operation of nuclear reactors poses no undue risk to the health and safety of the public."[14]

Conclusion

The year of internal AEC debate revealed the disparate motives behind WASH-1400. For the commissioners and AEC leadership, the study might rid the agency of WASH-740's ghost, persuade the public that nuclear power was safe, and restore the agency's authority. In this hope, WASH-1400 was not successful. The Energy Reorganization Act of 1974 dissolved the agency and created in the NRC an

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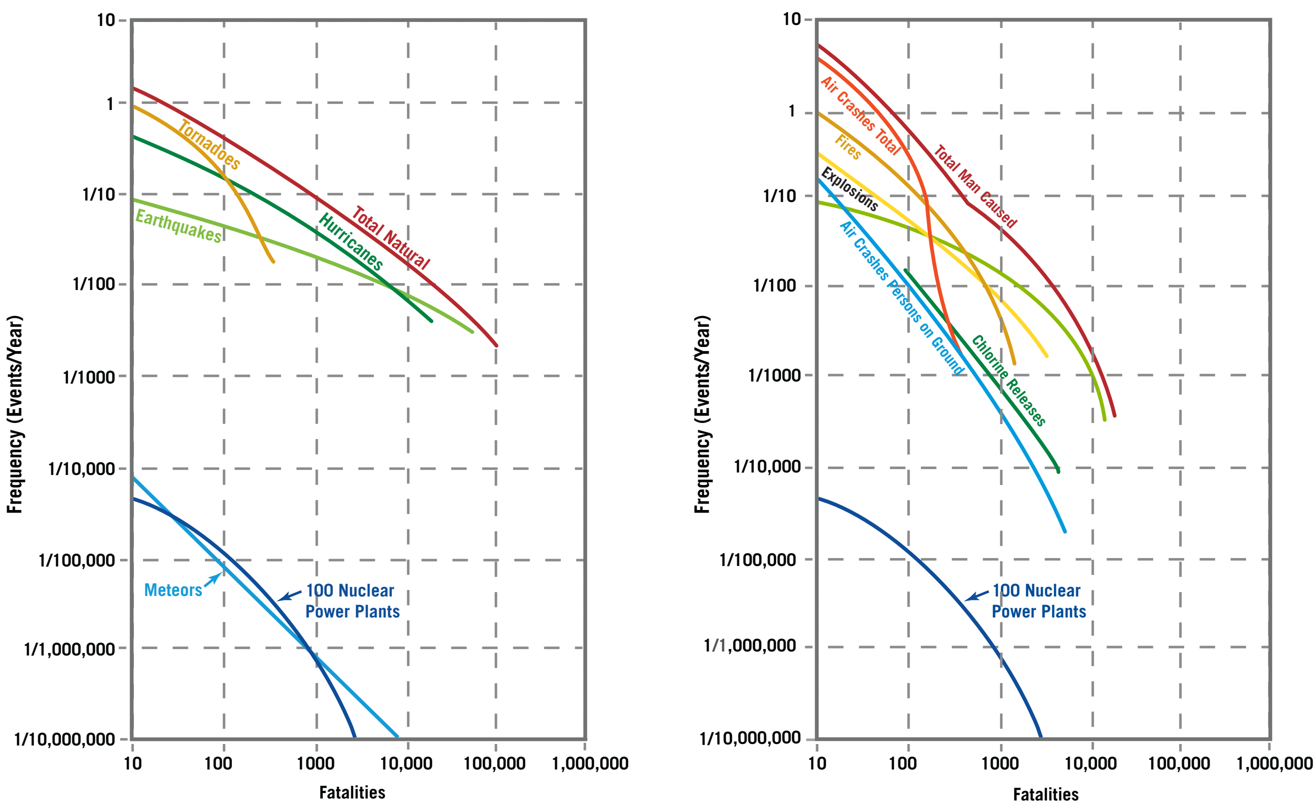
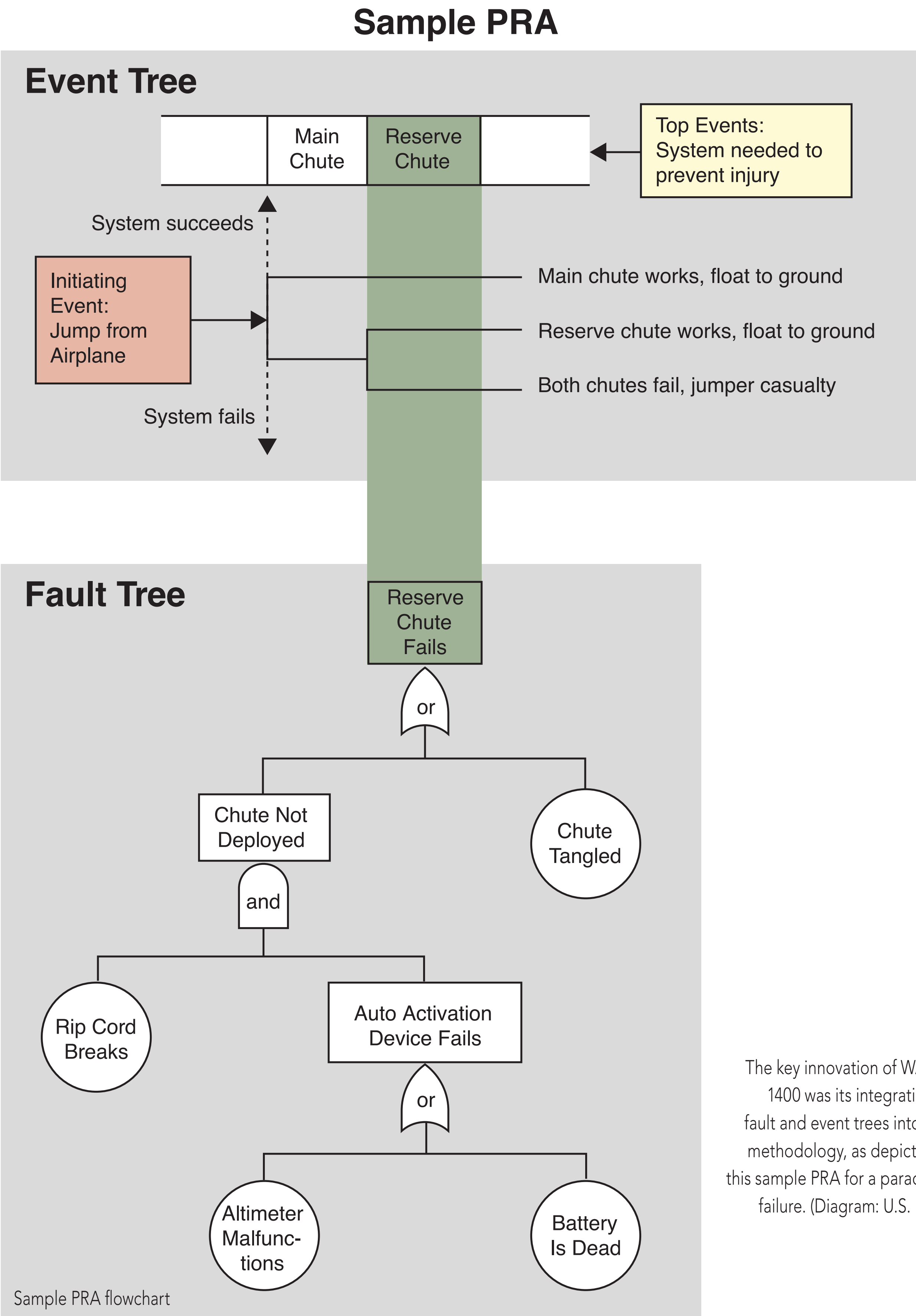


Comparisons of natural and human-made hazards as depicted in WASH-1400's executive summary. (Graphs adapted from *The Reactor Safety Study*, NUREG-75/014)



Sample PRA flowchart

The key innovation of WASH-1400 was its integration of fault and event trees into one methodology, as depicted in this sample PRA for a parachute failure. (Diagram: U.S. NRC) independent safety regulator. Unpersuaded by quantitative assessments of risks and benefits, public support for nuclear power eroded throughout the 1970s. The study was more successful as the regulatory tool envisioned by Levine, Hanauer, and the nuclear industry, although the road to risk-informed regulation has been long.

WASH-1400's importance, however, exceeds this simple summation of failed and fulfilled expectations. The results were a revelation, even to Rasmussen. Comfortable in the assurance that he would confirm the old saw that a meltdown was a one-in-a-million probability, the commission gave Rasmussen the go-ahead in May 1973. His estimate was wide of the mark, more judgment than method, since he had yet to do much fault-tree work.

By the time the draft study was published in August 1974, Rasmussen and Levine had uncovered something unexpected. While it confirmed that accident consequences would be low, its overall accident probability estimate of one in 17,000 was so high that it broke the spell one-in-a-million held in the regulatory imagination. The major contributors to overall risk came not from a design basis accident or catastrophic vessel failure, but seemingly minor events such as small-break LOCAs, human error, and common-cause events. Despite the flaws in its calculations, WASH-1400's insights found application in NRC regulations after the Three Mile Island accident in 1979.

The significance of WASH-1400 today is quite different than that envisaged by the AEC or its authors. Conceived of as a public relations tool that would confirm what experts thought they already knew about safety, it revealed what they did not know. Making accident risk knowable is PRA's greatest legacy. As Saul Levine wrote in 1982, "It seems that the United States nuclear power community is finally taking to heart the words of Cicero (circa 40 B.C.): 'Probabilities direct the conduct of wise men.'"[15]

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This article reflects the views of the author. It does not represent an official position of the NRC.

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Matthew Denman: On Probabilistic Risk Assessment

Probabilistic risk assessment is a systematic methodology for evaluating risks associated with a complex engineered technology such as nuclear energy. PRA risk is defined in terms of possible detrimental outcomes of an activity or action, and as such, risk is characterized by three quantities: what can go wrong, the likelihood of the problem, and the resulting consequences of the problem.

Matthew Denman is principal engineer for reliability engineering at Kairos Power and the chair of the American Nuclear Society and American Society of Mechanical Engineers Joint Committee on Nuclear Risk Management's Subcommittee of Standards Development. As a college student at the University of Florida, Denman took a course on PRA but didn't enjoy it, because he did not see its connection to the nuclear power industry. Later, during his Ph.D. study at the Massachusetts Institute of Technology, his advisor was Neil Todreas, a well-known thermal hydraulics expert. Todreas was working on a project with George Apostolakis, who would leave MIT to become a commissioner of the Nuclear Regulatory Commission. The project, "Risk Informing the Design of the Sodium-Cooled Fast Reactor," was a multi-university effort funded through a Department of Energy Nuclear Energy Research Initiative (NERI) grant. Todreas and Apostolakis were joined in this project by a who's who of nuclear academia, including Andy Kadak (MIT, ANS past president [1999–2000]), Mike Driscoll (MIT), Mike Golay (MIT), Mike Lineberry (Idaho State University, former ANS treasurer), Rich Denning (Ohio State University), and Tunc Aldemir (Ohio State University).

Denman had started work on his Ph.D. by concentrating on more traditional reactor design concepts, but he was also briefing the "Risk Informing" project team. Because the idea behind the project was to risk inform the design of a sodium reactor, Denman was exposed to risk concepts. He started taking classes on how to use probabilities and risk insights to solve a range of problems. The light went on for Denman, and he realized that PRA wasn't something that was an abstract assessment of a system but was part of an integrated decision-making process. Working on the project and taking those classes changed his view of what could be accomplished with PRA. By the time he finished his Ph.D. work, he knew that PRA was what he wanted to work on.

Denman talked about PRA with Rick Michal, *NN* editor-in-chief.

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Is PRA another name for a safety assessment?

The international community would call it probabilistic safety assessment. The International Atomic Energy Agency's standards are known as PSA instead of PRA. Safety and risk are reciprocal quantities. With safety, it's ensuring that things don't break. With risk, it's asking what happens when they do break. There is a "risk triplet," as it is called, within PRA: What can go wrong? How likely is it? and What are the consequences? With those three in tandem we can assess how concerned or not someone should be about anything in life, whether it is operating a nuclear power plant or driving a car down the road. PRA is predicting the consequences that can happen and how likely they are to happen so that informed decisions can be made.

> **There is a "risk triplet" within PRA: What can go wrong? How likely is it? What are the consequences?**

Does a deterministic safety analysis figure into PRA?

Yes. Imagine an accident where radionuclides are mobilized and leaking out of containment. It must be shown that the dose thresholds that exist at the site boundary and the low population zone boundary are below regulatory allowance. That understanding is very deterministic. There is no frequency of that event, which is just postulated.

By looking at the frequencies and the consequences of events, you can begin to say that perhaps you should not be as concerned about, for example, the occurrence of a large catastrophic rupture in the reactor coolant boundary as you should be about a valve that could get stuck open. In fact, that's one of the first big insights that came out of WASH-1400, which was the first integrated risk study in the 1970s and where it was revealed that the nuclear safety community was focused on large-break loss of coolant accidents (LOCAs), but the risk in plant designs was highest for the smaller-break LOCAs. There are more small pipes in a nuclear power plant than large pipes, and large pipes are not likely to catastrophically fail. The small pipes are more likely to fail, such as from the fittings coming loose because small valves get stuck open.

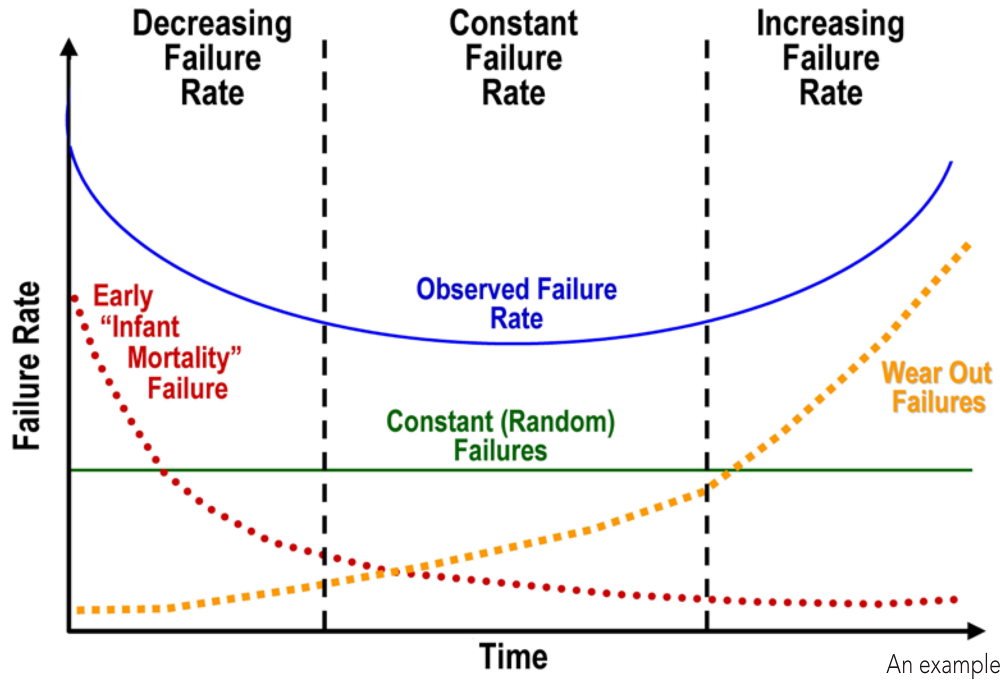
There was a lot of skepticism regarding WASH-1400, but then the Three Mile Island accident happened. TMI was a core damage event caused not by a large-break LOCA but by a small stuck-open-valve LOCA. TMI reinforced what WASH-1400 was saying all along, which was, "If all you're doing is looking at the worst events possible, you might be missing part of the story."

What was needed was something that was going to march systematically through the system and what can go wrong, so that appropriate controls could be applied and time wasn't spent on over-defending against events that were highly unlikely to happen. Resources needed to be devoted to what actually might happen, and that's where PRA came in.

How is probability assigned to a failure?

That's a good question and there is not a single answer. For most parts and components of a nuclear power plant, we have years of operating experience. For many parts, statistics on failures are consulted. Each plant has a database of events at operating light water reactors and at that specific plant. As an example, a type of valve might have cycled a million times and experienced only two "valve stuck open" events. We now are able to say how many failures were experienced over how many trials, and we now have a failure probability for that event.

There are some components for which we don't have failure data, but we have seen significant demands on the component. If you think about the exact same process—for example, there were one million cycles of a valve but there has never been a failure—that is still evidence. There might not have been a failure, but you know that a failure probability exists. How were a million trials performed without a single failure? That is where Bayesian statistics come in. There is a big area of disagreement in the statistical community between the Bayesians and the frequentists on how to interpret probabilities and information. A Bayesian would say that there can be a prior understanding of what this failure would be and then it



An example of a bathtub curve

can be updated with new evidence, which can be considered on a quantitative basis as the subjective and the objective. One way of doing that, if there were no failures but a million trials, is to assume half a failure in one million trials. This concept does not exist in frequentist statistics, where the objective is everything. But for rare events subjective information is often needed to calculate a failure probability.

You could go even further. You could say, "I have a million tests of this type of valve but I have a billion tests of a much wider set of valves, some of which are applicable, and I experienced a couple of failures there." So, you could craft an understanding of general valve failure probabilities from that other source of objective data, which would be updated as new data came in. Bayesian statistical combination of subjective and objective information is a powerful enabler of modern risk assessments.

Is there a chance that there is a "dud" part that fails much earlier than a normal part? What would that do to the PRA calculations?

Yes, you can have a dud. There is a well-known "bathtub curve" where the first part of the curve describes an early mortality rate that is typically higher, because for parts coming off the assembly line, if their tolerances are incorrect, they are more likely to wear out early. And then, continuing on the bathtub curve, there is a low and flat failure rate for most of the parts' lives. And at the other end of the bathtub curve, as the pieces of equipment start to wear out, the failure rate starts to go up—these parts have exceeded their natural lifespan.

If there is a piece of equipment that fails in the early mortality period, two things can happen, and it really depends on how much data you have. If you have enough data that that early failure doesn't influence your bottom-line statistics, or if it does but it's not an important piece of equipment so having a high failure estimate isn't going to hurt you too much in your bottom-line results, you might just lump this data in with everything else and go along your merry way. If you can't live with that piece of data, you might segment up your data set to treat your duds separately. Unfortunately, every time you break up your data set, you have less data to work with within each bin. Say I'm going to split the data set into a bin of early equipment failures and then a bin of everything else and then characterize each bin separately. You might model out early failures into a different basic event that goes into your PRA, or you might document a qualitative argument that says, "Note: this data set doesn't apply to my model because of 'X'—for example, because we do shake-down testing for early failures before putting this part into the plant because we have increased monitoring on it." And thus there would be a more immediate response to failures in the early phase. The arguments can vary from component to component depending on how important the component is. In general, if you have data that you can't live with, you're going to do something to try to limit its effect on the rest

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of the data set while ensuring that the data on your duds are addressed. That's always a balancing act.

What about assessing new technology?

The cutting edge of risk assessment is being pushed on advanced designs where neither the numerator nor the denominator of the failure probability is characterized well. In a situation concerning new technology, there would not be one million trials to use as data. This is where a panel of experts would come in to document all the different things that could fail and to qualitatively assess the failure probabilities, with some simulation data possibly mixed in. Here, your failure probabilities would be dominated by the subjective understanding of the system.

Do plant personnel use PRA to be proactive toward systems?

Yes, it's kind of a watershed thing that's happened over the past 15 or so years. Different plants are more proactive than others, and different utilities embrace PRA more than others. PRAs, for an operating plant, can be used to inform a plant's maintenance intervals. In fact, for a number of plants, every time the maintenance staff is scheduled to do something on plant equipment, there is a pre-job briefing where they do a walk-through of the procedures. They might say something like, "This is our core damage frequency, and these are the components that are the most risk-significant at this point in time in your area of interest. So, don't do anything that could challenge those components while you're doing your routine maintenance activities on other parts of the system." It is impressive how PRA has intertwined itself with the day-to-day operations of nuclear power plants.

> **It is impressive how PRA has intertwined itself with the day-to-day operations of nuclear power plants.**

How does human error play into PRA?

Operators are an integral part of reactor safety. Human error is an integral part of everything. For example, if I'm driving on the highway, the car is much more likely to crash because I was being careless than because the brakes locked up unexpectedly and someone slammed into the rear of my vehicle. Both are possible, but it's much more likely that I'm the cause of the car wreck. It's the same thing at nuclear power plants. Staff at the plants are very well trained, but events do happen. The PRA standards are process standards. They will tell you what to do but not how to do it. The PRA standards have a human reliability section, which has a number of steps to look through—maintenance procedures, historical records, and failures—to identify accident precursors that could exist.

Plant technicians have a certain amount of time to perform an action. Sometimes an action might be to don an anti-contamination suit for protection to travel across the plant and go down three levels to turn a valve to open a flow path to get the water injection working again. The time the technician will take to do all those things is variable. The technician will train and drill on it, and the plant will have data on how long it's going to take to do the job. But there is always a probability that the technician, for any number of reasons, isn't going to be able to achieve the task in the appropriate time. That gets into a human error probability for the technician enacting the procedure as written.

Is there a PRA correlation between the nuclear and airline industries because they are higher-risk industries?

The airline industry uses PRAs. NASA used a lot of PRAs back in the day. In fact, in early risk assessment as the field was starting up, it was NASA and the nuclear industry bouncing ideas and thoughts off each other to advance the technology to move forward. For a full risk assessment, where there are fault trees that are the logical constructs of how a system does or doesn't perform its function, and Venn diagrams that connect all the fault trees in a linear progression as a temporal marching of how an accident progresses—that is reserved for your highly regulated, high-consequence, low-probability systems. A lot of industries employ fault trees as a visual way of representing how failures can propagate up to fail a system.

How does nuclear PRA take into consideration the natural environment?

That happens through a lot of requirements in the PRA standards. The non–light water reactor PRA standard has nine parts, which deal variously with internal events and then external events such as fires, floods, and high winds. The standard considers everything from plumes of sea scallops clogging water intake pipes to forest fires to meteor strikes to airplane impacts. A nuclear plant has to do risk assessments to say what these events would mean for core damage or things of that nature.

Was PRA done for the Fukushima plant?

PRA is applied differently around the world. The United States was the early proponent of PRA in producing risk analysis for our facilities and expanding it to external events. PRAs were done at Fukushima and other sites, but in general, their design was based on deterministic and prescriptive rules for defending against a tsunami-type event. These requirements did identify that external flooding vulnerabilities existed in 2008, but the upgrades to the plant were not implemented in time to prevent the accident. The Japanese nuclear industry is currently doing a lot of work to make their PRAs more robust and expansive to cover different types of external hazards. My understanding is that at the time, the Japanese regulatory structure was focused largely on complying with deterministic requirements.

It is important to recognize that, in a risk-informed framework, PRAs are only a part of the decision-making process. Economics, biases, deterministic safety analyses, performance monitoring, defense in depth—all of that information is combined to make an ultimate decision. For existing plants, for example, simple economic considerations might result in shutdown of a plant in lieu of backfitting new safety requirements.

Is the science of PRA a living science?

Yes, it's a living science. The PRA standards are constantly being revised. The light water reactor PRA standard originally existed as separate—for internal and external—standards within ANS and ASME. Those societies merged these efforts together to form the Joint Committee on Nuclear Risk Management and in 2007 produced the first light water reactor standard that unified internal and external events. That standard was revised in 2011 and then again in 2013, and currently it's being revised again and is going through the editing process. The current revision provides more guidance on external hazards.

ANS's Subcommittee of Standards Development is simultaneously developing standards on advanced light water reactors like the AP1000 and NuScale's small modular reactor. Given the fact that these new designs rely more on inherent safety, passive safety, natural circulation of water and large pools of water, and things of that nature, the PRA standards are revised to be more applicable to those designs.

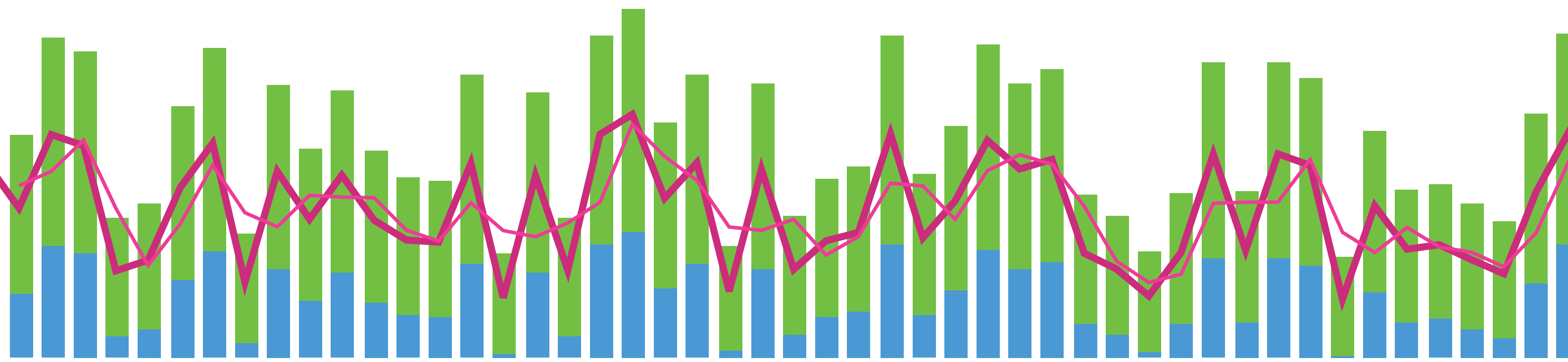
Are there PRAs for various contingencies or possible accidents?

Yes, there are three levels of PRAs plus guidance for various other operating modes and externalities. Level 1 considers failures out to core damage and large releases for all internal and external hazards. The next edition of the Level 1 standard is currently going through copyediting and should be released later this year. Level 2 says, given the fact that there is core damage, how much radiation can get out of the plant? Level 3 says, given what gets released from the plant, what does that mean to an off-site individual? There also is a multiunit PRA standard—which Fukushima highlighted the need for—that looks at having multiple units on a site: When an accident occurs, how do the units interact with each other? There is a low-power and shutdown standard that address the unique configurations of the plants when not at full power. There is an advanced light water reactor PRA standard, which adapts the Level 1 standard to address the AP1000s and NuScale. And then the non–light water reactor PRA standard, published in early 2021, is the first integrated Level 1 through 3 PRA—for all internal and external hazards, all modes (at power and low-power or shutdown), and for multiunit sites. There is a lot of ongoing work on various aspects of PRA and what it means to do PRA.

HELPING TO SOLVE THE

PUZZLE:

AN OVERVIEW OF PROBABILISTIC RISK ASSESSMENT



By Curtis Smith, Andrew Miller, Stephen Hess, and Fernando Ferrante

Probabilistic risk assessments (PRAs) have advanced the safe operation of the U.S. reactor fleet over many decades. Risk insights from PRAs have provided information from many different perspectives, from what is most important to maintain at a facility to a better understanding of how to address new information regarding safety issues. The methods and tools that have supported the creation and enhancement of PRA models were established through multiple decades of research, starting with WASH-1400, *The Reactor Safety Study*,[1] published in 1975, through the comprehensive plant-specific models in use today.

The use of PRA technology has been a critical element in achieving demonstrable improvements in plant safety over time. A recent study[2] by the Nuclear Energy Institute analyzed data from the updates of plant PRA models showing a significant reduction in the average core damage frequency over the previous 30 years of operations. It is notable that these improvements in safety occurred over a time in which the average plant capacity factor increased from about 70 percent to over 90 percent. Further, the risk focus using PRA is an instrumental part of the risk-informed regulatory framework used throughout multiple applications in the United States, including the following:

- Maintenance Rule programs, including plant configuration risk management programs for conducting on line maintenance activities.
- Plant licensing basis changes using a risk-informed approach.
- Ensuring overall baseline plant safety via risk assessment.
- Fire protection programs.
- Risk-managed technical specifications, including completion time and surveillance frequency control programs.
- Programs allowing for alternative regulatory treatments for structures, systems, and components that use a risk-informed categorization process.

Because PRA models are being used to support such a wide array of plant decisions, they are now being applied to analyze an increasing number and diverse set of aspects of the plant, which is well beyond the initial intent envisioned in the 1970s. These demands on PRA methods and tools have led to challenges in further expanding the use of PRAs and have raised the potential for future research into how to address these challenges to ensure continued nuclear safety. In addition to the PRA needs, the domain of computer science has led to advances in computational approaches that may serve to help nuclear power plant PRA applications. These newer technologies have great potential to improve the effectiveness and economics of PRA and are being explored for their potential benefits to the PRA and nuclear power communities.

1. nrc.gov/docs/ML1622/ML16225A002.pdf
2. nei.org/resources/reports-briefs/performance-safety

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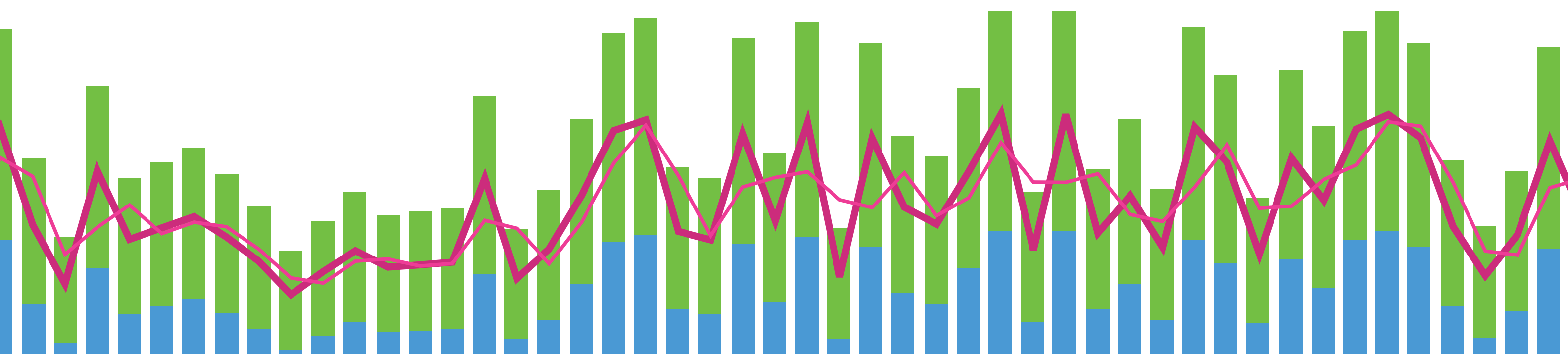


CHALLENGES IN EXPANDING RISK ASSESSMENT AND MANAGEMENT TOOLS

Efforts have been made to reach out to a spectrum of industry PRA users to identify potential issues with the current PRA methods and tools. The intent was to determine which issues were most significant with respect to supporting timely and efficient risk-informed decision-making. Based on the feedback, several challenges were identified that could prevent the further use of risk insights from PRA models based on current PRA practices:

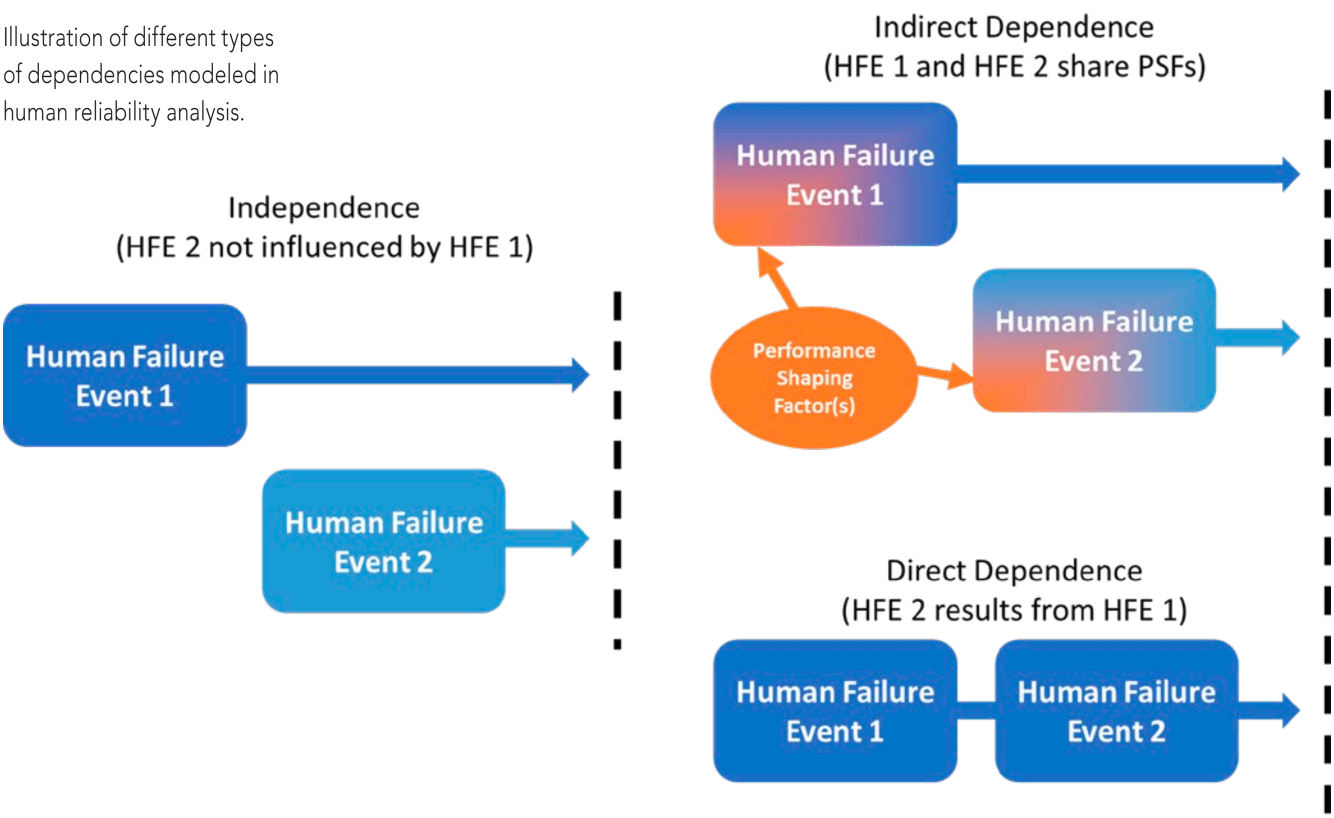
■ **Quantification speed and efficiency.** One of the most cited issues was the fact that current PRA software methods and tools take hours to solve for many models. This stems from the increased complexity and details of the models, requiring greater computing power and memory. An example of this issue is the time required for fire PRA models, which can be as long as several days for quantification. Enhancements to the time it takes to solve PRA models has been a continuing issue over the past two decades, and further improvements are needed.

■ **Dependency analysis.** Another frequently mentioned issue is related to how dependency is represented for human reliability analysis. Typically, in PRA models, multiple human actions may exist in a single scenario representing core damage. However, dependencies may exist between these events, such as the same crew performing multiple actions, or the time needed to perform actions being shared across different activities. The current practice is to create complex relationships in the PRA model to look for these dependencies and then modify the results as needed. Not only are these dependency models complex and difficult to understand, they slow down the analysis, increasing the overall quantification time.

■ **Model development, maintenance, and updates.** The process of managing and updating PRA models is mostly a manual, labor-intensive, and specialized activity, and in many cases, multiple PRA models must be maintained to represent the different risk-informed applications. An automated way of providing, managing, and checking the PRA model would benefit many day-to-day risk-related activities.

■ **Risk aggregation.** Risk aggregation consists of activities combining different elements of the PRA to develop insights and metrics to support decision-making. The aggregation of risk is challenging in terms of

Illustration of different types of dependencies modeled in human reliability analysis.



decision-making (e.g., how to understand the implications of different inputs with different levels of detail, confidence, and uncertainties). With the expansion of PRA models into multiple types of hazards—including internal fire, external flood, pipe breaks, high winds, and seismic events—as well as considering the possible impact of a single hazard (or a combination of hazards) on a site with multiple units and multiple potential sources of radiological release, properly comparing the overall collective risk, and the contribution from individual hazards, can be challenging.

■ **Uncertainty analysis.** One benefit of using risk assessment is the ability to address inherent uncertainties in our state of understanding. Most PRA models include the capability to explicitly incorporate uncertainties considered for failure parameters, including common-cause failure probability, failure rates, and initiating event frequencies. However, most PRAs treat uncertainties related to physical phenomena (success criteria, the margin between success and failure, and the causal mechanisms to failures) in diverse ways via sensitivities, bounding assessments, expert elicitation, and other approaches. Given that uncertainties in physical phenomena may drive uncertainty in current PRAs, improving methods to account for an integrated understanding of the overall contributions is essential.

■ **Communication of risk insights.** Commercial nuclear power plants are complex, and, consequently, their associated PRA models are becoming increasingly complex. In addition, the process of creating, maintaining, and deploying PRA requires a high level of specialized knowledge and experience, limiting the ease of communication behind risk insights and drivers of results. Further, the computer support tools currently used rely on decades-old basic visualization methods and approaches. Communication of the results of PRA models and their implications is essential to permit effective decision-making by a broad array of stakeholders, including plant managers and regulatory authorities. This is particularly critical because many of the intended stakeholders and decision-makers are not experts in the details of PRA methods. As a result, substantial benefits can be obtained by the development of improved methods to display data and results from PRAs. An example of risk communication using visualization from the Nuclear Regulatory Commission's Accident Sequence Precursor Program dashboard[3] is shown below.

3. nrc.gov/about-nrc/regulatory/research/asp.html#dashboard

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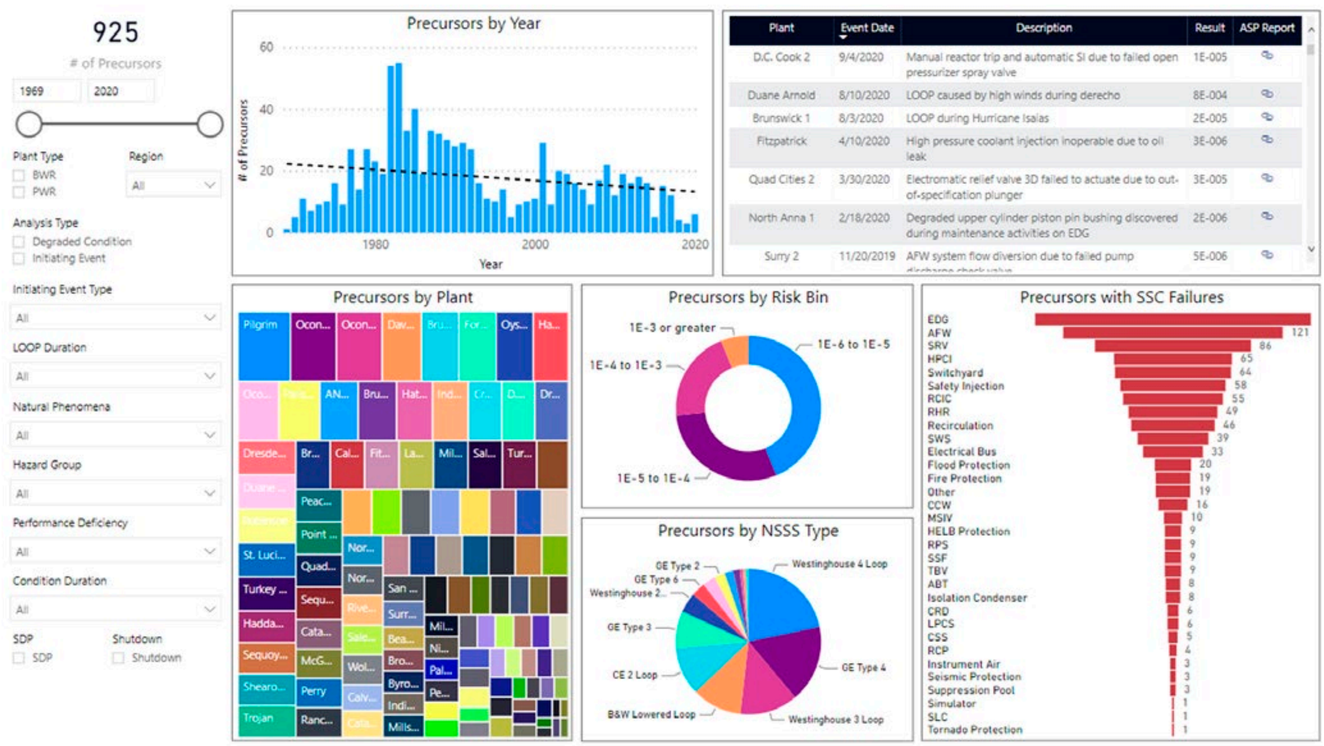


Example communication dashboard showing risk insights from the Nuclear Regulatory Commission's Accident Sequence Precursor Program.

Types of PRAs

Probabilistic risk assessment is a concept, not one tool or method. PRA is a risk assessment approach that relies on quantitative risk modeling, informed by additional qualitative inputs, used to assess the risk of a current design or operation, as well as to identify performance shortfalls.

- **Traditional, classical, or legacy PRAs:** These are PRAs that are based on event trees to define potential accident sequences and probabilities and fault trees to represent the branch points as one follows a sequence through the event tree. The outcome of a traditional PRA for a nuclear power plant is a set of minimal cut sets (i.e., combinations that, if seen, will result in the accident condition being modeled) that reflect ways to experience the condition being analyzed, which for a nuclear power plant typically is core damage and large early release of fission products. The term "safety case" is sometimes confused with PRA. A safety case is a structured approach relying on evidence to argue that a system is safe. While a PRA is not required to be part of a safety case, often the evidence supporting the safety case takes the form of a PRA. It has been shown that using probabilistic approaches can complement deterministic ones, strengthening the overall nuclear safety approach.
- **Dynamic PRAs:** These PRAs are typically created to capture timing information into what is normally a static model. Dynamic PRAs were initially created in the late 1970s and early 1980s and over time have expanded to include physical phenomena in the scenario modeling. Historically, many different approaches have been used to represent dynamic PRA, including the extension of fault trees and event trees with time, graph-based models, Markovian-based approaches, and various simulation techniques.
- **Computational risk assessments (CRAs):** These are simulations that represent the operations, timing, likelihoods, and physics of scenarios. The output of a CRA includes scenario information such as physical parameters (e.g., core temperature and pressure), detailed time histories, margin to failure or success, and the probabilities of experiencing a variety of outcomes ranging from success to failure. Since a rich variety of information can be provided by a CRA, including the physics of an operational facility, it can be used for making a detailed engineering design, supporting a safety case, identifying important physical phenomena, uncertainty quantification, and risk-informed applications.

- **Integration of new technologies and existing models.** Existing PRA approaches rely on a framework that was built using methods mostly developed during the 1970s. As new advanced technologies develop (e.g., use of parallel processing, multi-physics modeling of phenomena, and simulation to capture timing), the integration and acceptance of these advanced methods needs to be considered for enhancing the current state of practice and continuing to foster innovation.

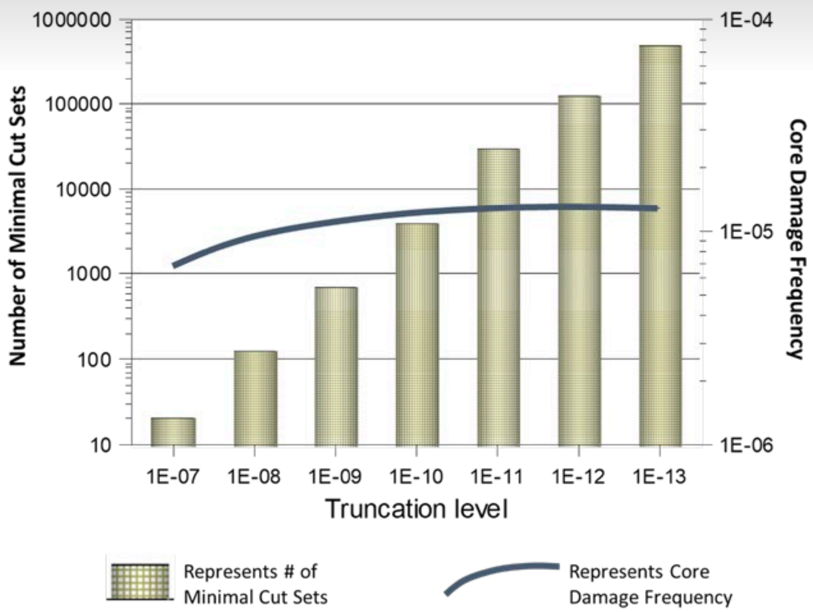
RESEARCH NEEDS AND ROAD MAP

The challenges presented highlight the key areas where research is needed to enhance the technical capabilities and cost-effectiveness of PRA technology. We note that some of the challenges may be difficult to address in the near term (over the next one to two years). Nonetheless, we believe that risk research from the nuclear community can bring about enhancements and solutions to today's challenging PRA issues.

Our research organizations have been collaborating on a prioritized list of issues. Most recently, with support from the Department of Energy's Light Water Reactor Sustainability Program and the Electric Power Research Institute, we have been focusing on three near-term research activities: (1) quantification speed to support decision-making, (2) dependency modeling of human-related basic events, and (3) integration of multi-hazard models.

Quantification speed to support decision-making

PRA quantification speed continues to represent the most significant challenge to more effectively and efficiently using these models to support risk-informed decision-making. Quantification speed affects all aspects of how a PRA can be used, modified, and checked. Thus, the largest benefit to both the PRA community and the nuclear industry can be obtained from research to decrease quantification times while maintaining acceptable levels of accuracy. As an example of the type of complexity seen in nuclear power plant PRAs, see the figure at right, where the number



Representation of a nuclear power plant PRA output in terms of number of core damage combinations and the associated core damage frequency.

of minimal cut sets (i.e., different combinations of ways the plant can experience core damage) grows very large as additional details are captured by lowering the PRA model quantification truncation level to smaller and smaller values wherein combinations are not considered below this frequency level.

There are a few potential options to address quantification speed. One option is to have a tailored, case-specific approach to higher truncation values, thereby decreasing quantification times. Another approach is to develop a better understanding of the details of the PRA structure and its impact on quantification times. A third potential option is to leverage the computer science investment in high-performance computing and advance software development to solve PRA models using new methods.

Dependency modeling of human-related basic events

Human reliability analysis modeling is an accepted and required element in legacy PRAs representing human actions as part of a PRA scenario. However, a significant challenge exists when multiple human actions appear in a single scenario (which occurs frequently). A key question is how these separate events interact dependently through factors such as events occurring close in time or relying on the use of the same plant staff to accomplish multiple required tasks. Current approaches to human reliability analysis focus on manually determining the degree of dependency through the application of simple "if-then" types of rules. This approach is suboptimal, since it may have to rely on conservative assumptions, the rules themselves can become complex, and scrutiny from external reviewers may lead to further conservatism and/or complexity, which may or may not yield additional insights.

Similar to the case of quantification speed research, there are multiple potential solutions to the human dependency issue. For example, one approach may be to create an automated rule-based process to identify and apply dependency factors. Another approach might be to apply machine learning methods to find and apply the dependency factors. A third potential approach might be to move the dependency model directly into the fault or event trees where possible, thereby bypassing the rule-based approach entirely.

Integration of multi-hazard models

Increasingly, multi-hazard models are being developed and used to support plant operational needs. The ability to assess the risk that occurs due to all potential hazards, understand their individual contribution, and recognize what risk insights are most optimal to address is critical to properly implementing risk-informed decision-making. However, the full integration of multi-hazard models can be cumbersome to perform, maintain, and use. In addition, aggregating risk insights into a single output can often lead to additional communication challenges without providing a better understanding of how the individual PRA models have been integrated and what specific component, scenario, or uncertainty is driving the risk. A useful research activity could focus on how to more effectively integrate various hazards into existing PRA models without overly complicating the original model. In addition, this research ties back to the quantification speed issue and associated research, since adding additional elements will increase—sometimes greatly—the overall analysis time.

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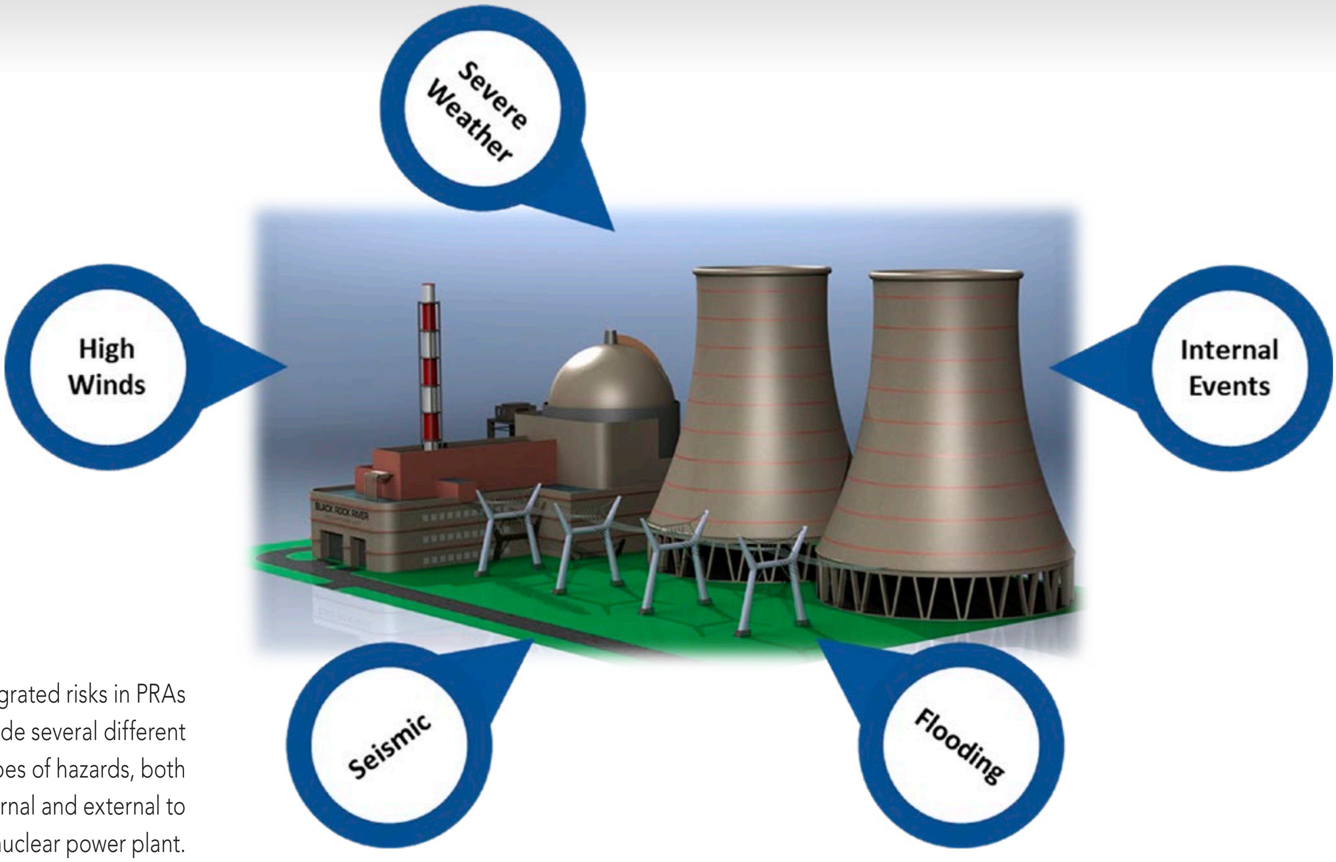

Integrated risks in PRAs include several different types of hazards, both internal and external to the nuclear power plant.

NEXT STEPS

PRA has provided the nuclear industry with an effective tool to manage risks when operating a complex facility such as a nuclear power plant. This process, though, is not without challenges and limitations in terms of continued progress in PRA usage expansion and improvement of risk-informed decision-making. Through feedback from industry practitioners, we have identified and prioritized current issues when developing and using PRAs for risk-informed applications. We are now applying resources to investigate and solve some of the more vexing outstanding issues. As these solutions are created, they will be integrated into current and new PRA approaches used to further strengthen the United States' investment in risk technology while continuing to ensure the safety of the nuclear reactor fleet.

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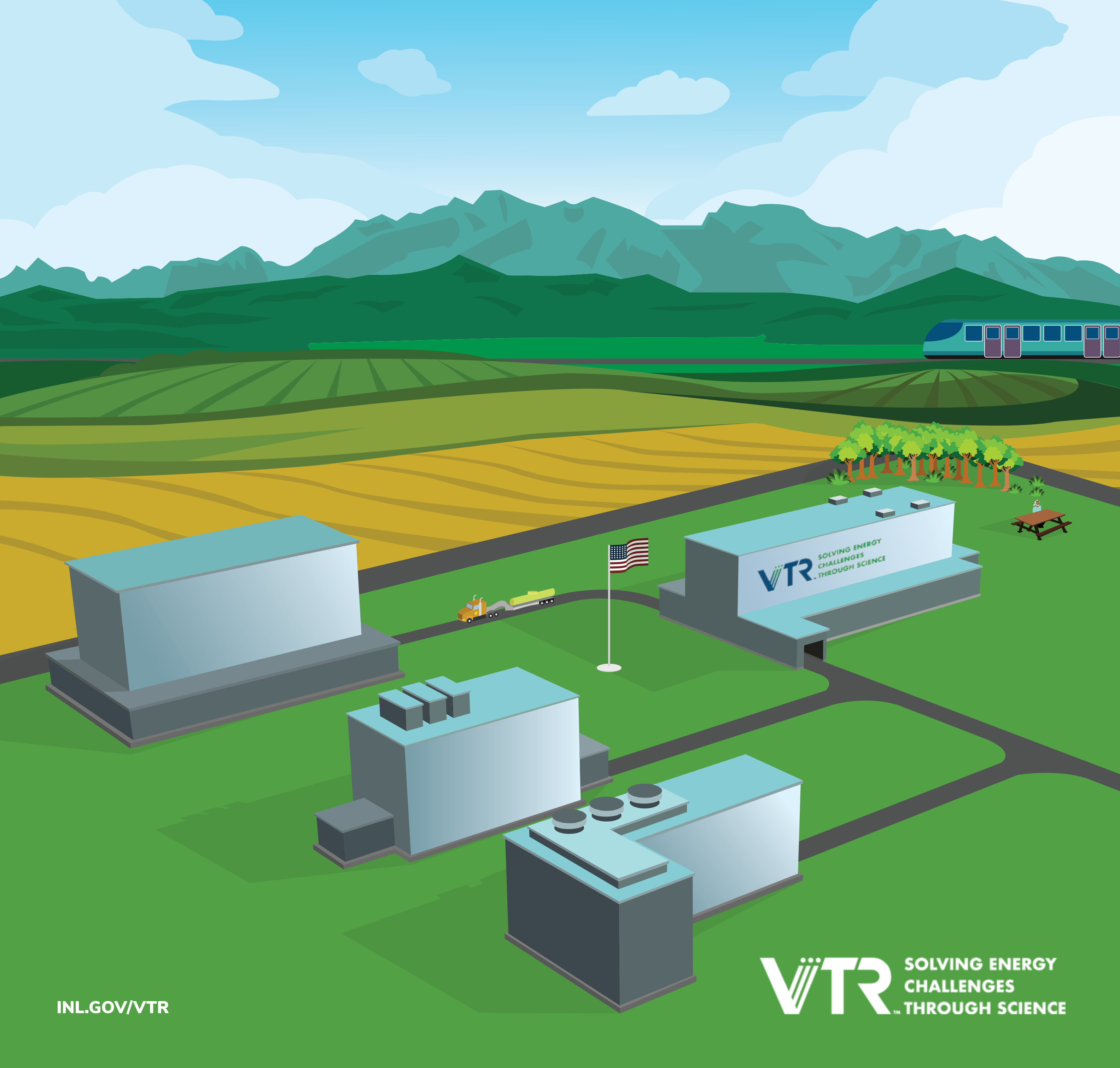

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VTR SOLVING ENERGY CHALLENGES THROUGH SCIENCE

FirstEnergy charged with fraud, accepts $230 million fine

Akron, Ohio–based FirstEnergy Corporation has been charged with wire fraud and has agreed to pay a $230 million monetary penalty over its role in a $61 million corruption and racketeering scheme to secure state subsidies for Ohio's nuclear power plants, Davis-Besse and Perry.

The scheme involved efforts to pass H.B. 6, a bill establishing a seven-year program to charge Ohio's electricity consumers fees to support payments of about $150 million annually to the plants' operator, Energy Harbor Corporation, then a subsidiary of FirstEnergy known as FirstEnergy Solutions. FES had announced in March 2018 that it would be forced to close Davis-Besse and Perry without some form of financial support from the state. Those efforts succeeded, and H.B. 6 was signed into law two years ago, in July 2019.

According to a July 22 media release from the U.S. Attorney's Office for the Southern District of Ohio, FirstEnergy conspired "with public officials and other individuals and entities to pay millions of dollars to public officials in exchange for specific official action for FirstEnergy Corp.'s benefit."

In a statement on its website, the company admitted to the charge, saying, "Central to FirstEnergy Corp.'s effort to influence the legislative process in Ohio was the use of 501(c)(4) corporate entities. FirstEnergy Corp. used the 501(c)(4) corporate form as a mechanism to conceal payments for the benefit of public officials and in return for official action. FirstEnergy Corp. used 501(c)(4) entities in this way because the law does not require disclosure of donors to a 501(c)(4) and there is no ceiling that limits the amount of expenditures that can be paid to a 501(c)(4) entity for the purpose of influencing the legislative process."

The wire fraud charge will be dropped in three years if the company complies with all terms of the deferred prosecution agreement, FirstEnergy said in a separate statement.

The payment of the $230 million fine is to be split equally between the U.S. Treasury and the Ohio Development Service Agency for the benefit of Ohio utility customers. The fine "will not be recovered in rates or charged to customers," according to FirstEnergy.

Above: The Davis-Besse nuclear power plant, owned and operated by Energy Harbor. (Photo: NRC)

The scandal surrounding H.B. 6 erupted in July of last year when federal prosecutors arrested Larry Householder, then speaker of the Ohio House of Representatives, and four associates for taking $61 million from what the criminal complaint termed “Company A entities” in exchange for help in passing H.B. 6 and preventing the bill from being repealed through a ballot initiative organized by its opponents.

Householder and two of those associates, former Republican Party chairman Matt Borges and lobbyist Neil Clark, entered not guilty pleas. The two other associates, lobbyist Juan Cespedes and political strategist Jeff Longstreth, pleaded guilty.

Householder, who is still awaiting trial at this writing, was expelled from the Ohio House in June, while Clark took his own life in March. Also in March, after much legislative dithering, H.B. 6’s nuclear subsidies were repealed.

VOGTLE

Reactor expansion project suffers another setback

Georgia Power on July 29 announced that due to “productivity challenges” and the need for “additional time for testing and quality assurance,” it has revised the schedule for the Vogtle-3 and -4 nuclear expansion project. The new schedule pushes back the Unit 3 in-service date to the second quarter of 2022 and the Unit 4 date to the first quarter of 2023—a three-to-four-month shift for each unit.

The Southern Company subsidiary also said that it has revised the total project capital cost forecast to reflect the new schedule, resulting in a $460 million cost increase to the company.

“[The Vogtle project] remains a critical investment for the state to provide low-cost, reliable, and emissions-free electricity for the state of Georgia for 60 to 80 years,” said Chris Womack, Georgia Power’s chairman, president, and chief executive officer. “This is too important to our customers, our state, and our nation for us not to get it right, and we will.”

According to Womack, the project has “endured extraordinary circumstances during construction,” including, most recently, the COVID-19 pandemic. “Through these challenges,” he said, “we have learned a great deal. Unit 3 hot functional testing has now been successfully completed with no significant issues identified, which is a critical step toward completion.”

In December 2017, the Georgia Public Service Commission (GPSC), in its “Order on the

Georgia Power’s Vogtle Units 3 and 4 in July. (Photo: Georgia Power)

Power & Operations continues

17th Semi-Annual Vogtle Construction Monitoring Report," approved November 2021 and November 2022 as the target in-service dates for Vogtle-3 and -4, respectively. In a filing with the Securities and Exchange Commission in March of this year, however, Georgia Power said that commercial operation at Unit 3 could be delayed by a month or more beyond November 2021. "While [Vogtle plant operator] Southern Nuclear continues to target a November 2021 in-service date for Unit 3, the schedule is challenged and . . . a delay is likely," Georgia Power stated.

That prediction became somewhat more specific in April, when Southern Company's chief executive officer, Tom Fanning, in a first-quarter earnings call, offered a Unit 3 startup target date of late December 2021. That date was revised again the following month, when Georgia Power announced at a GPSC hearing that the startup of Unit 3 would be delayed to January 2022.

And in early June, in testimony filed with the GPSC, Don Grace, vice president of engineering for the Vogtle Monitoring Group, expressed the view that Unit 3 was unlikely to enter commercial operation before the summer of 2022, with Unit 4 not coming on line until the following summer.

OCONEE

First SLR application from Duke docketed

The Nuclear Regulatory Commission has accepted for review the subsequent license renewal application for Duke Energy's Oconee nuclear plant, the agency announced July 28. The utility submitted the application for an additional 20 years of operational life for Oconee on June 7.

Located on Lake Keowee in Seneca, S.C., Oconee is Duke's largest nuclear plant, housing three pressurized water reactors: the 847-MWe Unit 1, 848-MWe Unit 2, and 859-MWe Unit 3.

Duke Energy's Oconee plant in Seneca, S.C. (Photo: Duke Energy)

The NRC approved initial license renewals for the units in May 2000, with Oconee-1 currently licensed to operate through February 6, 2033; Oconee-2 through October 26, 2033; and Unit 3 through July 19, 2034. Subsequent, or second, license renewals would extend those licenses to 2053 and 2054.

An NRC notice regarding the opportunity to petition for an adjudicatory hearing on the SLR review process was published in the July 28 *Federal Register*. The deadline for submitting petitions is September 27. More information on the hearing process is available on the NRC website at nrc.gov.

In September 2019, Duke announced its intent to seek SLRs for its entire nuclear fleet of 11 reactors, with Oconee scheduled to be the first. SLR applications are expected to follow for Brunswick-1 and -2 in Southport, N.C.; Catawba-1 and -2 in York, S.C.; Harris in New Hill, N.C.; McGuire-1 and -2 in Huntersville, N.C.; and Robinson in Hartsville, S.C. Robinson, the oldest reactor in the fleet, could operate until 2050 if its application is approved, while Harris, the last Duke reactor to begin commercial operation, could be licensed to operate into 2066.

CHINA

Taishan-1 taken off line over fuel rod damage

The Taishan nuclear power plant, in China's Guangdong Province. (Photo: EDF Group)

Unit 1 at the Taishan nuclear power plant in China was shut down in late July to examine fuel rod damage and conduct maintenance.

Located in Guangdong Province, Taishan is home to twin 1,660-MWe EPRs, the first two such reactors in the world to enter commercial operation (in December 2018 and September 2019, respectively). The plant is owned and operated by Taishan Nuclear Power JVC (TNPJVC)—a joint venture of China General Nuclear Power Group (CGN); France's EDF Group, which is also the majority owner of Framatome, the Taishan reactors' designer and supplier; and the Guangdong Energy Group.

"At present, a small amount of fuel damage has occurred during the operation of Taishan Nuclear Power Unit 1, but it is still within the allowable range of technical specifications, and the unit can continue to operate stably," CGN stated July 30. "After full communication between Chinese and French technical personnel, [TNPJVC] insists on safety first and conservative decision-making in accordance with nuclear safety regulations and nuclear power plant operating procedures . . . . The unit will be shut down for maintenance, find the cause of fuel damage, and replace the damaged fuel."

Taishan-1 became the subject of a few breathless headlines after an initial June 14 report from CNN suggested the possibility of an "imminent radiological threat" from fuel rod failures. As more factual information became available, it became clear that the issue had been overblown.

On July 22, however, EDF, in a diplomatically worded press release, suggested that the reactor be taken off line. While stating that the radiochemical parameters of the primary circuit water "remain below the regulatory thresholds in force at the Taishan plant, thresholds which are consistent with international practices," EDF said that if the reactor were in France, the company's operating procedures would lead it to "shut down the reactor in order to accurately assess the situation in progress and stop its development. In Taishan, the corresponding decisions belong to TNPJVC."

LEGISLATION

Measure to preserve, expand U.S. nuclear sector reintroduced

Capito

A bipartisan group of senators on July 15 reintroduced the American Nuclear Infrastructure Act (ANIA), initially introduced last fall in the previous Congress. Sponsors include Sens. Shelley Moore Capito (R., W.Va.), the ranking member of the Senate's Environment and Public Works Committee; John Barrasso (R., Wyo.); Cory Booker (D., N.J.); Mike Crapo (R., Idaho); and Sheldon Whitehouse (D., R.I.).

In June, the American Nuclear Society joined 23 other nuclear-focused entities in signing a letter to those lawmakers urging reintroduction of the bill.

The legislation aims to revitalize the U.S. nuclear sector. According to its supporters, ANIA would accomplish the following:

Power & Operations continues

- Empower the Nuclear Regulatory Commission to lead a consensus-building process in international forums to establish regulations for advanced nuclear reactor designs.
- Provide the NRC authority to deny imports of Russian nuclear fuel on national security grounds.
- Create a prize to incentivize the successful licensing process of next-generation nuclear technologies and fuels.
- Require the NRC to identify and resolve regulatory barriers to enable advanced nuclear technologies to reduce industrial emissions.
- Authorize a targeted credit program to preserve nuclear plants at risk of prematurely shutting down.
- Modernize outdated rules that restrict investment in nuclear energy.
- Identify modern manufacturing techniques to build nuclear reactors better, faster, cheaper, and smarter.

"It's important that we continue to position the United States as a global energy leader, and that requires us to take full advantage of all sources of America's energy potential," Capito said in a July 16 statement. "Along with our nation's coal and natural gas resources, nuclear power can provide critical clean and reliable electricity needed to power our homes and businesses. I'm proud to join my colleagues in reintroducing this important legislation that will help preserve and expand our use of nuclear energy, which will create jobs and strengthen our energy and national security."

Companion bills to spur clean energy innovation debut on Capitol Hill

Approximately 40 percent of cumulative carbon dioxide emission reductions needed to meet sustainability targets rely on technologies not yet commercially deployed on a mass-market scale, according to last year's *Special Report on Clean Energy Innovation* from the International Energy Agency.

Intent on lowering that percentage, both the Senate and House in late July introduced bipartisan legislation to rapidly scale up and diversify emerging energy technologies. On July 27, Sens. Mike Crapo (R., Idaho), ranking member of the Senate Finance Committee, and committee member Sheldon Whitehouse (D., R.I.) introduced the Energy Sector Innovation Credit (ESIC) Act, or S. 2475. The credit, according to Crapo's office, is a technology-inclusive, flexible investment tax credit (ITC) or production tax credit (PTC) designed to promote innovation across a range of clean energy technologies, including generation, energy storage, carbon capture, and hydrogen production.

Cosponsors include fellow committee members John Barrasso (R., Wyo.) and Michael Bennet (D., Colo.) and Energy and Natural Resources Committee members Sens. Jim Risch (R., Idaho) and John Hickenlooper (D., Colo.).

Also on July 27, House Ways and Means Committee members Tom Reed (R., N.Y.) and Jimmy Panetta (D., Calif.) introduced the lower chamber's companion bill as H.R. 4720.

"ESIC will advance us toward the goals of energy independence and a clean energy future by ensuring that nuclear, hydrogen, geothermal, and other groundbreaking technologies play a key role in our energy mix," said Risch.

ESIC, according to its backers, would:

- Promote clean energy innovation by allowing up to a 40 percent ITC or 60 percent PTC for low market penetration technologies across a range of energy sources.
- Phase out credits as technologies mature, which provides an on-ramp for the most innovative technologies to get to market and then compete on their own, rather than allowing Congress to pick winners and losers when temporary credits expire.
- Group technologies substantively different from one another as determined by experts at the Department of Energy, national labs, and other stakeholders.
- Provide flexibility for unforeseen clean energy technologies to be eligible for ESIC by including an expedited-consideration provision

In Case You Missed It—Power & Operations

Legislation that would keep California's Diablo Canyon in operation beyond its expected 2025 closure date was introduced on July 9 by Rep. Devin Nunes (R., Calif.). Dubbed the Clean Energy Production Act (H.R. 4394), the bill is cosponsored by the rest of the Golden State's GOP House contingent: Reps. Ken Calvert, Mike Garcia, Darrell Issa, Young Kim, Doug LaMalfa, Kevin McCarthy, Tom McClintock, Jay Obernolte, Michelle Steel, and David G. Valadao.

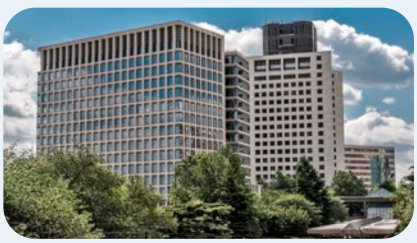

Nunes

"Should California Democrats succeed in wiping out both fossil fuels and nuclear power, Californians will face a bleak energy future of even higher electricity prices and more unreliable energy production," Nunes wrote in a blog post on his website. "That's why today I introduced in Congress the Clean Energy Protection Act, a bill that will require California to issue Diablo Canyon the permits needed to keep nuclear power operating in the state, as well as direct the appropriate federal agencies to issue permits to allow the plant to develop an additional 8,000 megawatts of next-generation nuclear capacity. In short, the bill will stop California from shutting down a crucial source of reliable, clean baseload energy."

Egypt's Nuclear Power Plants Authority has applied to the Egyptian Nuclear and Radiological Regulation Authority for a construction permit to begin building the first two of four proposed Russian-designed and -supplied reactors at Egypt's El Dabaa site. Full-scale construction of Units 1 and 2 will start once the permit is granted, according to a June 30 statement from ASE Rosatom, the engineering division of Rosatom, Russia's state atomic energy corporation.

In a March TV interview, Rosatom's director general, Alexei Likhachev, stated, "The objective for this year is to submit project documentation. We expect the permit in 2022 and the full-scale roll-out of work. I want to note that we have reached agreement and understanding with our Egyptian partners on all the complexities and aspects of this project's implementation."

An NRC staff activity to mull the feasibility of 40-year license renewals has been completed, the agency announced via Facebook and Twitter on July 2. (Currently, the maximum potential operating lifespan for a plant is 80 years: 40 years with the original license, 20 more with an initial license renewal, and another 20 with a second renewal.) The social media statement linked to a June 22 staff memo advising the commission to "discontinue the activity to consider regulatory and other changes to enable license renewal for 40 years." The memo also recommended, however, that the industry be queried periodically "to determine its interest and timing to pursue operation to 100 years, so that the staff can identify the need, and time frame, to initiate the development of guidance documents that would support 100 years of plant operation."


Nuclear Regulatory Commission headquarters. (Photo: NRC)

For in-depth coverage of these stories and more, see ANS's Nuclear Newswire *at ans.org/news.*

Power & Operations continues

for Congress to take up new technology recommendations from the DOE.

The new legislation is supported by a wide array of companies and environmental groups, including the American Public Power Association, the Clean Air Task Force, ClearPath Action, the Nuclear Energy Institute, the Nuclear Innovation Alliance, NuScale Power, Oklo Inc., Third Way, the U.S. Nuclear Industry Council, and Xcel Energy.

CANADA

First major component removed at Bruce-6

Bruce Power has removed the first of eight steam generators from Unit 6 at the Bruce nuclear plant in Ontario, the company announced on July 26. The work was done as part of the facility's major component replacement (MCR) project.

As with the first component, the seven remaining generators, at 320,000 pounds each, are to be lifted out through a port in the reactor building's roof using Mammoet's 1,600-ton-capacity PTC-35 crane, one of the largest such machines in the world.

The unit's replacement generators were fabricated at BWXT Canada's Cambridge, Ontario, location and shipped to the Bruce site in late 2020, according to the announcement.

The vendor responsible for generator removal is the Steam Generator Replacement Team (SGRT), a 50/50 joint venture between Aecon and the Steam Generating Team, itself a partnership between Framatome and United Engineers & Constructors. On July 9, Framatome announced that SGRT had been awarded an approximately C$350 million (about $278 million) contract by Bruce Power to replace the steam generators at Units 3 and 4.


A crane removes the first Bruce-6 steam generator on July 23. (Photo: Bruce Power)

"The steam generator replacement is a major milestone for the Unit 6 MCR and represents years of hard work and collaboration between Bruce Power and our partners like SGRT, BWXT, Mammoet, Nuvia, and the building trades unions," said Mike Rencheck, Bruce Power's president and chief executive officer. "Bruce Power's 'Made in Ontario' nuclear supply chain supports Canada's largest private infrastructure and clean energy project, which injects billions into Ontario's economy and creates and sustains 22,000 high-skilled jobs annually."

In December 2015, Bruce Power reached an agreement with Ontario's Independent Electricity System Operator to advance a long-term investment program aimed at refurbishing the company's nuclear fleet and securing the Bruce plant's operation until 2064.

The plant's life-extension program started in January 2016 and involves the gradual replacement of older systems in Bruce's eight reactor units during regularly scheduled maintenance outages. As part of this effort, Bruce Power began the MCR project in January of last year, with a focus on replacing key reactor components in Units 3–8, including steam generators, pressure tubes, calandria tubes, and feeder tubes.

Nuclear propulsion on the rise as private companies and NASA redefine space travel

Above: Hot-fire test at Blue Origin's West Texas launch facility in July 2019. (Photo: Blue Origin)

As NASA invests in nuclear propulsion research and development to stretch the limits of U.S. space missions, private companies Virgin Galactic and Blue Origin are stretching the definition of "astronaut" and proving they can offer a high-altitude thrill to paying customers.

NASA and the Department of Energy are working together to support the development of nuclear thermal propulsion, which offers more propellant efficiency than conventional chemical rockets and could enable faster and more robust space missions.

The DOE's Idaho National Laboratory announced July 13 that it is awarding 12-month, $5 million contracts to three companies leading design teams. The contracts go to BWX Technologies of Lynchburg, Va., partnered with Lockheed Martin; General Atomics Electromagnetic Systems of San Diego, Calif., partnered with X-energy and Aerojet Rocketdyne; and Ultra Safe Nuclear Technologies of Seattle, Wash., partnered with Ultra Safe Nuclear Corporation, Blue Origin, GE Hitachi Nuclear Energy, General Electric Research, Framatome, and Materion.

While all three potential reactor designs are fueled by high-assay low-enriched uranium (HALEU), they use different strategies to reach the specified performance requirements that could transport crew and cargo missions to Mars and science missions to the outer solar system. At the end of the contracted 12-month performance period, INL will conduct design reviews of the reactor concepts and provide recommendations to NASA to guide future technology design and development efforts.

"INL is excited to enable the development of nuclear propulsion technology for potential use by

NASA in future space exploration," said Stephen Johnson, national technical director for space nuclear power and director of the Space Nuclear Power and Isotope Technologies Division at INL. "Our national laboratories, working in partnership with industry, bring unparalleled expertise and capabilities to assist NASA in solving highly complex challenges that come with nuclear power and propulsion."

NASA is also developing a fission surface power system for use on the moon and Mars and plans to once again partner with the DOE and INL to release a request for proposals that asks industry for preliminary designs of a 10-kW class system that NASA could demonstrate on the lunar surface. According to NASA, work on fission surface power can also aid in the development of nuclear electric propulsion systems, another candidate propulsion technology for distant space missions.

The Department of Defense is interested in space transportation closer to planet Earth. In April, the Pentagon's Defense Advanced Research Projects Agency (DARPA) awarded contracts for work on the first phase of a program known as the Demonstration Rocket for Agile Cislunar Operations, or DRACO, that is aimed at demonstrating a nuclear thermal propulsion system above low Earth orbit by 2025, and some of the companies recently selected for NASA's reactor design program also got the nod from the DOD. Following a competitive solicitation process, DARPA awarded a contract to General Atomics Electromagnetic Systems for the design of the nuclear reactor that will power DRACO, while Blue Origin and Lockheed Martin are working on a parallel track to design a spacecraft tailor-made to demonstrate the nuclear thermal propulsion system.

Blue Origin, participating in both the NASA and the DARPA contracts, is one of two companies—Virgin Galactic is the other—that successfully sent passengers on a brief trip to space and back in July. As the potential for commercial travel to space—or at least suborbital space—is proven feasible, it is prompting some to ask who should be considered an astronaut. The Federal Aviation Administration, the U.S. military, and NASA all have different definitions of "astronaut," which generally exclude those who are not employees performing a task on board.

Nonetheless, Blue Origin and Virgin Galactic are betting that customers will pay for the privilege of calling themselves astronauts. A Blue Origin press release called the four passengers on its successful July 20 launch "commercial astronauts," while Virgin Galactic invites the public to "take the leap with us as we get one step closer to filling the world with astronauts."

REACTOR PHYSICS

Mapping the scattered family tree of fission neutrons

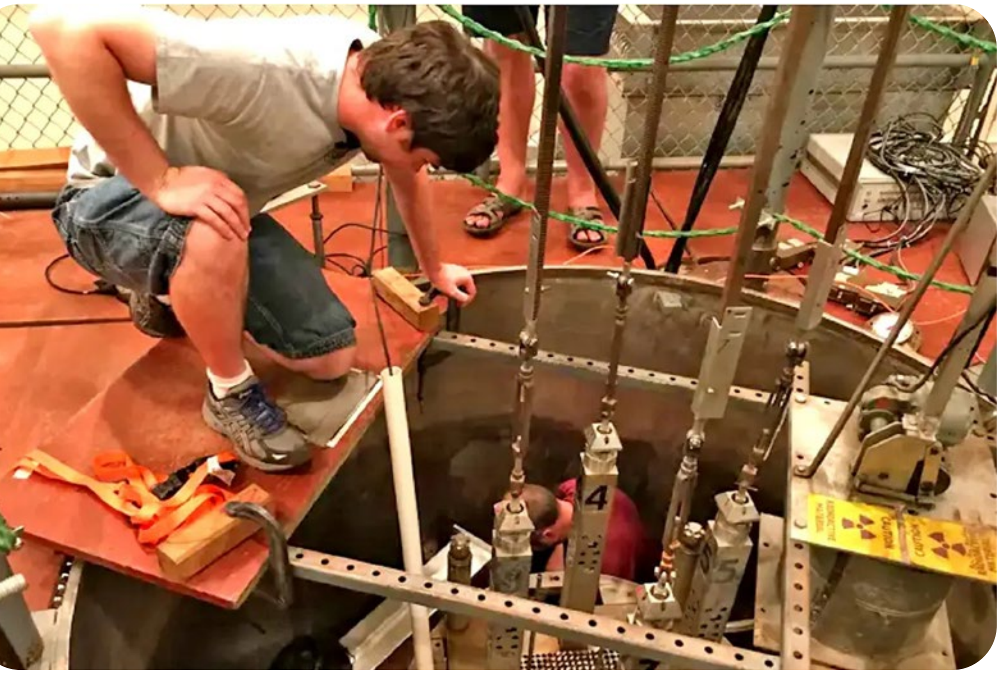
A statistically predicted tendency for neutrons produced inside fission reactors to form in clusters can cause asymmetrical energy production that is counterbalanced, at least in part, by the spontaneous fission of radioactive material in the reactor.

This neutron-clustering effect theory has been demonstrated in a nuclear reactor for the first time and was described in an article published by Los Alamos National Laboratory on July 12. The findings of a study supported by the Department of Energy's Nuclear Criticality Safety Program, funded through the National Nuclear Security Administration, and carried out in collaboration with two French nuclear agencies—the Institute for Radiological Protection and Nuclear Safety (IRSN) and the Atomic Energy Commission (CEA)—could improve reactor safety and lead to more accurate simulations, according to LANL. The team's conclusions were recently published in the journal *Nature Communications Physics* in an article titled "Patchy nuclear chain reactions."

"The neutron-clustering phenomenon had

Research & Applications continues

been theorized for years, but it had never been analyzed in a working reactor," says Nicholas Thompson, an engineer with LANL's Advanced Nuclear Technology Group. "The findings indicate that, as neutrons fission and create more neutrons, some go on to form large lineages of clusters while others quickly die off, resulting in so-called power tilts, or asymmetrical energy production."



Nicholas Thompson of LANL helps set up the neutron clustering measurements at the Walthousen Reactor Critical Facility at Rensselaer Polytechnic Institute in Schenectady, NY. (Photo: LANL)

A statistical concept known as the gambler's ruin, believed to have been derived centuries ago by French mathematician Blaise Pascal, suggests that even if the chances of a gambler winning or losing each individual bet are 50 percent, the chance that the gambler will eventually go bankrupt is 100 percent. The concept has been demonstrated repeatedly in the life sciences in contexts including the spread of epidemics and the growth of bacteria on petri dishes.

Each neutron produced through a fission chain reaction in a nuclear reactor can be said to have a similar 50 percent chance of dying or fissioning to create more neutrons, according to LANL. According to the gambler's ruin concept, the neutrons in a reactor would have the statistical chance of dying off completely in a future generation, stopping the chain reaction and leading to an unexpected reactor shutdown. The risk of asymmetrical energy production from neutron clustering effects leading to an unplanned scram is increased during reactor startup.

To understand the extent to which the gambler's ruin concept holds true for neutrons in nuclear reactors, the researchers collected data over the course of a week in August 2017 at the low-power Walthousen Reactor Critical Facility at Rensselaer Polytechnic Institute in New York. According to LANL, the team used three different neutron detectors, including the Los Alamos–developed Neutron Multiplicity ^{3}He Array Detector (NoMAD), to trace interactions inside the reactor.

"We were able to model the life of each neutron in the nuclear reactor, basically building a family tree for each," said Thompson. "What we saw is that even if the reactor is perfectly critical, so the number of fissions from one generation to the next is even, there can be bursts of clusters that form and others that quickly die off."

The team found that a complete die-off was avoided in the small reactor because spontaneous fission—nuclear splitting of radioactive material inside reactors that is not caused by direct impact from a fission neutron—creates more neutrons. The balance of fission chain reactions and spontaneous fission lessens the impact of energy bursts created by clustering neutrons.

"Commercial-sized nuclear reactors don't depend on the neutron population alone to reach criticality, because they have other interventions like temperature and control rod settings," according to Jesson Hutchinson, of LANL's Advanced Nuclear Technology Group. "But this test was interested in answering fundamental questions about neutron behavior in reactors, and the results will have an impact on the math we use to simulate reactors and could even affect future design and safety procedures."

First concrete pour for the research reactor begins at a Bolivian nuclear research center. (Photo: Rosatom)

INTERNATIONAL

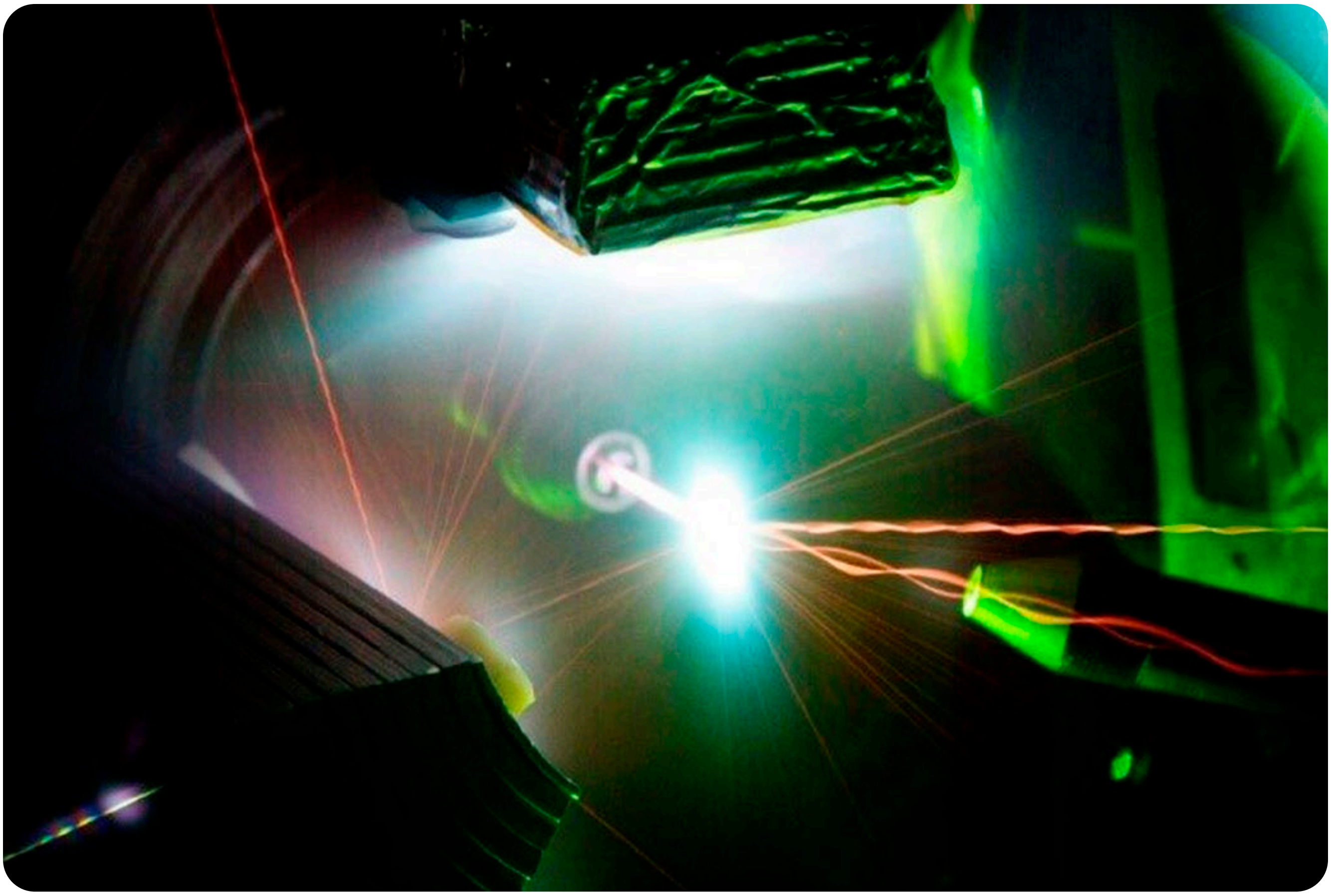
First concrete poured for Bolivian research reactor

Key facilities at a multipurpose nuclear research center in the high plains of Bolivia are nearing operation, and a ceremonial first concrete pour for the nuclear research reactor that will serve as the centerpiece of the project was held on July 26. Bolivian president Luis Arce attended the ceremony at the Center for Nuclear Technology Research and Development (CNTRD). Also attending were Kirill Komarov, first deputy director general for corporate development and international business at Rosatom (Russia's state atomic energy agency), and authorities from the Ministry of Hydrocarbons and Energies and the Bolivian Nuclear Energy Agency (ABEN).

El Alto in Bolivia is one of the highest-altitude major cities in the world, with a population that approaches 1 million. Located in the arid high plains just west of the Andes Mountains, the city sits near Bolivia's government center of La Paz at about 4,000 meters (13,123 feet) above sea level. Its research reactor will be the highest-altitude nuclear facility, according to Rosatom, which is cooperating with ABEN through JSC GSPI (managed by Rusatom Overseas) to construct the facility.

The Cyclotron Radiopharmacy Preclinical Complex and the Multipurpose Irradiation Center represent the first and second phases of construction at the CNTRD and are to be commissioned in the next few months. The deadline for commissioning all facilities at the research center, including the reactor complex, is set for 2024, according to Rosatom. The CNTRD will be used for scientific research and to produce radiopharmaceuticals, enabling more than 5,000 diagnostic and therapeutic procedures for cancer treatment each year. The center will also be used to irradiate agricultural and food products to ensure their safety and extend their shelf life and to sterilize various medical devices.

Research & Applications continues



Invisible infrared light from the 200-trillion-watt Trident Laser at Los Alamos National Laboratory interacts with a 1-micrometer thick foil target (in the center of the photo) to generate a high-energy-density plasma. (Photo: Joseph Cowan and Kirk Flippo, LANL)

PLASMA PHYSICS

DOE puts $9.35 million toward high-energy-density plasma research

The Department of Energy's Office of Science (DOE-SC) and the National Nuclear Security Administration (NNSA) on July 27 announced $9.35 million for 21 research projects in high-energy-density laboratory plasmas. High-energy-density (HED) plasma research, originally developed to support the U.S. nuclear weapons program, has applications in astrophysics, fusion power plant development, medicine, nuclear and particle physics, and radioisotope production.

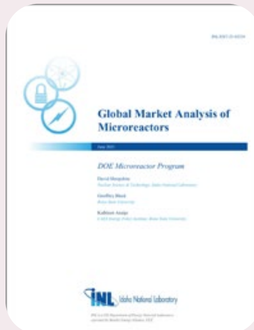
While ordinary plasmas are one of the four basic states of matter, along with solids, gases, and liquids, HED plasmas are an exotic state of matter that may, for example, simultaneously behave like a solid and a gas. To create and study HED plasmas, researchers compress materials in solid or liquid form or bombard them with high-energy particles or photons.

U.S. HED research is managed by the NNSA and the DOE-SC Fusion Energy Sciences (FES) program. The Joint Program in High-Energy Density Laboratory Plasmas, established by the DOE-SC and the NNSA, coordinated the selection of research projects. Total funding includes $7.95 million in fiscal year 2021 for research projects of up to three years' duration, with $1.4 million in out-year funding contingent on congressional appropriations.

Funded research will investigate the physics of magnetic reconnection that drives flares in stars and accelerates particles in astrophysical jets, explore the physical properties of plasmas with applications in fusion energy and planetary sciences, enable novel accelerators, and lead to innovative technologies.

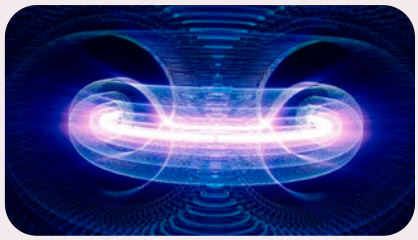
Awards have been made to researchers from Colorado State University, Cornell University,

In Case You Missed It—Research & Applications



Microreactors have "significant potential" for global deployment, concluded a 147-page technical report from Idaho National Laboratory, *Global Market Analysis of Microreactors*, that also identifies "significant challenges in achieving the technical capacities, meeting regulatory requirements and international accords, achieving competitive costs, and for gaining public acceptance." The report authors assessed the unique capabilities of microreactors and their potential deployment in specific global markets in the 2030–2050 timeframe.

Basic fusion research is accelerating with funds from the DOE, which has named seven companies as the recipients of cost-shared funding granted through the Innovation Network for Fusion Energy (INFUSE), a program established in 2019 by the Office of Fusion Energy Sciences, within the Department of Energy's Office of Science. A total of $2.1 million in first-round fiscal year 2021 funding was awarded on July 1 across nine collaborative projects between DOE national laboratories and private industry aimed at overcoming challenges in fusion energy development. INFUSE supports challenging research in five topical areas: enabling technologies; materials science; plasma diagnostics; theory and simulation, including artificial intelligence; and research requiring unique DOE experimental facilities.



Isotopic analysis is being used to ID fraudulent truffles—rare and expensive edible fungi that can demand a premium price based on their origin. Thanks to techniques developed by scientists from the Jožef Stefan Institute in Slovenia, with technical advice and analytical support from the International Atomic Energy Agency and the Food and Agriculture Organization of the United Nations, laboratories worldwide can test truffles, establish their geographical origin, and verify whether they are being accurately marketed. The researchers have created a database of naturally occurring stable isotope ratios of hydrogen, carbon, nitrogen, oxygen, sulfur, and strontium, as well as the elemental and isotopic composition of Slovenian truffle samples from a range of geographical, geological, and climatic origins.

European white truffles may be the most expensive food on earth per kilogram. (Photo: Evan Sung)

For in-depth coverage of these stories and more, see ANS's Nuclear Newswire *at ans.org/news.*

Research & Applications continues

Johns Hopkins University, the Massachusetts Institute of Technology, Ohio State University, Polymath Research, Princeton University, Prism Computational Sciences, the University of California–Berkeley, the University of California–San Diego, the University of Michigan, the University of Nevada–Reno, the University of Texas–Austin, and the Virginia Polytechnic Institute and State University. Some of the listed institutions received multiple awards.

NUCLEAR PHYSICS

Radioactive molecules could probe origins of the universe

Physicists from the Massachusetts Institute of Technology and other institutions have measured the effect of a single neutron in a molecule of radium monofluoride and hypothesize that radioactive molecules could be used as a tool to explore why there is more matter than antimatter in the universe. The research team's findings were published in the journal *Physical Review Letters* on July 7, and on the same day, an article published online by *MIT News* explained the implications of their work.

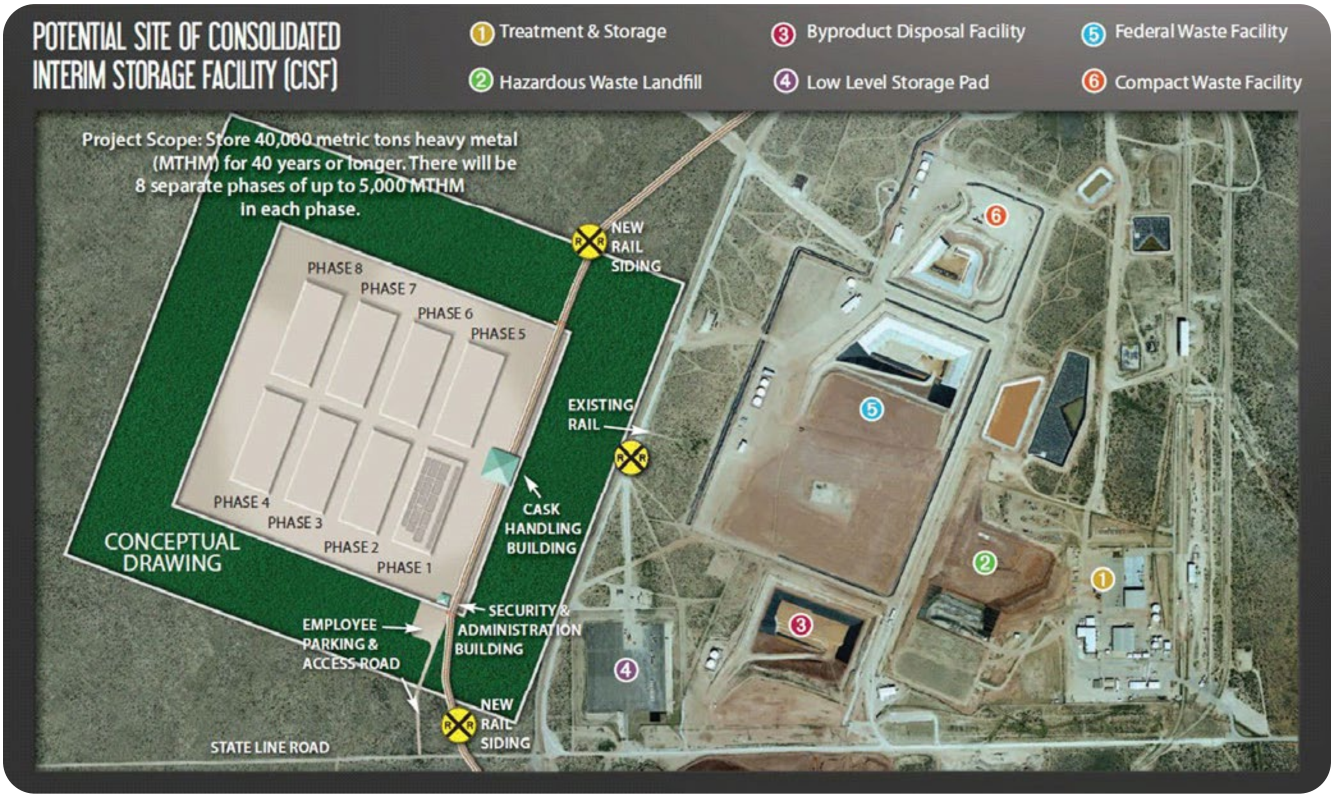
Ronald Fernando Garcia Ruiz, an assistant professor of physics at MIT, has worked with colleagues to refine techniques to create radioactive molecules and study their properties. Last year, Garcia Ruiz and his colleagues reported on a method to produce molecules of radium monofluoride, or RaF, a radioactive molecule that contains one unstable radium atom and a fluoride atom.

In their new study, the team used similar techniques to produce RaF isotopes and measured each molecule's mass to estimate the number of neutrons in its nucleus. They then sorted the molecules by isotopes, according to their neutron numbers.

When they measured each molecule's energy, they were able to detect small, nearly imperceptible changes due to a single neutron one-millionth the size of the entire molecule. The detection of such small effects is expected to lead to a search for even subtler effects caused by dark matter or by symmetry violations related to unanswered questions about the origins of the universe.

Unlike most atoms in nature, which have spherical nuclei, atomic nuclei in certain radioactive elements (including radium) are pear-shaped, with an uneven distribution of neutrons and protons. Physicists hypothesize that this shape distortion could enhance the violation of symmetries that produced matter in the universe.

"If the laws of physics are symmetrical, as we think they are, then the Big Bang should have created matter and antimatter in the same amount," Garcia Ruiz said. "The fact that most of what we see is matter, and there is only about one part per billon of antimatter, means there is a violation of the most fundamental symmetries of physics, in a way that we can't explain with all that we know. Now we have a chance to measure these symmetry violations, using these heavy radioactive molecules, which have extreme sensitivity to nuclear phenomena that we cannot see in other molecules in nature. That could provide answers to one of the main mysteries of how the universe was created."



NRC releases final EIS for Texas spent fuel storage facility

Above: ISP's proposed interim storage site for commercial spent nuclear fuel. (Image: NRC)

The Nuclear Regulatory Commission has issued its final environmental impact statement on an application by Interim Storage Partners for a license to construct and operate a consolidated interim storage facility for spent nuclear fuel in Andrews County, Texas. After considering the environmental impacts of the proposed action, the NRC announced on July 29 that its staff has recommended granting the proposed license.

Interim Storage Partners is a joint venture of Waste Control Specialists and Orano CIS, a subsidiary of Orano USA. If granted, the license would authorize ISP to construct a facility to store up to 5,000 metric tons of spent commercial nuclear fuel, as well as greater-than-Class C waste, for a period of 40 years. ISP plans to expand the facility to a total capacity of 40,000 metric tons of spent fuel. The facility would be built adjacent to Waste Control Specialists' low-level radioactive waste disposal facility.

The NRC published a draft EIS on the project in May 2020. Agency staff held four public meetings by webinar to present the draft findings and receive public comments. They received and evaluated about 2,500 unique comments submitted by nearly 10,600 members of the public.

The NRC will provide the final EIS to the Environmental Protection Agency for filing. Once the EPA publishes in the *Federal Register* a notice that it has received the document, the NRC must wait at least 30 days before issuing a licensing decision. When it announces its licensing decision, the NRC will also publish its final safety evaluation report detailing its technical review of the ISP application.

Additional information about the NRC staff's review of the ISP application is available on the NRC website at nrc.gov.

Decision on Holtec CISF delayed to 2022

The Nuclear Regulatory Commission plans to complete its safety review of Holtec International's proposed HI-STORE consolidated interim storage facility by January 2022. A final licensing decision on the facility will be made in conjunction with the release of the agency's final safety evaluation report, the NRC said in a July 2 letter to Holtec.

The NRC has also revised its schedule for completing its environmental review, with a final environmental impact statement to be published by November of this year. The agency had previously said that the final EIS would be released by July.

In 2017, Holtec submitted to the NRC an application for a license to build and operate an interim storage facility for spent nuclear fuel and high-level radioactive waste in Lea County, N.M. The license application seeks NRC approval to store up to 8,680 metric tons of spent fuel for a 40-year license term.

The NRC said the delay in completing its environmental and safety reviews of Holtec's application is the result of the time the agency staff needs to process requests made to Holtec for additional information regarding the application. Holtec has said it will respond by August 30 to the staff's latest request for additional information (RAI), issued on May 20.

The NRC staff's current schedule for completing its review is dependent on Holtec's responses to its RAIs.

"The staff's schedule assumes that Holtec will provide timely and high-quality responses to all outstanding RAIs, and that no follow-up RAIs will be necessary," the NRC letter states. "If additional RAIs are necessary, the staff will appropriately consider whether to further delay its schedule or to suspend its review."

SPENT NUCLEAR FUEL

Holtec steps up its production of HI-STAR casks

Holtec International is increasing the production of its HI-STAR casks for storing and transporting spent nuclear fuel following recent regulatory approvals and new orders in Europe.

In July, the company was awarded a contract by Spain's waste management organization Enresa for 10 HI-STAR 150 casks, and Holtec is currently in the advanced stages of production of two HI-STAR 180D casks destined for the Doel nuclear power plant in Belgium, with additional orders pending. The casks are being produced at Holtec's manufacturing facilities in New Jersey, Pennsylvania, and Ohio.

Enresa initially awarded Holtec a contract in 2017 for the design, engineering, licensing, and manufacturing of five HI-STAR 150 casks for the Cofrentes nuclear power plant near Valencia. The Spanish Nuclear Safety Council signed off on the HI-STAR 150 design for storage in April of this year, and on May 23, Spain's Ministry of Ecological Transition and the Demographic Challenge granted a license for the cask, which is designed to store up to 52 boiling water reactor spent fuel assemblies, including damaged fuel assemblies.

Waste Management continues

A Holtec HI-STAR 150 cask is placed into storage at Cofrentes in Spain on June 23. (Photo: Holtec)

The first HI-STAR 150 was loaded at the Cofrentes plant and placed into the storage facility on June 23. This was Holtec's first dual-purpose metal cask loaded in Europe.

On June 18, after a lengthy review process, Belgium's Federal Agency for Nuclear Control (FANC) approved Holtec's HI-STAR 180D for transportation, making it Holtec's first dual-purpose storage and transportation cask (with no internal canister) licensed for transport in Europe. The HI-STAR 180D is the sister cask to Holtec's HI-STAR 180 cask, which was first approved for transportation in 2009 by the Nuclear Regulatory Commission.

According to Holtec, the first HI-STAR 180D is expected to be loaded at Doel next year after authorization from Bel-V, the subsidiary of FANC with regulatory oversight for storage. Bel-V has already completed its review of the cask, Holtec said.

In addition to the five HI-STAR 150 casks delivered to Spain, Holtec said that it delivered 14 HI-STAR 100 casks to South Africa and three HI-STAR 190 casks to Ukraine, with seven HI-STAR 100MB casks now destined for China.

LOS ALAMOS

Waste management at PF-4 a continuing challenge, DNFSB says

The Defense Nuclear Facility Safety Board, which provides independent federal oversight of Department of Energy weapons facilities, has reported that low-level radioactive and other combustible waste is accumulating in the basement of Los Alamos National Laboratory's Plutonium Facility (PF-4), and that housekeeping and waste management in the PF-4 basement have been a continuing challenge.

In a June 18 inspection report, the DNFSB noted that the increased pace of work to support plutonium pit production has correspondingly increased the amount of waste generated at PF-4. The DOE's National Nuclear Security Administration, which is required by Congress to have the capacity to produce 80 new plutonium pits per year by 2030, has been undertaking work to improve the equipment and capabilities of PF-4, including adding upgraded glove boxes.

LANL is expected to produce 30 plutonium pits each year, while the remaining 50 will be made at the DOE's Savannah River Site in South Carolina. The new pits are intended to replace the aging cores of nuclear weapons.

According to the DNFSB report, which was made public on July 9, a board inspector found numerous plastic bags filled with garbage accumulating in the PF-4 basement. “Of note, several undated plastic bags filled with cardboard-framed air filters have been staged for the past month,” the report states. “An informal marking on one bag notes that these filters have no waste acceptance form and are of questionable provenance. There is also no transient combustible permit associated with the bags.”

LANL’s PF-4 is the only fully operational, full capability plutonium facility in the nation. Facing problems with its criticality safety program, however, lab officials temporarily paused some work at the facility in 2013. A review of Los Alamos’s safety program conducted that year by the DNFSB found that the program did not comply with DOE requirements or industry standards. The DNFSB review also identified criticality safety concerns “stemming from weaknesses in conduct of operations” at PF-4.

The Plutonium Facility at Los Alamos National Laboratory. (Photo: LANL)

Waste Management continues

In June 2020, 15 workers at PF-4 were evaluated for Pu-238 exposure when a damaged glove box glove set off a continuous air monitor alarm. The glove box was due to be replaced the following day, according to the *Los Alamos Reporter*.

The DNFSB acknowledged that facility management does have a plan for improving housekeeping in PF-4's basement. "On a positive note, during the last plant inventory, the amount of combustible waste in the basement was significantly lower than normally observed," the DNFSB report said.

SAVANNAH RIVER SITE

DOE doubles pace to process its surplus plutonium

The Department of Energy's Office of Environmental Management has doubled the number of work shifts for employees in glove box operations at its Savannah River Site in South Carolina. The increased work pace will help the department meet its commitment to South Carolina to remove surplus plutonium from the state, the DOE said.

"Moving from two- to four-shift glove box operations increases our plutonium downblending rates through our existing glove box," said Maxwell Smith, K Area deputy operations manager for SRS management and operations contractor Savannah River Nuclear Solutions (SRNS).

SRNS put together a team of 48 operators and support personnel needed to fill the four shifts and is managing a pipeline program of 10 employees to fill positions as needed from attrition, Smith said.

The DOE was legally required to remove 9.5 metric tons of plutonium from South Carolina by January 1, 2022. In September 2020, however, the DOE reached an agreement with the state, extending the deadline to 2037. The DOE required more time to remove the material after the cancellation of the Mixed Oxide Fuel Fabrication Facility in 2018 in favor of using a "dilute and dispose" method of managing the plutonium.

A view of Savannah River's K Area Complex, where plutonium downblending operations take place. (Photo: DOE)

According to the DOE, moving to four shifts is part of a plan to increase the efficiency of Savannah River's K Area Complex. Last year, workers improved the K Area Interim Surveillance glove box, where downblending currently occurs.

Workers also recently completed construction of a storage and shipping pad for interim storage of downblended materials before they are shipped out of South Carolina for permanent disposal at the DOE's Waste Isolation Pilot Plant in New Mexico. The DOE said the first shipment is planned for March 2022.

In Case You Missed It—Waste Management

A bipartisan House caucus to tackle the stranded spent fuel issue has been formed by Reps. Mike Levin (D., Calif.) and Rodney Davis (R., Ill.). According to Levin and Davis, the Spent Nuclear Fuel Solutions Caucus seeks to address the challenges associated with stranded commercial spent fuel across the country and serve as a forum where House members can come together to make headway on the issue, regardless of whether or not they have a preferred solution.

In announcing the formation of the caucus on July 21, Levin and Davis said that the current system of spent nuclear fuel storage is not sustainable, particularly for sites that no longer have operating reactors and could be redeveloped for other beneficial uses.


Levin


Davis

Other members of the Spent Nuclear Fuel Solutions Caucus include Reps. Sara Jacobs (D., Calif.), Michelle Steel (R., Calif.), Scott Peters (D., Calif.), Jared Huffman (D., Calif.), Chellie Pingree (D., Maine), Salud Carbajal (D., Calif.), Mondaire Jones (D., N.Y.), and Suzanne Bonamici (D., Ore.).

Decommissioning of the Fort Greely reactor in Alaska is set to begin in 2022, according to the U.S. Army Corps of Engineers, which said it expects to release a request for proposals soliciting contractor bids for the decommissioning of Fort Greely's mothballed SM-1A nuclear power reactor this year. The decommissioning and dismantlement project is expected to take six years to complete.

Col. John Litz of the USACE Baltimore District examines the containment vessel door of the SM-1A deactivated nuclear power plant during a site visit in April 2019.

The USACE issued a final environmental assessment and finding of no significant impact for the SM-1A decommissioning on June 28, which was officially finalized on July 28 after a 30-day waiting period.

A public review period was held between February 26 and March 28, and comments received during that time are addressed in the final documents. The USACE intends to decommission the deactivated plant site to a level that will allow it to be released for unrestricted use.

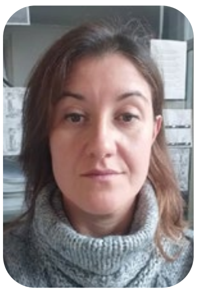
SM-1A operated from 1962 to 1972 and was used an "in-service" test facility for nuclear power in an arctic environment, supplying electrical power and heating steam for Fort Greely.

For in-depth coverage of these stories and more, see ANS's* Nuclear Newswire *at ans.org/news.

New associate editors, advisory board members named for ANS journals

The editorial staffs of the American Nuclear Society's three technical journals have seen some additions recently.

For *Nuclear Science and Engineering*, editor Farzad Rahnema has selected three new associate editors. Sandra Dulla (Politecnico di Torino), Katrina M. Groth (University of Maryland), and Kan Wang (Tsinghua University) join associate editors Michael L. Corradini (University of Wisconsin–Madison) and William R. Martin (University of Michigan).


Dulla


Groth


Wang

Dulla will support the journal's recruitment of papers from Europe, while Groth aims to drum up submissions in the area of risk and reliability. Wang will serve as the point of contact for research derived from the Asia geographic region.

In addition, Rahnema has staffed the *NSE* editorial advisory board with a number of additions, bringing the roster of the journal's EAB to 22 members. "The expansion of the *NSE* editorial board, including the EAB, is expected to further enhance the journal's quality and output," Rahnema said.

Andrew C. Klein, editor of *Nuclear Technology*, has also appointed two new associate editors: Jamie Coble (University of Tennessee–Knoxville) and Tomasz Kozlowski (University of Illinois–Urbana-Champaign). They join Man-Sung Yim (Korea Advanced Institute of Science and Technology). Coble and Kozlowski will support peer review and paper solicitation in their topical areas of interest and expertise. Additionally, Sama Bilbao y León, the current Europe region associate editor, has stepped down to focus on her new position as director general of the World Nuclear Association.


Coble


Kozlowski

A couple of years ago, Klein instituted a rotating membership for *NT*'s 12-member EAB. "The rotation enables a broad set of ANS members to contribute to the editorial direction of the journal," he stated. "Now, the important additions of Drs. Coble and Kozlowski as associate editors will help us to manage the growing submissions to the journal and also enable us to expand our reach even further."

Leigh Winfrey, editor of *Fusion Science and Technology*, has added Arkady Serikov (Karlsruhe Institute of Technology) as an associate editor in the area of fusion neutronics. Serikov joins Jeanette Berry (Oak Ridge National Laboratory, retired) along with six EAB members. Winfrey is currently seeking new applicants to increase that number. "All fusion scientists and engineers who have an interest in helping shape our journal are welcome," she said. "Those who work in industry or are [ANS] young members are especially encouraged to apply." To express interest in joining *FST*, please email leigh.winfrey@psu.edu.


Serikov

Meet the new ANS Board members

The original story published in the August issue of Nuclear News *did not include Amanda Bachmann, the newly elected student director. We sincerely apologize for the error.*

Amanda M. Bachmann is one of the four newly elected and three newly appointed members of the ANS Board of Directors who began their terms during the 2021 ANS Virtual Annual Meeting.

AMANDA M. BACHMANN

The basics: Bachmann, ANS member since 2016, is a graduate research assistant at the University of Illinois–Urbana-Champaign. She started in that position in August 2020 after earning her bachelor's and master's degrees in nuclear engineering from the University of Tennessee.

Board goals: Bachmann said she hopes to be a strong voice for the student members, to help ensure that post–Change Plan actions will benefit students, and to position ANS in a way to help future generations. She also hopes to empower more student participation across the Society, such as in divisions and committees, by ensuring that students are well informed of society activities and positions.

Hobbies: Her hobbies include watching sports (just about any sport), knitting and crocheting gifts for friends, and playing with her rabbit, named Rontgen. She says her hobbies serve as a distraction from the stress of grad school.

Bet you didn't know: Bachmann earned the Girl Scout Gold Award in 2015, the highest award given by the Girl Scouts of the USA. Fewer than 6 percent of eligible Girl Scouts earn the Gold Award each year. Bachmann received her award for the Luck of the Irish Food Drive, which resulted in more than 800 pounds of food for Metropolitan Ministries in Florida.

New Spanish Communications Subcommittee seeks volunteers

The newly created Spanish Communications Subcommittee (SCS) of the ANS Diversity and Inclusion Committee needs translators, transcribers, and original content developers. Already the group has attracted interested members from all over the world, including Argentina, Spain, Chile, Mexico, and the United States.

"We are preparing for the future by developing content in Spanish due to the growth rate projection of the Hispanic population in the United States," said SCS chair Ira Strong, a nuclear engineer at the Palo Verde plant in Arizona. "Bringing content related to nuclear science and technology in the preferred language will help boost confidence toward atomic energy in our Spanish-speaking communities."

The SCS invites any interested ANS member to join the team. The group's goal is to provide language-accessible material

ANS News continues

in neutral Spanish to ANS members and the public. It intends to foster the development and application of nuclear science, engineering, and technology by ensuring proper terminology, faithful translations/transcriptions, and original content in Spanish widely accepted in Spain and Latin America.

In addition, the SCS is seeking help with content development from transcribers/translators. Transcribers will help translate content or transcribe videos or other content in English for a Spanish-speaking audience. Content development is an option for members interested in helping develop videos or animations. The SCS plans to create a three-part video series about radiation. Video production and animation software will be outsourced once the content is created.

Cochair Bobbi Riedel, a nuclear engineering graduate student at the University of New Mexico and graduate research intern at Los Alamos National Laboratory, proposed the idea to start the subcommittee, which aims to offer accessible material to Spanish-speaking communities, bringing technical information on nuclear topics that would give Spanish-speaking communities fair and meaningful participation in environmental decision-making laws, regulations, and policies related to nuclear energy.

New Members

The ANS members and student members listed below joined the Society in July 2021.

Andrianov, Andrey, PE Science and Innovations (Russia)

Blaise, Patrick, CEA Saclay (France)
Brooksby, Sydney L., AZ Isotopes
Brophy, Doug, United Engineers & Constructors
Bulso, Riley L., Los Alamos National Laboratory

Clawson, Dalmer R., III, Sulzer Pumps
Culp, David, NAC International

DeCastro, Sam M.
Drennan, Joel, Framatome (France)
Dutrow, David, Lisega (Germany)

Ellis, Toria, Reed College

Gasque, Jason L., Tennessee Valley Authority
Giebel, Joseph E., Fluor Idaho
Gonzalez, Luis, Weschler Instruments

Hoffman, Kathy, Gamma Industry Processing Alliance

Keefer, Gregory J., Lawrence Livermore National Laboratory
King, Seth, Sandia National Laboratories
Knauf, Florence V., Nuclear Energy Institute
Konovalov, Igor, PE Science and Innovations (Russia)
Kuhlman, Steve, Lean Power
Kvyatkovsky, Stepan, PE Science and Innovations (Russia)

Long, Michael A., North Carolina State University
Lubbe, Steven W., Inert Corp.

Ma, Nancy, Oak Ridge National Laboratory
Macdonald, Ruaridh R., Massachusetts Institute of Technology
Mansurov, Oleg, PE Science and Innovations (Russia)
Margotta, Daniel, BCP Engineers and Consultants
Martin, Richard J., American Association of Physicists in Medicine
Miller, John, International Isotopes Idaho
Moody, Dave, Entergy
Murphy, Paul M., Murphy Energy & Infrastructure Consulting
Mushakov, Andrey V., Lightbridge

Newhouse, Jerry, Reed College

Pacio, Julio C., Belgian Nuclear Research Centre (Belgium)
Ponomarev, Anton

Reiter, Matt, Capitol Associates
Resz, Matthew, Savannah River National Laboratory

Roy, Christine H., Simpson Gumpertz & Heger
Rumrill, Nathaniel M., Leader Professional Services

Saxena, Shefali, Argonne National Laboratory
Segovia, Valerie G., Nuclear Power Institute
Smith, Colton, Electric Power Research Institute
Stepanovic, Daniel M., Ameren

Triska, Paul, System One Holdings

Wassenaar, Richard, Nordion (Canada)
Williams, Gerald E., Enercon
Wilmes, Emmett, MPR Associates

Yang, Se Ro, Texas A&M University

Zach, Andrew, U.S. Senate Committee on Environment and Public Works
Zaluzhnyy, Alexander, PE Science and Innovations (Russia)

STUDENT MEMBERS

Boise State University
Cole, Sarah E.

Brigham Young University
Carson, Thomas S.
Dromey, Jonathan M. E.
Edgerton, Brent A.
Thorum, Aaron

Colorado School of Mines
Hutchins, Samuel

Florida International University
Boza, Roger

Georgia Institute of Technology
Tsui, Tiffany
Wicks, Sadie A.

Grenoble Institute of Technology (France)
Khanpour, Farrah

Hokkaido University (Japan)
Yanagihara, Kento

Marshall University
Burbery, Peter C.

Pennsylvania State University
Walker, Jasmine C.

Purdue University
Ram, Raghav

Rensselaer Polytechnic Institute
Rahman, Rida

University of Michigan–Dearborn
Self, Jared

University of New Mexico
Garcia, Kevin S.

University of Pittsburgh
Sanver, Sevda

University of Tennessee–Knoxville
Drey, Devon L.

University of Wisconsin–Madison
Wagner, Nathan A.

Virginia Commonwealth University
Zou, Yue

Virginia Polytechnic Institute and State University
Roghanizad, Mohsen

Institution not provided
Cha, Minsik

Note: Nuclear News *publishes news about nuclear industry contracts—but only about contract awards. We generally do not publish announcements that the work is underway or announcements that the work has been completed. Email your new contract award announcements to nucnews@ans.org.*

Framatome Healthcare created to apply industry expertise to medical sector

France-based **Framatome** has established a new member of its brand family: **Framatome Healthcare**. Activities under the new brand include work with medical professionals to provide irradiation targets—a by-product of nuclear technology. In addition, Framatome designs and produces medical radioisotope activation systems, specialized alloys used in the manufacturing of surgical implants, and industrial and medical sterilization systems. Framatome provides a variety of products and services devoted to medical applications and cancer-fighting treatments.

In addition, Framatome announced in July that the U.S. Nuclear Regulatory Commission recently accepted for review a topical report to apply the company's suite of advanced codes and methods to operating conditions with uranium-235 enrichments above the industry standard of 5 weight percent. This could lead to the introduction of advanced products with increased enrichments and burnups, which improve fuel utilization for nuclear plant operators and could improve safety and plant economics.

■ **Nawah Energy Company**, the subsidiary created by joint venture partners Emirates Nuclear Energy Corporation and Korea Electric Power Corporation to operate and maintain the Barakah nuclear plant, signed a maintenance and engineering services agreement (MESA) with **Framatome**. Under the MESA's scope, Framatome will provide maintenance and engineering services. Framatome will also provide training, technical and operational support, and fuel services for Barakah's four APR1400 units. The work will be completed under the leadership of Nawah and in strict accordance with the United Arab Emirates' nuclear energy regulator's quality and safety standards.

■ **SHINE Medical Technologies** has announced that it has closed a $150 million Series C-5 financing. **Koch Disruptive Technologies** (KDT) led the round, which also included participation by **Fidelity Management and Research Company**, **Baillie Gifford**, and other new and current investors. The financing will support SHINE's commercialization of its diagnostic and therapeutic medical isotope technologies.

■ **Lightbridge** has executed a cooperative research and development agreement (CRADA) with the **Battelle Memorial Institute**, Pacific Northwest Division, the operating contractor of the Pacific Northwest National Laboratory, in collaboration with the Department of Energy. The principal goal of the agreement is to advance a critical stage in the manufacturing process of Lightbridge fuel by demonstrating a casting process using depleted uranium–zirconium material. The total project value of the CRADA is approximately $663,000, with three-quarters of this amount funded by the DOE for the scope performed by PNNL.

■ **First Nations Power Authority** (FNPA) and **GE Hitachi Nuclear Energy** (GEH) in July announced a collaboration on training and employment opportunities available to qualified Indigenous peoples in Canada. GEH has created 30 highly skilled field service technician roles. Through the collaboration, FNPA will engage communities to support the recruitment of qualified Indigenous peoples for these positions. GEH will train any Canadian Indigenous peoples hired as field service technicians to support maintenance and refueling outages at nuclear power plants.

Industry continues

CONTRACTS

Bilfinger wins additional order at Hinkley Point C

London-based EDF Energy has commissioned Bilfinger to carry out inspection services for the Hinkley Point C plant, currently under construction in Somerset, England. Over the course of the next five years, Bilfinger, based in Mannheim, Germany, will apply various nondestructive testing methods to monitor the integrity of safety-critical systems at the plant. The contract, worth more than €20 million (approximately $23.5 million), will create more than 80 new jobs at Bilfinger Salamis U.K. sites in Somerset, Bristol, and Humberside.

■ **Westinghouse Electric Company** has been awarded several integrated outage and refueling service contract extensions from the **Tennessee Valley Authority** (TVA). Under the terms of the agreement, Westinghouse will continue to deliver outage support to the Sequoyah and Watts Bar nuclear plants beginning in the fall 2021 outage season. The multiyear contract extensions will secure the fuel supply for pressurized water reactor refueling, as well as steam generator inspection and maintenance services.

■ **Framatome** has announced a contract award with Hungary's state-owned **Public Limited Company for Radioactive Waste Management** to upgrade the seismic monitoring and detaching system at its spent fuel interim storage facility in Paks, Hungary. This announcement marks the first contract signed by **Framatome Kft**, a subsidiary created following the acquisition of nuclear and process automation company Evopro Kft.

■ The Department of Energy's **Office of Environmental Management** (EM) has awarded a new contract to **North Wind Site Services** for cleanup services at the Naval Reactors Knolls Atomic Power Laboratory located in Niskayuna, N.Y. It is an indefinite delivery/indefinite quantity (IDIQ) contract from which firm-fixed-price and time-and-materials task orders are anticipated to be issued during the performance period. The contract is valued at up to $22 million over five years.

In addition, EM has announced that it has awarded the Carlsbad Field Office (CBFO) Technical Assistance Contract to **Navarro Research and Engineering**. Navarro will support EM's mission by performing technical support services at the CBFO and at the Waste Isolation Pilot Plant. This IDIQ contract will allow for firm-fixed-price and time-and-materials task orders for an ordering period of five years and a contract ceiling of $100 million.

ADVANCED REACTOR MARKETPLACE

GE Hitachi, Global Nuclear Fuel, Cameco sign MOU to support SMR deployment

GE Hitachi Nuclear Energy (GEH), **Global Nuclear Fuel–Americas**, and **Cameco** have entered into a memorandum of understanding to explore several areas of cooperation to advance the commercialization and deployment of BWRX-300 small modular reactors in Canada and around the world. The MOU is not exclusive and does not preclude GEH or Cameco from pursuing similar arrangements with other companies in the nuclear energy sector.

■ **NuScale Power** announced that it has finalized an investment agreement with **GS Energy North America Investments** (GS Energy), the U.S. entity of the South Korean leading energy services provider. As part of a long-term strategic relationship established under the agreement, GS Energy will provide a cash investment in NuScale Power and support deployment of NuScale plants. The two parties will also look to develop regional NuScale power plant service delivery opportunities.

■ **Oklo** has announced a $2 million cost-share award from the **Department of Energy** supported by the Technology Commercialization Fund (TCF). Oklo is matching $1 million in funds and is teaming with the DOE and **Argonne National Laboratory** on this public-private partnership. The TCF project will enable the commercialization of advanced fuel recycling capabilities by utilizing electrorefining technology.

NEW PRODUCTS

Sensor Networks releases a new high-temp, dual-element transducer

Sensor Networks recently announced the release of its newest product, The SensorScan DHT-400 ultrasonic transducer. The DHT-400 is a general-purpose transducer designed to measure the wall thickness of high-temperature, rough inner diameter and outer diameter surfaces to detect metal loss due to corrosion and erosion. The DHT-400 can operate intermittently at temperatures ranging from 0°F to 932°F (-17.8°C to 500°C) and continuously from 0°F to 400°F (-17.8°C to 204°C). Typical applications for the DHT-400 include use with most commercially available digital thickness gauges or flaw detectors measuring wall thickness of boiler/furnace tubes, pipes, tanks, vessels, structures, and other safety-critical components at power plants and other facilities.

Comments requested

Comments are requested on the following standard by September 14, 2021:

■ ANS-2.21-202x, *Criteria for Assessing Atmospheric Effects on the Ultimate Heat Sink* (revision of ANSI/ANS-2.21-2012 [R2016]).

This standard establishes criteria for the use of meteorological and hydrological data by nuclear facilities to evaluate the atmospheric effects from meteorological parameters on ultimate heat sinks. These input parameters may include dry-bulb temperature, wet-bulb temperature, dewpoint, cloud cover, relative humidity, precipitation, wind speed, incoming short-wave solar radiation, incoming long-wave radiation, surface water temperature, and atmospheric pressure.

Comments are requested on the following standards by September 20, 2021:

■ ANS-19.10-2009 (R202x), *Methods for Determining Neutron Fluence in BWR and PWR Pressure Vessel and Reactor Internals* (reaffirmation of ANSI/ANS-19.10-2009 [R2016]).

This standard provides criteria for performing and validating the sequence of calculations required for the prediction of the fast neutron fluence in the reactor vessel. Applicable to pressurized water reactor and boiling water reactor plants, the standard addresses flux attenuation from the core through the vessel to the cavity and provides criteria for generating cross sections, spectra, transport, comparisons with in- and ex-vessel measurements, validation, uncertainties, and flux extrapolation to the inside vessel surface.

■ ANS-53.1-2011 (R202x), *Nuclear Safety Design Process for Modular Helium-Cooled Reactor Plants* (reaffirmation of ANSI/ANS-53.1-2011 [R2016]).

This standard establishes the nuclear safety criteria, functional performance, and design requirements of structures, systems, and components for modular helium reactor plants applicable to performance-based, risk-informed regulation.

Approved

The following standards have been approved:

■ ANSI/ANS-2.17-2010 (R2021), *Evaluation of Subsurface Radionuclide Transport at Commercial Nuclear Power Plants* (reaffirmation of ANSI/ANS-2.17-2010 [R2016]).

This standard provides criteria for determining the concentration of radionuclides in the groundwater resulting from both postulated accidents and routine releases from nuclear facilities.

■ ANSI/ANS-2.3-2011 (R2021), *Estimating Tornado, Hurricane, and Extreme Straight Line Wind Characteristics at Nuclear Facility Sites* (reaffirmation of ANSI/ANS-2.3-2011 [R2016]).

This standard defines site phenomena caused by (1) extreme straight winds, (2) hurricanes, and (3) tornados in various geographic regions of the United States. These phenomena are used for the design of nuclear facilities.

■ ANSI/ANS-15.11-2016 (R2021), *Radiation Protection at Research Reactors* (reaffirmation of ANSI/ANS-15.11-2016).

This standard establishes the elements of a radiation protection program and the criteria necessary to provide an acceptable level of radiation protection for personnel at research reactor facilities and the public consistent with keeping exposures and releases as low as reasonably achievable.

PINS

Under the Project Initiation Notification System (PINS), the following standard is being developed:

■ ANS-2.36-202x, *Accident Analysis for Aircraft Crash into Reactor and Non-Reactor Nuclear Facilities* (new standard).

This standard's broad reactor and non-reactor nuclear facility applicability provides the user with the requirements and guidance to evaluate and assess the significance of aircraft crash risk on nuclear facility safety. It provides a framework of stepwise increases in analytical sophistication aimed at demonstrating that an aircraft crash either does or does not exceed a risk level of concern equivalent to other generally applied sources of risk from the operation of nuclear facilities.

All published ANS standards can be ordered through Techstreet at techstreet.com/ans or 855-999-9870. Comments on draft standards should be sent to ANS standards manager Patricia Schroeder at pschroeder@ans.org, with a copy of the comments sent to the Board of Standards Review at the American National Standards Institute.

Volunteer support needed

The following standards projects are in need of volunteer support. Interested individuals should contact standards@ans.org for more information.

■ ANS-2.17, *Evaluation of Subsurface Radionuclide Transport at Commercial Nuclear Power Plants* (revision of ANS-2.17-2010 [R2016]).

■ ANS-2.18, *Standards for Evaluating Radionuclide Transport in Surface Water for Nuclear Power Sites* (proposed new standard).

■ ANS-3.2, *Managerial, Administrative, and Quality Assurance Controls for the Operational Phase of Nuclear Power Plants* (revision of ANSI/ANS-3.2-2012 [R2017]).

■ ANS-8.14, *Use of Soluble Neutron Absorbers in Nuclear Facilities Outside Reactors* (revision of ANSI/ANS-8.14-2004 [R2016]).

■ ANS-3.13, *Nuclear Facility Reliability Assurance Program (RAP) Development* (proposed new standard).

■ ANS-53.1, *Nuclear Safety Design Process for Modular Helium-Cooled Reactor Plants* (revision of ANSI/ANS-53.1-2011 [R2016]).

■ ANS-56.2, *Containment Isolation Provisions for Fluid Systems After a LOCA* (new standard, historical revision of ANS-56.2-1989 [W1999]).

Why global emissions are still rising

By James Conca

After the world has spent a few trillion dollars over the past 10 years trying to decarbonize—$503 billion in 2020 alone—carbon emissions are still increasing. Even as the pandemic slowed that growth for a bit during 2020 and 2021, 2022–2023 emissions will break all records, exceeding 55 billion tons per year by more than a little.

According to the International Energy Agency, global electricity demand will increase by 5 percent in 2021 and 4 percent in 2022, and half of this increase will be met by fossil fuels, particularly new coal, in the developing world. CO_2 emissions from the power sector will rise to record levels in 2022, exceeding 34 billion tons.

"Our analyses show that the short-term trend in global electricity markets is not consistent with a zero-emissions pathway," the IEA said.

After dropping by 4 percent in 2020, nuclear power generation is forecast to grow, but only by 1 percent in 2021. This is one important reason why carbon emissions will grow so much during this period.

Renewable electricity generation, which grew by 7 percent in 2020, will continue to rise, but it cannot keep up with increasing demand, not by half. Until growth in renewables and nuclear exceeds that of fossil fuels—and by a lot—we will make no headway against the environmental problems we need to solve in the next three decades.

Extracting, refining, and burning fossil fuels has led to enormous greenhouse gas emissions—over 50 billion tons per year. Bringing this down to zero by 2050 will take more than wishful thinking. (Photo: National Renewable Energy Laboratory)

Renewables and fully electric vehicles aside, the use of all fossil fuels is increasing worldwide, primarily because of economic growth in the developing world. Even coal generation is increasing, producing more power than hydro, nuclear, and renewables combined.

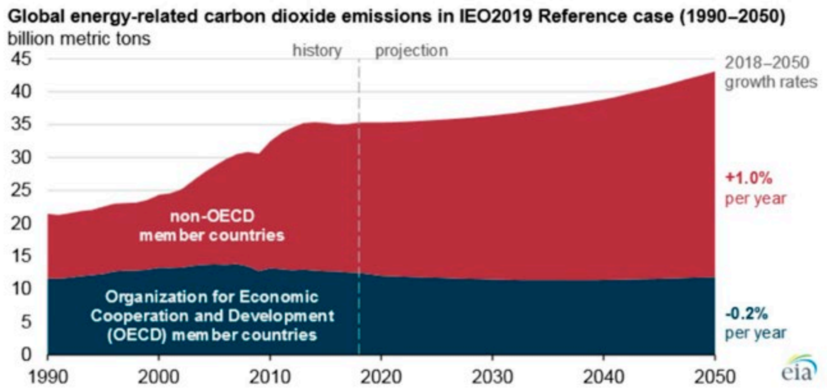
While the developed world is switching from coal to natural gas, developing countries see coal as their savior. This is not because coal is cheapest—it's not. Of all energy sources, coal is merely the easiest to set up in a poor or developing country that has little existing infrastructure. It is the easiest to transport—by ship, rail, or truck. It is straightforward to build a coal-fired power plant, and to operate it. Thus, fossil fuel use will keep increasing.

While there are plenty of "road maps to net zero by 2050," there are no actual projections that this will happen. No serious projections even have global emissions much lower than 30 billion tons per year by 2050. That's because the use of oil and natural gas keeps increasing and only will flatten by about 2040.

It doesn't decrease until the second half of this century. And coal decreases by only 15 percent or so.

This is not the trend that's going to get us to a low-carbon future. In fact, the only things that will get us to net-zero must include some form of the following, although other issues such as infrastructure needs must also be addressed:

- Stop building any new fossil fuel plants as soon as possible; once a plant is built, you're locked into that fossil fuel for at least 40 years.
- Stop closing perfectly performing and safe nuclear plants that have already been relicensed for another 20 or 40 years.
- Install 3.5 million MW of new wind turbine capacity (12 trillion kWh/year).
- Install 1.4 million MW of new nuclear reactors, particularly small modular reactors, which are especially ideal for load following renewables (11 trillion kWh/year).
- Install 2.1 million MW of new solar (7 trillion kWh/year).
- Install 1.2 million new MW of hydro, with 80,000 MW existing (7 trillion kWh/yr).
- Build a fleet of 3 billion fully electric vehicles by 2050; much fewer will not sufficiently drop our consumption of oil.
- Secure sources of lithium, cobalt, neodymium, iron, and other metals needed to build these fully electric vehicles, especially the batteries.



While emissions are going down a bit in the developed world, they keep increasing in the developing world. (Graph: U.S. Energy Information Association)

It turns out that the cost of this new low-carbon energy mix is about the same as business-as-usual—$65 trillion versus $63 trillion—over about 30 years. It's just that more of the total cost is in up-front capital costs instead of fuel costs—$28 trillion versus $11 trillion. It will take over 12 billion tons of steel alone for that much renewable capacity (the annual global output of steel is presently 1.6 billion tons).

Cost estimates by the International Renewable Energy Agency for decarbonizing the world—all sectors, not just energy—top $100 trillion by 2050. In a recent McKinsey report, the estimated cost of decarbonizing just the industrial sector would be about $21 trillion between now and 2050, although both could be significantly lower if technologies and efficiencies continue to advance.

But it's the lack of nuclear that really puts the stake in the heart of the decarbonization dream. The Mochovce-3 nuclear unit in the Slovak Republic is expected to start commercial operation this year, but the retirement in 2020 of the Fessenheim nuclear plant in France and Ringhals in Sweden negates that.

With the retirement before the end of 2022 of 4.3 GW of nuclear in Germany, 2 GW in the United Kingdom, and 1 GW in Belgium, nuclear electricity generation is likely to drop by 3 percent in 2022, even if the Olkiluoto-3 EPR in Finland starts commercial operation.

In the United States, the EIA predicts that 9.1 GW of nuclear capacity will be added by 2050, as well as another 4.7 GW of added nuclear capacity resulting from uprates—operational changes that allow existing plants to produce more electricity.

Opinion continues

Diablo Canyon in San Luis Obispo County, Calif., is slated for premature closure, mainly for political reasons. Some of the world's leading climate scientists sent a letter to the governor of California, stating that nuclear energy is essential to fighting global warming and decarbonizing society. (Photo: PG&E)

More than offsetting this additional capacity, however, is the projected retirement of 29.9 GW of nuclear capacity through 2050, especially those plants expected to close by 2026. The foolish recent closing of Indian Point has erased most of New York's progress in lowering its carbon footprint with renewables.

China is planning 180 GW of new nuclear capacity by 2035. If the rest of the world followed suit in proportion, we would have a chance.

So, if you think we've been doing a reasonable job of curbing fossil fuel use, even after spending some trillions of dollars, you are sadly mistaken. It's nice to have a plan, but if it's not based on reality, it's not going to happen.

James Conca is a scientist in the field of the earth and environmental sciences, specializing in geologic disposal of nuclear waste, energy-related research, planetary surface processes, radiobiology and shielding for space colonies, and subsurface transport and environmental cleanup of heavy metals. Conca also writes about nuclear, the environment, and energy for Forbes*; you can view his stories online at forbes.com/sites/jamesconca.*


Dilling

Jens Dilling has been selected as director of institutional strategic planning for the Department of Energy's Oak Ridge National Laboratory. Dilling will guide the development of laboratory strategies, strategic investments, and annual planning, as well as manage the laboratory's discretionary investment portfolio. His responsibilities will also include ORNL's research library. He previously served as associate laboratory director for physical sciences at TRIUMF, Canada's particle accelerator center.

NorthStar Medical Technologies has appointed **Frank Scholz** as its senior


Scholz

vice president and chief operating officer. In this new position, Scholz will hold oversight over several teams and play a key role in expanding the company's molybdenum-99 production capacity, among other duties. Prior to joining NorthStar, Scholz was a managing director at AlixPartners, where he was a global leader of the health care and life sciences practice.

Ultra Energy, a subsidiary of Ultra Electronics Holdings, has appointed


Freel

Steven L. Freel as its vice president of business development. Freel previously served as president and chief executive officer of Studsvik Scandpower and as the chief technology officer of GSE Systems. His new business line includes support to light water reactors, small modular reactors, advanced reactors, and development of advanced digital systems as well as support to space programs.

The Nuclear Regulatory Commission


Coffman

has selected **Zach Coffman** as the new resident inspector at the two-unit Quad Cities nuclear plant in Cordova, Ill., approximately 20 miles northeast of Moline and operated by Exelon Generation. Coffman joined the NRC in 2018 as a reliability and risk analyst in the Office of Nuclear Reactor Regulation at the agency's Rockville, Md., headquarters. He later joined the Resident Inspector Development Program in Region I.

Jacobs scientist **John Stairmand** was recently named cochair of the technical advisory board of SINDRI—Synergistic utilization of


Stairmand

INformatics and Data centRic Integrity engineering—a government- and private sector–funded partnership of academic and industrial experts in the United Kingdom. Stairmand, who is based in Warrington, England, as Jacobs' technical director of technology and cyber solutions, will lead U.K. research into materials for new nuclear reactors capable of powering a net-zero-carbon economy.

In addition, Jacobs has seconded


Maddison

John Maddison as program director for the Industrial Solutions Hub, a new initiative that aims to tap the economic potential of companies supplying the Sellafield nuclear site in the U.K.

Obituaries


Carbon

Max W. Carbon, 99, ANS Fellow and member since 1959; nuclear engineering research and education pioneer; renowned for advances in nuclear reactor safety and heat transfer; founding chair of the University of

People continues

Wisconsin–Madison Department of Nuclear Engineering; earned his bachelor's degree in mechanical engineering from Purdue University in August 1943; returned to Purdue following World War II to earn his master's degree in 1947 and a Ph.D. in 1949; from February 1949 until September 1955, worked at the General Electric Company's Hanford Works in Richland, Wash., producing plutonium for atomic and hydrogen bombs used for national defense; later joined the Avco Manufacturing Corp. as head of its thermodynamics section, successfully designing the nose cone for the Titan Intercontinental Ballistic Missile; in 1958, went to the University of Wisconsin–Madison to establish a nuclear engineering program as part of a growing postwar research emphasis on designing better, more efficient nuclear power plants for generating electricity; led the department in establishing bachelor's, master's, and Ph.D. curricula; oversaw construction of the university's research and training nuclear reactor, which achieved initial criticality in early 1961; served as chair for 34 years until his retirement in 1992; in 1997, authored the book, *Nuclear Power: Villain or Victim? Our Most Misunderstood Source of Electricity*, now in its fifth printing; served on the Nuclear Regulatory Commission's Advisory Committee on Reactor Safeguards for eight years and consulted for the nuclear power industry in several capacities throughout his career; died June 23.

Index to Advertisers

Since the magazine accepted its first advertisement in 1960, Nuclear News has proudly partnered with hundreds of vendors and organizations to help keep the worldwide nuclear field informed about the latest products and services, conferences and events, employment opportunities, and academic/training courses. If you are performing or seeking nuclear-related work, make sure advertising in our magazine is part of your business development strategy and annual budget.

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Calendar

● First time listed or significant change made
✖ Meeting canceled or postponed; see listing for details

●■✖ ANS event
●■✖ Non-ANS event cosponsored by ANS

September

Sep. 5–10—**Particles and Nuclei International Conference (PANIC 2021)**, virtual meeting. indico.lip.pt/event/592/

Sep. 6–9—**30th International Conference Nuclear Energy for New Europe (NENE 2021)**, Bled, Slovenia. djs.si/nene2021/

Sep. 7–9—**16th IAEA-FORATOM Joint Event on Management Systems—Management Systems for a Sustainable Nuclear Supply Chain**, virtual meeting. events.foratom.org/mse2021/

Sep. 8–10—**2021 National Cleanup Workshop**, Alexandria, Va. cleanupworkshop.com/home-1.html

● Sep. 8–10—**World Nuclear Association Symposium 2021**, virtual meeting. wna-symposium.org/

Sep. 8–10—**RICOMET 2021**, Budapest, Hungary. ssh-share.eu/ricomet2021/

✖ Sep. 12–16—**14th International Conference on Radiation Shielding and 21st Topical Meeting of the Radiation Protection and Shielding Division (ICRS 14/RPSD 2021)**, Seattle, Wash. ans.org/meetings/icrs14rpsd21/
Meeting has been postponed until September 25–29, 2022

Sep. 12–17—**Applied Nuclear Physics (ANP) Conference 2021**, Prague, Czech Republic. anpc2021.cz/

Sep. 13–15—**International Conference on Decommissioning Challenges: Industrial Reality, Lessons Learned and Prospects**, Avignon, France. sfen-dem2021.org/

Sep. 13–17—**2021 European Conference on Radiation and Its Effects on Components and Systems (RADECS)**, Vienna, Austria. seibersdorf-laboratories.at/en/radecs-2021

Sep. 15–17—**CNA2021**, virtual meeting. conference2021.cna.ca/

Sep. 19–23—**Materials in Nuclear Energy Systems (MiNES) 2021**, Pittsburgh, Pa. tms.org/MINES2021

Sep. 20–21—**Decommissioning Strategy Forum**, Las Vegas, Nev. decommissioningstrategy.com/

Sep. 21–22—**Advanced Clean Energy Summit (ACES 2021)**, virtual meeting. event.asme.org/ACES

Sep. 22–24—**RadWaste Summit**, Las Vegas, Nev. radwastesummit.com/

Sep. 23–24—**Valve World Expo & Conference Asia 2021**, Shanghai, China. valve-world.net/vwa2021/valve-world-asia-2021.html

Sep. 27–28—**2nd International Conference of Materials, Chemistry and Fitness-for-Service Solutions for Nuclear Systems (MCFD 2021)**, virtual meeting. cns-snc.ca/events/mcfd2021/
Meeting has been rescheduled to October 14–15

Sep. 27–30—**European Nuclear Young Generation Forum (ENYGF 2021)**, Tarragona, Spain. enygf.org/

Sep. 27–Oct. 1—**NPC 2021: International Conference on Nuclear Plant Chemistry**, Antibes, France. new.sfen.org/evenement/npc-2021/

Sep. 28–29—**Enlit Asia**, virtual meeting. enlit-asia.com/

October

■ Oct. 3–7—**International Conference on Mathematics and Computational Methods Applied to Nuclear Science and Engineering (M&C 2021)**, Raleigh, N.C. mc.ans.org

Oct. 4–5—**2021 AtomExpo**, Sochi, Russia. 2021.atomexpo.ru/en/

Oct. 4–6—**International Conference on Environmental Remediation and Radioactive Waste Management (ICEM 2021)**, virtual meeting. asme.org/conferences-events/events/international-conference-on-environmental-remediation-and-radioactive-waste-management

Oct. 5–7—**ETEBA Business Opportunities & Technical Conference**, Knoxville, Tenn. eteba.org/botc/

Oct. 12–13—**TotalDECOM 2021**, Manchester, U.K. totaldecom.com/2021-expo-manchester/

● Oct. 13–14—**NuFor 2021: Nuclear Forensics Conference**, London, U.K. nufor.iopconfs.org/home

Oct. 14–15—**2nd International Conference of Materials, Chemistry and Fitness-for-Service Solutions for Nuclear Systems (MCFD 2021)**, virtual meeting. cns-snc.ca/events/mcfd2021/

■ Oct. 16–20—**2021 International Congress on Advances in Nuclear Power Plants (ICAPP2021)**, Abu Dhabi, UAE. icapp2021.org/

Oct. 16–23—**2021 IEEE Nuclear Science Symposium and Medical Imaging Conference (NSS/MIC)**, virtual meeting. nssmic.ieee.org/2021/

Oct. 17–21—**2021 Test, Research and Training Reactors (TRTR) Annual Conference**, Raleigh, N.C. projects.ncsu.edu/mckimmon/cpe/opd/trtr/

Meetings listed in the calendar that are not sponsored by ANS do not have the endorsement of ANS, nor does ANS have financial or legal responsibility for these meetings.

- Oct. 18–21—**10th International Conference on Nuclear Decommissioning**, Aachen, Germany. icond.de/welcome.html

Oct. 18–21—**Experience POWER**, San Antonio, Texas. experience-power.com/

Oct. 24–28—**TopFuel 2021**, Santander, Spain. euronuclear.org/topfuel2021

Oct. 25–29—**Technical Meeting on Artificial Intelligence for Nuclear Technology and Applications**, virtual event. iaea.org/events/evt2004304

Oct. 27–28—**All-Energy Australia**, Melbourne, Australia. all-energy.com.au/en-gb.html

Oct. 27–29—**POWERGEN India**, New Delhi, India. powergen-india.com/

November

- Nov. 7–12—**2021 International Topical Meeting on Probabilistic Safety Assessment and Analysis (PSA 2021)**, Columbus, Ohio. psa.ans.org/2021

Nov. 8–12—**International Conference on a Decade of Progress after Fukushima-Daiichi: Building on the Lessons Learned to Further Strengthen Nuclear Safety**, Vienna, Austria. iaea.org/events/international-conference-on-a-decade-of-progress-after-fukushima-daiichi-building-on-the-lessons-learned-to-further-strengthen-nuclear-safety-2021

- Nov. 12, 15–17—**G4SR-3 Virtual Summit**, virtual meeting. g4sr.org/

Nov. 14–21—**FUSION20**, Shizuoka City, Japan. asrc.jaea.go.jp/soshiki/gr/HENS-gr/fusion20/index.html

Nov. 15–17—**NESTet 2021—Nuclear Education & Training Conference**, Brussels, Belgium. ens.eventsair.com/nuclear-education-and-training/

Nov. 30–Dec. 2—**Enlit Europe**, Milan, Italy. enlit-europe.com/live

Nov. 30–Dec. 2—**World Nuclear Exhibition**, Paris, France. world-nuclear-exhibition.com/

- Nov. 30–Dec. 4—**2021 ANS Winter Meeting and Technology Expo**, Washington, D.C. ans.org/meetings/wm2021/

December

Dec. 1–3—**Perma-Fix 18th Annual Nuclear Waste Management Forum**, Nashville, Tenn. ir.perma-fix.com/upcoming-events/detail/824/perma-fixs-18th-annual-nuclear-waste-management-forum

Dec. 12–16—**23rd IEEE Pulsed Power Conference (PPC) and the 29th IEEE Symposium on Fusion Engineering (SOFE)**, Denver, Colo. uta.engineering/ppcsofe2021/

January 2022

Jan. 11–13—**IGD-TP Symposium and Webinar: The Role of Optimisation in Radioactive Waste Geological Disposal Programmes**, Zurich, Switzerland. igdtp.eu/event/igd-tp-symposium/

Jan. 25–27—**19th Annual USA Supply Chain Winter Conference**, Rancho Mirage, Calif. usainc.org/winter-conference/

Jan. 26–28—**PowerGen International**, Dallas, Texas. powergen.com/welcome

February

- Feb. 7–11—**First International Conference on Nuclear Law: The Global Debate**, Vienna, Austria. iaea.org/events/icnl-2022

Feb. 8–9—**International Conference on Clean Energy Technologies and Power Issues (ICCETPI 2022)**, Lisbon, Portugal. waset.org/clean-energy-technologies-and-power-issues-conference-in-february-2022-in-lisbon

Feb. 20–24—**IRPA North American Regional Congress**, St. Louis, Mo. burkclients.com/hps/2022IRPA/site/

Feb. 23–24—**8th Nuclear Decommissioning and Waste Management Summit**, London, U.K. wplgroup.com/aci/event/nuclear-decommissioning-waste-management-summit/

Feb. 27–Mar. 3—**TMS 2022 Annual Meeting & Exhibition**, Anaheim, Calif. htms.org/AnnualMeeting/TMS2022

March

- Mar. 6–10—**WM Symposia 2022**, Phoenix, Ariz. wmsym.org/
- Mar. 6–11—**19th International Topical Meeting on Nuclear Reactor Thermal Hydraulics (NURETH-19)**, Brussels, Belgium. showsbee.com/fairs/NURETH.html
- Mar. 16–17—**Enlit Australia**, Melbourne, Australia. enlit-australia.com/

International Topical Meeting on Advances in Thermal Hydraulics 2022 (ATH'22)

EMBEDDED IN THE 2022 ANS ANNUAL MEETING

June 12-16, 2022 | Anaheim, California, USA | Anaheim Hilton Hotel

CALL FOR PAPERS

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Dillon Shaver (ANL)
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IMPORTANT DUE DATES

JANUARY → FULL PAPERS AND SUMMARIES DUE: **January 3, 2022**

FEBRUARY → AUTHOR NOTIFICATION: **February 15, 2022**

MARCH → FINAL FULL PAPERS AND SUMMARIES DUE: **March 15, 2022**

ABOUT THE MEETING

Papers are solicited for the **International Topical Meeting on Advances in Thermal Hydraulics 2022 (ATH'22), to be held as an embedded topical meeting at the 2022 ANS Annual Meeting on June 12-16, 2022 at the Anaheim Hilton, Anaheim, CA**. Organized by the American Nuclear Society Thermal Hydraulics Division, this embedded topical meeting is the sixth in a growing series featuring peer-reviewed, full-length technical papers covering recent advances in thermal hydraulics. Authors and presenters are cordially invited to participate in this event to exchange ideas and knowledge, develop strong relationships across organizations, and establish collaborations to solve challenging problems.

Paper acceptance will be based upon originality of the work, strictly implemented methods or models, quality of results, impact of the scientific advances to the field of thermal hydraulics, conclusions supported by data, proper citation of references, and use of correct grammar and spelling. Full papers and summaries must use the meeting templates and formatting, which can be found at https://www.ans.org/meetings/view-312/. Papers will incur a publication fee of $25 per page.

Selected papers will be published in a special edition of *Nuclear Technology*.

SUBMIT A SUMMARY OR PAPER

https://epsr.ans.org/meeting/?m=338

PROGRAM SPECIALIST

Janet Davis
708-579-8253
jdavis@ans.org

International Topical Meeting on Advances in Thermal Hydraulics 2022 (ATH'22)

EMBEDDED IN THE 2022 ANS ANNUAL MEETING

June 12-16, 2022 | Anaheim, California, USA | Anaheim Hilton Hotel

SUBJECT AREAS

High-quality full-length papers (14-page maximum) are solicited on the following topics:

1. FUNDAMENTAL THERMAL-HYDRAULICS
   a. Boiling and Condensation Phenomena
   b. Experimental Methods and Instrumentation
   c. Fluid-Structures and Materials Interaction
   d. Heat Transfer Enhancement Phenomena
   e. Micro-Channel Flow and Heat Transfer Phenomena
   f. Rod Bundle Flow and Heat Transfer Phenomena
   g. Two-Phase Flow and Heat Transfer Fundamentals
2. CODE DEVELOPMENT AND APPLICATIONS
   a. Applications of Computational Methods to Nuclear Systems
   b. Computational Fluid Dynamics Methods
   c. Multiphysics-Coupled Thermal-Hydraulic Analysis Methods
   d. Multiscale Methods
   e. Novel System Code Development
   f. Subchannel Analysis Methods
   g. System Thermal Hydraulics Methods
   h. Verification & Validation Methods for Thermal Hydraulics Analyses
3. OPERATING LWRS THERMAL HYDRAULICS AND SAFETY
   a. Best Estimate LOCA and BEPU Analysis
   b. Nuclear Reactor Plant Thermal Hydraulics and Safety
   c. Operating LWRs Thermal Hydraulics and Safety
   d. Thermal Hydraulics in Power Uprating/Life Extension
4. SEVERE ACCIDENTS, PHENOMENA, MODELING AND EXPERIMENTS
   a. Combustion and Fires, Modeling and Experiments
   b. Thermal Hydraulics in Accident Management
   c. Thermal Hydraulics of Severe Accidents — Fundamentals
5. THERMAL HYDRAULICS OF ADVANCED REACTORS
   a. Gas-Cooled Reactor Thermal Hydraulics
   b. Microreactor Thermal Hydraulics
   c. Molten-Salt Reactor Thermal Hydraulics
   d. Next Generation LWR Thermal Hydraulics
   e. Small Modular Reactor Thermal Hydraulics
   f. Sodium-Cooled Fast Reactor Thermal Hydraulics
6. THERMAL HYDRAULICS OF NUCLEAR INSTALLATIONS
   a. TH of Nuclear Reactors Coupled with Energy Storage
   b. TH of Nuclear Hydrogen Production Systems
   c. TH of Used Fuel Management Systems
   d. TH of Nuclear-Renewable Coupled Energy Systems
7. SPECIAL SESSIONS
   a. Advances in High-Fidelity Measurements and Data Analysis
   b. Advanced Heat Exchanger Design
   c. Artificial Intelligence for Nuclear System and Thermal-Hydraulics Modeling
   d. Direct Numerical Simulations as High-Fidelity Data for Model Development
   e. High Performance Computing Applications in Nuclear Engineering
   f. Interface-Resolved Two-Phase Flow Simulation
   g. Multiphase Multiscale Modelling and Simulation
   h. NEAMS TH IRP: Thermal-Fluids Applications in Nuclear Energy
   i. Reliability of Passively Operating Systems
   j. Thermal Hydraulic Optimization for Additively Manufactured Components

In addition to full papers, we will also accept summary submissions (4-pages maximum) for the following two topics:

8. GENERAL THERMAL HYDRAULICS
9. YOUNG PROFESSIONAL THERMAL-HYDRAULIC RESEARCH COMPETITION

NCSD 2022

Nuclear Criticality Safety Division Embedded Topical Meeting

June 12-16, 2022 | Anaheim, California, USA | Anaheim Hilton Hotel

CALL FOR PAPERS

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Social Chair
James Bunsen, LANL

SUBMISSION OF ABSTRACTS: OCTOBER 15, 2021

OCTOBER	SUBMISSION OF ABSTRACTS: **October 15, 2021**
NOVEMBER	NOTIFICATION OF ABSTRACT ACCEPTANCE: **November 15, 2021**
FEBRUARY	SUBMISSION OF SUMMARY AND FULL PAPERS: **February 1, 2022**
MARCH	FINAL SUBMISSION OF PAPERS: **March 15, 2022**
MAY	VIDEO SUBMISSION: **May 27, 2022**

ABOUT THE MEETING

The ANS Nuclear Criticality Safety Division Topical bridges the four- year gap between successive International Conferences on Nuclear Criticality (ICNC) and provides a forum for exchange among technical disciplines that impact criticality safety, including operational criticality safety, experimental criticality, nuclear data, and radiation transport code development. The field of criticality safety, like other related nuclear engineering fields, is experiencing significant personnel turnover and an increasingly less experienced staff makes the need for technical knowledge transfer ever more important.

The theme of NCSD 2022 is Learning from the Past and Looking to the Future. In the mindset of embracing the future, in addition to full papers (6-10 pages) and 2015- minute technical presentations or posters, the organizing committee encourages summary papers (1-4 pages) for 3- minute Lightning Talks, especially from more junior staff. In addition, all full paperposter authors are encouraged to submit a 60- second advertising video (similar to a Tik Tok videoformat) with their final paper submissiontwo2 weeks before the start of the conference. The videos for posters will be played during the relevant technical sessions, and the three best videos will be played at the opening plenary session.

ABSTRACT GUIDELINES

Maximum of one page identifying title, authors, and affiliations, and up to one figure or table, describing the key concepts of the paper. A wide range of topic areas are highlighted below. The abstract template is on the NCSD 2022 Meeting Page ans.org/meetings/view-312/ . Authors of accepted abstracts will be notified by November 15, 2021. As presentation time is limited, the conference organizers may request a paper become a lightning talk or poster based on the content of the abstract.

SUMMARY AND FULL PAPER SUBMISSION

Summary papers and full papers must describe work that is new, significant, and relevant to nuclear criticality safety. The summary (1-4 pages) and full paper (6-10 pages) template is the same for both types of papers and can be found on the NCSD 2022 Meeting Page ans.org/meetings/view-312/ . Authors of accepted papers will be notified by February 25, 2022. Authors of accepted papers must agree to register and attend the conference and present their papers. Papers that are not presented at the conference will not appear in the final conference publication. Summaries and full papers will incur a $100 publication fee.

SUBMIT AN ABSTRACT

https://epsr.ans.org/meeting/?m=360

PROGRAM SPECIALIST

Janet Davis
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jdavis@ans.org

ANS NCSD 2022

Nuclear Criticality Safety Division Embedded Topical Meeting

June 12-16, 2022 | Anaheim, California, USA | Anaheim Hilton Hotel

PAPER CATEGORIES AND SUBJECT AREAS

LEARNING FROM THE PAST

Track 1: Lessons Learned in Nuclear Criticality Safety- Accidents, infractions, and lessons learned.
Track Leads: Kermit Bunde (bundeka@id.doe.gov), Mark Dodds (dodds@lanl.gov)

Track 2: Decontamination and Decommissioning- Recovery, restoration, and their respective challenges.
Track Leads: Alfie O'Neill (alfie.m.o'neill@uknnl.com), Andy Prichard (andrewwprichard@gmail.com), Mandy Bowles-Tomaszewski (abowles@lanl.gov)

Track 3: Interesting Anomalies in Nuclear Criticality Safety- Non-intuitive phenomena, unexpected results, and interesting stories.
Track Leads: Justin Clarity (clarityjb@ornl.gov), Ben Martin (Benjamin.martin@cns.doe.gov)

ADVANCING THE PRESENT

Track 4: Operational Practices- Operational criticality safety activities and applications.
Track Leads: John Miller (millerj@sandia.gov), Kevin Reynolds (Kevin.Reynolds@cns.doe.gov)

Track 5: Fuel Storage, Transportation, and Disposal- Burnup credit, transportation needs, and storage issues.
Track Leads: Kaushik Banerjee (kaushik.banerjee@pnnl.gov), Matthieu Duluc (matthieu.duluc@irsn.fr)

Track 6: Experiments and Benchmarks- Measurements, experiments, and benchmarks.
Track Leads: Nicolas Leclaire (nicolas.leclaire@irsn.fr), Bill Myers (bmyers@lanl.gov), Michael Zerkle (Michael.Zerkle@unnpp.gov)

Track 7: Codes, Data, and Methods- Analyses, validation, and sensitivities/uncertainties.
Track Leads: Luiz Leal (luiz.leal@irsn.fr), Will Weiselquist (wieselquiswa@ornl.gov), Coralie Carmouze (coralie.carmouze@cea.fr)

TRANSITIONING TO THE FUTURE

Track 8: Nuclear Criticality Safety for LEU+/HALEU- Response to growing needs for increased uranium enrichment.
Track Leads: Joe Christensen (joe.christensen@shinemed.com), Dale Lancaster (dale@nuclearconsultants.com), Olivier Ravat (olivier.ravat@orano.group)

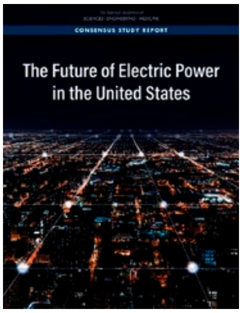
Track 9: Knowledge Transfer- Education, Professional Development, and Training.
Track Leads: Kirk Atkinson (Kirk.Atkinson@ontariotechu.ca), Amber McCarthy (amber.mccarthy@cns.doe.gov)

Track 10: Innovative Technologies and Thinking- Machine learning, Artificial Intelligence, etc.
Track Leads: Doug Bowen (bowendg@ornl.gov), Jesson Hutchinson (jesson@lanl.gov), Samir Sarker (Samir.Sarkar@arpansa.gov.au)

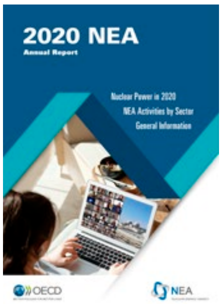
www.ans.org/meetings/ncsd2022/

Publications

Recently Published



The Future of Electric Power in the United States, from the National Academies of Sciences, Engineering, and Medicine. This congressionally mandated report presents an extensive set of policy and funding recommendations aimed at modernizing the U.S. electric system. The report addresses technology development, operations, grid architectures, and business practices, as well as ways to make the electricity system safe, secure, sustainable, equitable, and resilient. The report also recommends ways to accelerate innovations in technology, policy, and business models as global supply chains shift. (330 pages, paperback, $80, ISBN 978-0-309-68444-6, National Academies Press; order at nap.edu/catalog)



2020 NEA Annual Report, by the OECD Nuclear Energy Agency. Despite the ongoing COVID-19 pandemic, 2020 was a very active and impactful year at the NEA. The agency quickly adjusted to the situation, switched to virtual methods of interaction, and continued to serve its member countries. Each NEA Annual Report presents an overview of the NEA's activities and publications produced during that year, as well as the latest developments in the nuclear energy sector around the world. Published in English and French, the report covers a wide spectrum of topics that provide governments and other relevant stakeholders with authoritative, reliable information and analyses on current and future nuclear technologies. (99 pages, PDF, free download at oecd-nea.org/jcms/pl_59740/2020-nea-annual-report)

Applications of Nuclear and Radioisotope Technology: For Peace and Sustainable Development, by Khalid Al Nabhani. This book presents the latest technology and research on nuclear energy, with a practical focus on a variety of applications. Al Nabhani provides a thorough and well-rounded view of the status of nuclear power generation in order to promote its benefits toward a sustainable, clean, and secure future. This book offers innovative theoretical, analytical, methodological, and technological approaches and encourages a positive societal and political uptake. It enhances awareness of peaceful nuclear applications across a broad spectrum of industries, including power generation, agriculture, and medicine. It presents lessons learned across many countries that are working toward their sustainability goals in cooperation with the International Atomic Energy Agency and the Arab Atomic Energy Agency. (300 pages, paperback, $180, ISBN 978-0-12-821319-3, Academic Press; order at elsevier.com/books)

The following are listings of the most recent issues of ANS's three technical journals. ANS members, access your free electronic subscription by visiting ans.org/pubs/journals and signing in to your ANS account.

ANS Technical Journals

FUSION SCIENCE AND TECHNOLOGY • AUGUST 2021

Neutronics Analysis of the Stellarator-Type Fusion–Fission Hybrid Reactor Using Mesh Simplification *J.-Y. Li et al.*

First-Principles Study of the Effects of Carbon, Nitrogen, and Oxygen on Helium Behavior in Body-Centered-Cubic Vanadium *R. Li et al.*

Experimental Estimation of Dust Generation Under ELM-Like Transient Heat Loads in Divertor Plasma Simulator *I. Park et al.*

Study on Helium Bubble Coalescence in the Slip Plane of Titanium *B. Zhang et al.*

Determination of the Oxygen Concentration in GDP Thin Films Using Rutherford Backscattering Spectroscopy *X. Ma et al.*

Influence of Gas Pressure on the Infrared Blocking Property of Ultrathin Aluminum Films on Freestanding Polyimide Substrates *Y. Liu et al.*

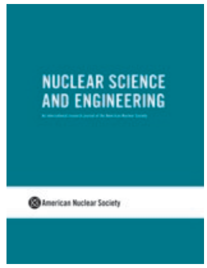
Research of the Characteristics of Semiconductor Bridge (SCB) Plasma *R. Wang et al.*

Calculation of Coil Currents for Equilibria with Reversed Plasma Current Density in J-Text Tokamak *Y. Chen et al.*

Multiscenario Electromagnetic Load Analysis of Blanket and VV for CFETR *J. Pan et al.*

Could Tokamaks Be the Vaccine for the Climate Change Pandemic? *E. Mazzucato*

NUCLEAR SCIENCE AND ENGINEERING • SEPTEMBER 2021



Multidual Sensitivity Method in Ray-Tracing Transport Simulations *M. R. Balcer et al.*

Verification and Validation of RAPID Formulations and Algorithms based on Dosimetry Measurements at the JSI TRIGA Mark-II Reactor *V. Mascolino et al.*

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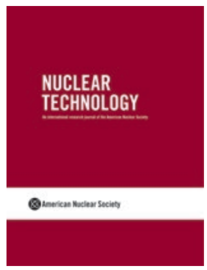

This special issue features 14 articles on the Nuclear, Humanities, and Social Science Nexus.

The Nuclear, Humanities, and Social Science Nexus: Challenges and Opportunities for Speaking Across the Disciplinary Divides *A. Verma*

ASTRID, Back to the Future: Bridging Scales in the Development of Nuclear Infrastructures *S. Tillement, F. Garcias*

From "Inherently Safe" to "Proliferation Resistant": New Perspectives on Reactor Designs *S. D. Schmid*

NEA Framing Nuclear Megaproject "Pathologies": Vices of the Modern Western Society? *M. Lehtonen*

Breaking Out of a Niche: Lessons for SMRs from Sustainability Transitions Studies *M. Iakovleva et al.*

Styles of Revaluation: The Case of the Levelized Cost of Electricity *B. Saraç-Lesavre*

Mankala Chronicles: Nuclear Energy Financing and Cooperative Corporate Form in Finland *V. Ialenti*

Social Scientists in an Adversarial Environment: The Nuclear Regulatory Commission and Organizational Factors Research *T. R. Wellock*

Revisiting Safety Culture: The Benefits of a New Cultural Analysis Framework for Safety Management *E. Gisquet et al.*

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Changing the System Culture: Mobilizing the Social Sciences in the Swedish Nuclear Waste System *T. Kaiserfeld, A. Kaijser*

The Power and Limits of Classification: Radioactive Waste Categories as Reshaped by Disposal Options *C. Parotte*

Geographies of Energy—A Course in Sociotechnical Decision Making *L. Marshall*

How should PRA adapt to a changing landscape?

Katrina Groth

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Probabilistic risk assessment has been around for over 40 years, helping us understand the amazing, complex engineering systems we design, build, and operate. It's a powerful tool, but the time has come to consider how we can modernize it. There are important gaps in PRA, including in areas such as human reliability, dynamics, natural hazards, and cybersecurity. However, there are three things that are even more important to do:

1. **Strongly reinforce the value of PRA.** We need to recognize and emphasize that PRA is essential. This can be tough, because PRA folks are primed to think in failure space. Too many engineers talk about PRA as something that adds costs to plants, as a regulatory burden, or as a box to check so they can get back to "real" engineering. As engineers, however, our first principle of professional conduct is to hold paramount the safety, health, and welfare of the public, workers, and the environment. Nowhere do our principles ask us to do that only if it's cheap, fast, and easy. PRA is an essential process that enables us to uphold the integrity of the engineering profession. It is a fundamental part of being an engineer.
2. **Invest in advancing PRA.** We need to accelerate the pace of bringing new ideas and people into PRA practice, education, and training. There is too much pressure to keep PRA the same as it was in the 1990s. PRA helps us understand how a plant—and everything in it—works and fails. It harnesses reliability engineering, statistics, logic models, and data spanning decades. PRA is an incredibly complex and powerful aspect of engineering. One course in PRA is not enough; indeed, one career is not enough to learn it all. We need to continuously learn and continuously improve. There are new ideas that overcome old problems and ideas that rethink PRA completely. We need to invest in those ideas and invest in our people—educating our experts and welcoming the next generation.
3. **Remember our fundamentals.** PRA is about insights, not just numbers. One misconception I often hear is that "risk is just frequency times consequences," and that's just not true. PRA starts with the risk triplet (scenarios, probabilities, and consequences). The scenarios—"what can go wrong?"—are the key to understanding. That includes understanding if the risk is commensurate with the benefits, what could happen if something changes, and how we can improve system safety and reliability. The risk triplet poses three powerful questions designed to bring us insights, and a tripod collapses if one leg is removed. Those insights, and the process by which we arrive at them, matter more than the final number. ⌧