LWRS Newsletter

Light Water Reactor Sustainability

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I am often asked why the Federal Government should fund a program that supports the continued operation of the existing nuclear power plants when our utilities have a large financial incentive to keep these plants running. I thought I would share with you my perspectives and welcome your thoughts as well.

President Obama has called for a reduction of carbon dioxide emissions to 1990 levels by the year 2020, with a further 80% reduction by the year 2050. Nuclear power is the largest contributor of non-greenhouse-gas-emitting electric power generation, comprising nearly three-quarters of the non-emitting sources and avoiding approximately 700 million metric tons of carbon dioxide annually. U.S. electricity demand is expected to rise nearly 28% by 2035. Current 60-year licenses for nuclear plants will begin to expire in 2029 requiring that planning for baseload replacement power must begin by 2014 or earlier. The scientific and technical basis to operate the existing nuclear fleet beyond the 60-year license period does not exist today.

Absent additional research to address critical plant-aging issues, these valuable generating stations may be retired after reaching 60 years of operation. Furthermore, with the state of present research, degradation and obsolescence threaten to decrease power production from these nuclear power plants even before their scheduled end of licensed lifetimes. Over the next three decades, this would result in a loss of 100-GWe, emission-free generating capacity. Continued safe and economical operation of current reactors for an even longer period of commercial operation, beyond the current license renewal lifetime of 60 years, is a low-risk option to fill the gap and maintain power generation at a fraction of the cost of building new plants.

Achieving the Administration's carbon dioxide emission goals will require the continued operation of existing nuclear power plants. The technical challenges associated with showing that existing plants can be safely and economically sustained beyond 60 years are formidable and beyond the capabilities of the private sector alone to address fully. While industry is likely to invest in applied research programs that are directed toward enhancing operations or in developing incremental improvements, they are unlikely to invest significantly in research programs that focus on longer-term or higher-risk gains. Additionally, because research necessary for nuclear power plant life extension is of a broad nature that provides benefits to the entire industry, it is unlikely that a single company will make the necessary investment on its own.

Over the past several decades, academia and national laboratories have made enormous advances in the area of general materials science and modeling of fundamental structures. Applications of these sciences, although not specifically nuclear in nature, have the potential to bring tremendous advances over the narrowly focused, step-wise improvements the nuclear industry alone has realized thus far. National laboratories are positioned to bridge the nuclear industry, R&D, and demonstration infrastructures because of their unique resources (such as experimental irradiation and post-irradiation examination facilities). The Light Water Reactor Sustainability (LWRS) Program serves to facilitate use of this knowledge with further R&D specific to the current fleet of nuclear power plants in understanding ongoing and complex challenges to long-term operations.

In summary, there are several important reasons for a sustained Federal investment in LWRS Program in collaboration with industry. Sustaining the existing nuclear power plant fleet is instrumental to meeting the Administration's carbon dioxide reduction goals. The Government holds a great deal of theoretical, computational, and experimental expertise in nuclear R&D that is not duplicated in industry. R&D conducted on nuclear power plant life extension is applicable to current plants, as well as to the next generation of reactor technologies still in development.

Risk-Informed Safety Margin Characterization

By Bob Youngblood
Risk-Informed Safety Margin Characterization Pathway Lead

Many owners of old cars have faced the decision of whether to invest substantially in major component replacement or junk the car. Often, this is not an easy decision. If one knew that a given major component replacement could assure long-term economic operation, the decision to invest and keep the car would be a no-brainer; however, in real life, this level of assurance is not attainable. We might replace the engine one week, lose the transmission the next week, and lose the clutch a month later. Note that in exceptional cases, safety standards imposed by the State Department of Motor Vehicles may make this decision an easy one (the vehicle may fail emissions standards and may not be economically fixable); however, the scope of considerations affecting economic operation far exceeds the scope of considerations affecting motor vehicle department concerns.

In some respects, this problem is analogous to the problem facing nuclear power plant decision-makers who are considering extension of nuclear power plant life beyond 60 years. With nuclear power plants, there is a regulatory body (the Nuclear Regulatory Commission [NRC]) concerned with certain safety features; however, satisfying that regulatory body does not assure economic operation, although it does protect human safety and the environment. There is a national stake in assuring clean, long-term energy sources, and there are significant financial stakes for the nuclear power plant operator. Therefore, uncertainties in our understanding of long-term nuclear power plant behavior are highly significant in the sense that they matter to the decision and in the sense that really long-term operation has received much less attention over the years than operation for the originally licensed period.

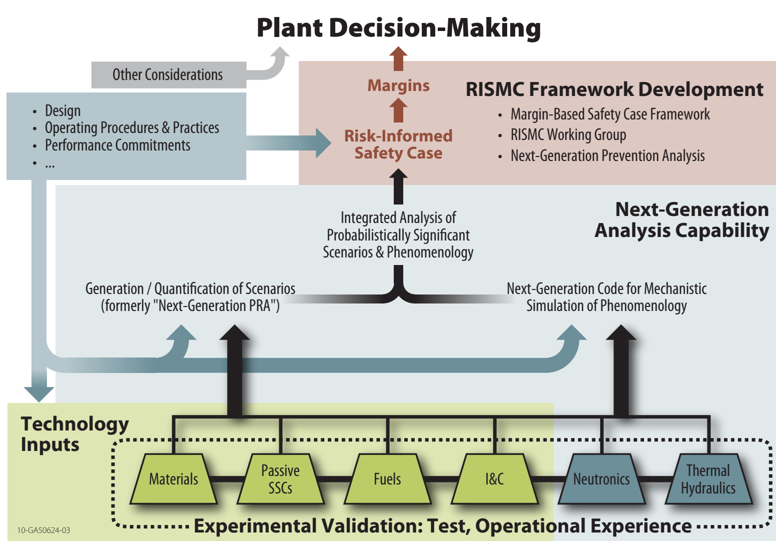
Accordingly, the U.S. Department of Energy's LWRS Program has been formulated to help the nuclear power plant decision-maker achieve economical operation beyond 60 years by identifying key issues and shedding light on how to resolve them. Within the LWRS Program, several other pathways address particular engineering domains (e.g., materials, fuels, and instrumentation and control). The Risk-Informed Safety Margin Characterization (RISMC) pathway is a simulation-driven approach to analyzing system and component safety margins in a way intended to help the decision-maker by showing the following:

- Significant uncertainties that adversely affect life-extension decisions
- Direct threats to economic operation that ought to be mitigated if doing so is practical
- Opportunities to improve plant economics by supporting recapture of safety margins that are not really needed for safety reasons.

This scope of work goes well beyond the scope of work needed to address NRC licensing considerations. Because the existing analysis tools are nowhere near optimal for carrying out this program of work, a principal focus of the RISMC pathway is a next-generation analysis capability to address the above issues and to address them in terms of safety margins characterized in a more realistic way than has been traditional in regulatory settings. Where traditional safety analysis has been based on limiting cases of design-basis scenarios, RISMC will need to analyze all probabilistically significant scenarios that bear on a given margin assessment, and reflect the state-of-knowledge uncertainties affecting the outcomes of those scenarios. Moreover, all this needs to be done in an integrated fashion for a range of issues affecting economical operation.

RISMC work is organized into three main activities:

(1) The centerpiece of the RISMC pathway is development of the next-generation analysis capability (sometimes called R7; corresponding to the light blue-shaded area in Figure 1). This development is aimed at characterizing margin in a risk-informed way (i.e., based on simulation and analysis of sufficient time histories to sample adequately within the appropriate domains of uncertainty and variability). Correspondingly, it



The Risk-Informed Safety Margin Characterization Pathway within the Light Water Reactor Sustainability Program.

will differ from current capability in several key respects:

- It is being formulated from the beginning to address uncertainty (e.g., in model parameters) and variability (e.g., in initial conditions and equipment behavior)
- Numerical methods used in the simulation engine reflect the current state of the art
- The simulation of system, structure, and component (SSC) behavior will be coupled more closely to scenario phenomenology than is practical in today's simulation codes.

The main output of R7 is characterization of key plant SSC margins in terms of the probabilistic load spectrum (showing the range of stresses applied to plant SSCs) and the probabilistic capacity spectrum (showing the state of our knowledge of the SSCs' ability to withstand the applied stresses).

(2) The RISMC Framework (shown in the reddish-tan area near the top of the figure) develops the life-extension safety case, in part, by driving R7 to characterize key margins. (The framework includes considerations that determine margins needing to be analyzed.) The output of the framework is the life-extension safety case, summarized to the decision-maker in terms of key safety margins.

(3) The Technology Inputs area (green area at the bottom) develops models for key SSCs that are compatible with the simulation approach implemented in R7 and can be coupled to relevant plant phenomenology parameters. For example, the Technology Inputs area is currently developing models for passive SSC failure that can be embedded into R7 and coupled to simulated temperature transients.

Currently, work within RISMC is being focused on case studies formulated and executed in collaboration with the Electric Power Research Institute and other nuclear industry parties.

Reconfigurable Simulator

By Bruce Hallbert
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Newer digital technologies afford greater functionality and are available to replace aging and obsolete analog instrumentation and control technologies. These replacements are widely recognized as potentially costly and risky, even though they are needed to ensure the long-term viability of safe and efficient nuclear power generation. The safe application of new technologies calls for a thorough understanding of how those technologies affect human performance and, in turn, nuclear power plant safety. In support of advancing instrumentation, information technologies, and controls in the existing fleet of light water reactors, the Idaho National Laboratory (INL) has developed a reconfigurable simulation laboratory capable of integrating advanced digital technologies with human-in-the-loop interactivity. The laboratory is being used to rapidly develop and conduct empirical studies on the safety, reliability, and performance of digital technologies for managing various aspects of nuclear power plant operations. This includes advanced control room information technologies and plant-wide information architectures that provide real time data access to support distributed work control and to improve plant status awareness and configuration control.

Studies are being initiated with partner utilities through a program of cost-shared research and development that demonstrates methods to advance the safety and efficiency of future operations through investments in modernization. As a part of these studies, a number of future concepts are being developed and tested that leverage digital capabilities and overcome limitations of current paradigms that are based on aging technologies and are labor intensive and error prone. In order to do this, the reconfigurable simulation laboratory is being equipped to support research and development of different advanced concepts and technologies.

The reconfigurable simulation laboratory provides a full-scale simulation model of an entire nuclear power plant control room or selected aspects of the nuclear power plant that are needed in an individual study to conduct research with advanced digital technologies. The representation of nuclear power plant systems and the human system interface is accomplished through a digital representation of nuclear power plant instrumentation and control systems (i.e., either a digital replica of analog interfaces or redesigned to a completely digital representation). Tests will be carried out, comparing the performance of advanced technologies with existing technologies, to evaluate the value of new technologies and to identify potential issues that must be addressed in future design and implementation of these technologies.

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INL has developed a reconfigurable simulation laboratory capable of testing human performance in multiple nuclear power plant (NPP) control room simulations.

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Each of these studies serves as pilot projects that will be used to develop best practices for deploying digital technologies to ensure that a viable and sustainable technology base is available for nuclear power plant control, to develop confidence in a process for technology migration, and to physically demonstrate safety improvements and other benefits that can be obtained and expected from investments in newer technologies. The reconfigurable simulator plays a key role in these studies and demonstrations and is used as the platform for tests and evaluations of new technologies and future concepts.

Cooling Water Issues for Nuclear Power Plants

By Gary Vine
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Water supply sustainability and energy-water conflicts related to consumptive use of water resources are emerging as global issues of increasing concern that may eclipse climate change as an environmental issue requiring societal action. Energy and water are both essential to sustainable development and economic productivity. Ample supplies of water are essential to energy production, and water management is dependent on ample supplies of energy for water treatment and transportation.

On both a global and national basis, the largest consumer of water is agriculture, with nearly 85% of water consumption in the United States dedicated to agriculture. In contrast, even though about 98% of U.S. electricity generation requires water for cooling or for direct use in generation, most of the water withdrawn for electricity production by the typical thermoelectric power plant (e.g., fossil, nuclear, and natural gas plants) is returned to the water body from which it was withdrawn, where it can be used for other purposes.

This "borrow and return" mode of cooling is called once-through cooling (OTC). Sixty percent of U.S. nuclear power plants use OTC, the other 40% uses closed-cycle cooling (CCC) technology that is based on either cooling towers or cooling ponds. It is important to note that CCC-based (i.e., evaporative) technology consumes about twice as much water as OTC.

U.S. Environmental Protection Agency implementation of the Clean Water Act requires CCC for new plants as a means of reducing impacts on fish and larvae. A forthcoming revision to the U.S. Environmental Protection Agency rules may result in the need to retrofit CCC systems on some operating plants. Such retrofits would be expensive (e.g., $500 million to $3 billion per reactor) and may introduce reliability problems and other environmental downsides (e.g., salt and particulate drift from towers). Further, because CCC consumes more water than OTC, an increased reliance on CCC will create additional stress on the nation's dwindling supplies of fresh water.

The U.S. Department of Energy's role in addressing these energy-water conflicts is important, because the conflicts have direct implications to national energy security, reactor plant performance, and grid reliability. Research, development, and demonstration can play an important role in addressing these issues through improved cooling tower technologies that consume less water, through less expensive and more effective alternatives to cooling towers, and through development of decision methodologies that can help decision-makers weigh and better align the competing environmental goals of clean water and air, climate change mitigation, water supply sustainability, aquatic life protection, and other relevant national objectives associated with energy supply.

The LWRS Program is beginning to address the challenges of water usage at existing nuclear power plants within the Economics and Efficiency Improvement Pathway. Energy-water nexus issues are included in the LWRS Program because they potentially threaten the long-term operation of nuclear power plants. Working closely with Electric Power Research Institute partners, identification of technologies and alternative assessment methods is underway and aimed toward reducing consumptive use of cooling water. A call for innovation will be issued in the near future to the general research and development community to stimulate ideas for technologies that reduce water use at nuclear power plants. Other collaborative research, development, and demonstration opportunities include the following:

- Field demonstrations of alternatives to cooling towers (e.g., wedge-wire or fine mesh screening technologies) and updated performance data on these and other alternatives
- Updated data on overall environmental impacts of OTC on host water bodies
- Cost-effective uses of waste heat
- Opportunities for expanded use of "non-traditional" sources of cooling water.

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