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PUR-1: A fully digital I&C installation driving innovation

The full implementation of a digital I&C system is reinvigorating Purdue's test, research, and teaching reactor, offering new possibilities for learning and understanding.

By Clive Townsend and Robert Bean

Nuclear industry insiders are quick to call for innovation and attracting the next generation of the nuclear workforce, but taking these bold steps into the future can take years or decades to accomplish. At Purdue University, work has been nearly completed on the design, installation, and, most important, licensing of a fully digitized instrumentation and control system.

The safety system utilizes an internationally certified neutron flux monitor in its scram circuitry, and the control system runs on a commercially available desktop computer. In a first of its kind implementation, the Purdue University reactor is moving toward a completely integrated digital nuclear space.

Framing the upgrade

The Purdue University Reactor Number One (PUR-1), a materials test reactor plate-type facility, first went critical in the late summer of 1962. Its initial mission was low-level neutronics research and materials testing, and it primarily served the undergraduate and graduate educational mission of the university. Early startup testing showed noise issues in the startup channel at low count rates, a problem that would plague the facility for the next 50 years. Noise spikes in this channel and its associated circuitry would cause spurious signals within the period meter, causing intermittent and unpredictable shutdowns. Facility documentation and log books show a perpetual cycle of problem identification, attempted correction, unexplainable return to operability, and approximately five years of consistent use. This cycle of "fail, find, fix" would rapidly accelerate in the 2000s, leading to a declared indefinite shutdown in 2013.

The Department of Energy has long supported the maintenance of the test, research, and teaching reactor (TRTR) fleet through infrastructure grants specifically targeting existing U.S. reactors. These critical grants have staved off the decline in the number of research reactors from a peak in the 1980s, and PUR-1 is no exception.

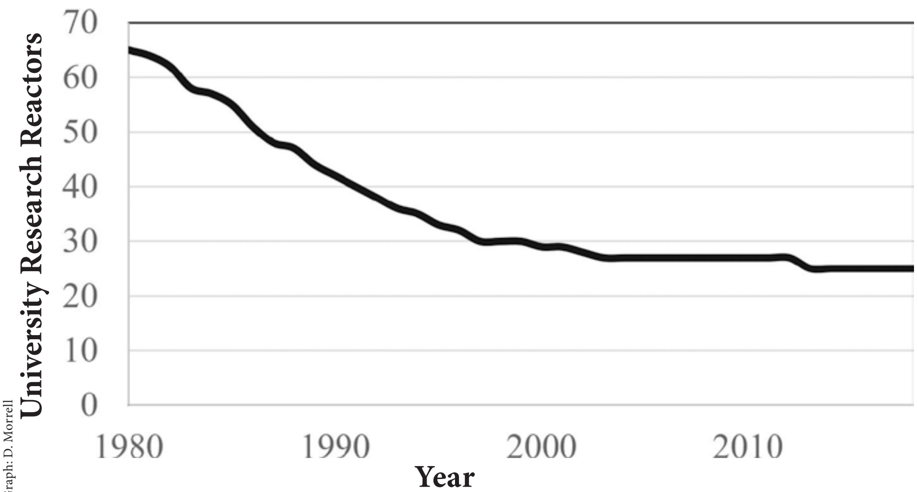
In 2012, Purdue received a grant from the DOE's Nuclear Energy University Program for the design and replacement of the PUR-1 console. This grant would enable the facility to remove legacy equipment that had long inhibited operational reliability and replace it with state-of-the-art I&C.

PUR-1's control console is augmented with a 150-square-foot video wall to maximize the data display capabilities. In addition to a reinvigoration of the educational space, the reactor is now poised to do fundamental research in cybersecurity applications at nuclear facilities. Aided by the flexible nature of research reactors, industry and university stakeholders are encouraged to actively collaborate in this important area.

Analog versus digital controls

A critical decision needed to be made early in the project: Should PUR-1 select proven solid-state circuitry using analog technology, or a digital paradigm that would have significantly greater data resolution and therefore potential future impact?

Analog systems have long served many facilities very well, and implementing them into reactor control and safety systems is straightforward and well understood. For many components, it would be



Graph: D. Morrell

Number of operating university research reactors in the United States

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Photo: School of Nuclear Engineering, Purdue University

Historic operations at PUR-1, measuring early operational characteristics.

a "like-for-like" replacement, easing the regulatory burden (under 10 CFR 50.59) and staff effort to approve and install. These systems are the workhorses of current reactor control electronics, and there was no doubt that they would allow the reactor to operate safely and maintain reliability for many years.

Over the first 50 years, PUR-1 had seen its mission shift from fundamental reactor physics research to serving primarily as an educational support facility. The reactor's primary use in recent years has been in several core nuclear engineering courses and to provide public outreach and education through tours and school visits. Looking ahead to the next 50 years of operation, the stakeholders of the reactor desired a return to impactful research while expanding and enhancing the reactor's teaching capabilities.

The advantages of a fully digital system were numerous. The current population of first-year engineering students have never lived in a world without a smartphone at the ready. They expect exciting new technology to be implemented in the classroom and in their future workplaces. The digital controls, augmented by the 150-square-foot video wall, provide significantly more excitement to an engineering student considering a nuclear career. The reality of the competitive educational realm is that nuclear engineering must compete with the rocketry and space engineers of aeronautical engineering, green and sustainability engineers of environmental engineering, and medical researchers of biomedical engineering. Without exciting new and impactful areas, nuclear engineering will experience significant brain drain to other fields as students seek worthwhile careers.

The digital scheme also allows the facility to open the door to important research in the area of nuclear security. A low-power reactor such as PUR-1 simply cannot compete with higher-flux facilities in the materials irradiation or isotope production fields. Given its extremely low-risk portfolio, however, it is a prime candidate for research into how integrated cyber-physical systems will play a role in delivering the efficiency and reliability expected from the commercial nuclear fleet. As digital components are integrated into distributed networks, the obvious cybersecurity questions must be answered. At Purdue, questions are being asked as to how this presents a new vulnerability to the facility, and also how this new technology can create an independent protection mechanism that is orthogonal to the historic defense-in-depth principles.

Finally, for both research and educational applications, a digital control system represents both a digital data acquisition system and a remote tool. Detector output and reactor operational parameters are tracked and stored on millisecond timescales by the system. Relevant data can be made available to researchers to enhance their ability to match reactor status to their experimental results, and the digital data can be viewed remotely, which makes distance-learning possible for those who do not have access to a nuclear facility.

In view of these advantages, the School of Nuclear Engineering at Purdue decided to install a fully digital reactor control and reactor safety system. The neutron detector signals, inherently analog by nature, are digitized when they first reach the instrumentation modules, and all control and safety actions are based on calculations and comparisons of the digital values. The question was less "Which system is better?" and more "What system do we want to have 10, 15, or 20 years from now?"

Expansive growth

Purdue's College of Engineering has seen significant growth under the tenure of President Mitch Daniels, former Dean of Engineering Leah Jamieson, and current Dean of Engineering Mung Chiang. In 2019, the college expects to see an enrollment of more than 10,000 undergraduates and a 70 percent increase in undergraduate applications. Over $25 million has been invested in reimagined space, including significant upgrades to the Nuclear Engineering Radiation Laboratory, which houses PUR-1. This year also marks 150 years since the founding of Purdue, and the university is actively exploring how its impact will be felt for the next century and a half. Likewise, the School of Nuclear Engineering has been experiencing a steady increase in enrollment in recent years, and 2020 marks its 60th anniversary. The choice to pursue digital I&C at the Purdue reactor facility complements mission statements by the university, the College of Engineering, and the School of Nuclear Engineering.

TRTR licensing

Research reactors such as PUR-1 are uniquely positioned to forge ahead into the application of digital technology within safety-significant systems. In 1954, when Congress passed the Atomic Energy Act, specific provisions were included to ensure that fundamental research in the field of nuclear energy would have as few inhibitions as possible. With respect to research and development activities, it read, "The [Atomic Energy] Commission is directed to impose only such minimum amount of regulation of the licensee as the Commission finds will permit the Commission to fulfill its obligations . . . to promote the common defense and security and to protect the health and safety of the public and will permit the conduct of widespread and diverse research and development."[1] Through the lens of this very specific language, the licensing process for research and test reactors is significantly less strenuous than for their commercial counterparts.

The Nuclear Regulatory Commission has also recently issued calls for its staff to develop a more risk-informed and flexible regulatory framework. The transformation should include a risk-informed process that is agile, innovative, predictable, anticipatory, and results driven, as stated in Project Aim 2020.[2] In the licensing of the digital I&C for PUR-1, the license amendment request acceptance-

1. *Atomic Energy Act of 1954.* United States of America, 1954.

2. K. Fitch et al., *Achieving Exemplary Nuclear Regulation in the 21st Century*, 2015.

Photo: School of Nuclear Engineering, Purdue University

The new PUR-1 control console with fully digital safety and control systems, to be commissioned in 2019.

to-approval timeline is expected to be just less than two years. This timeline includes supplements by the Purdue staff, requests for additional information from the NRC, an on-site document audit, and final approval.

The Purdue licensing strategy worked to leverage this call by the commission to its staff, as well as to minimize the change to facility operations. Both the reactor control system and its safety counterpart were designed to directly mimic the system-level functionality of the original design. The reactor retains the same number of control blades, neutron flux monitoring channels, diversity of parameter indication, and location of annunciators. The indications for rod height, reactor power, and rod drive selection are in similar locations in the old and new designs. By mimicking the design, the licensing conversation could center on digital implementation of the system rather than the suitability of the design.

Outlook

PUR-1 is now poised to pave the way for future nuclear engineers in teaching and research. The College of Engineering is driven to deliver in three principal areas, all of which PUR-1 is now in a position to perform. At the interface of virtual and physical engineering lies the principal source of efficiency improvements, concentration of cybersecurity vulnerabilities, and potential failure modes. PUR-1 will study and develop ways in which this interface can become an asset to the resiliency and risk assessment engineer.

The large pool of premier engineering talent is growing rapidly through online learning, diversity of background, and innovative cross-discipline studies. From this expansive population of students, nuclear engineers will grow and thrive to deliver solutions to today's most pressing issues. Finally, as the university continues to strengthen its industry partnerships in all areas, including curriculum innovation, workforce development, research impact, and entrepreneurship, the work being done at PUR-1 will have a rapid and lasting impact in the field.

Reference

D. Morrell, *2018 Status Report: DOE Research Reactor Infrastructure Program*, Newport, 2018. NN

Photo: School of Nuclear Engineering, Purdue University

Outreach and engagement remain central components of the mission of PUR-1 and Purdue University.