Safe and Sound

By Robert Mills

RESEARCHERS DEVELOP A NEW APPROACH TO CONTINUOUSLY MONITOR THE HEALTH OF THE NEXT GENERATION OF NUCLEAR POWER PLANTS

Nuclear power plants are producing electricity at record rates, providing about one-fifth of our nation's electricity. Helping to keep them running — and more important, running safely — is a powerful technology called nondestructive evaluation (NDE). By providing the ability to peer inside critical pipes and structures without having to destroy them, NDE has become essential to the nuclear power industry.

"But we can do better," says Norio Nakagawa, a physicist at the Center for Nondestructive Evaluation (CNDE) and Ames Laboratory. He and his collaborators are applying decades of NDE experience to future nuclear reactor designs. "We are giving NDE consideration while the system design is being developed. That's rather new in the nuclear business," Nakagawa says. The researchers are about two years into the three-year project, part of the U.S. Department of Energy's Nuclear Energy Research Initiative (NERI), being funded through the Ames Laboratory.

NERI's purpose is to address the long-term barriers to expanding the use of nuclear power to ensure that the U.S. can meet its future energy and environmental needs. The Ames Lab portion aims to develop concepts for on-line health monitoring of nuclear reactors, helping to overcome safety and economic hurdles to building new nuclear power plants. In addition to Nakagawa, the research team includes R. Bruce Thompson and Feyzi Inanc of CNDE and the Ames Lab and Warren Junker of Westinghouse Electric.

"We are addressing the safety issues of the next-generation nuclear power systems," Nakagawa says. "Safety is the ultimate need for those systems." Indeed, the on-line system will provide continuous monitoring so that deviations from normal operation can be detected immediately, and problems can be addressed before they become serious. Moreover, on-line monitoring is done remotely, greatly reducing exposure levels of maintenance workers.

Economics are also important, of course. "For nuclear power to be able to compete with other methods, it has to improve its operational costs," Nakagawa says. One way new reactor designs achieve this goal is by extending the refueling cycle to four years or more. This objective, however, makes today's "outage-based maintenance" approach problematic, where critical inspections are done when the plant is shut down for refueling, typically every 18 months. With the help of on-line health monitoring, designers of the next generation of nuclear reactors can reach the four-year goal to create plants that are safe and economically competitive.

One next-generation nuclear power plant design is called the International Reactor Innovative and Secure, or IRIS. It's being developed by an international consortium of researchers from industry and government in nine countries. This proposed reactor design is a descendant of the pressurized water reactor and will be built with proven components. The key innovation is integration of the reactor core, steam generators and pumps in a single reactor pressure vessel. An IRIS reactor is consequently compact and cost-effective, and requires less maintenance. This design is said to eliminate many of the safety problems with conventional nuclear power plants.

The Ames Lab team is developing concepts that can be engineered into the IRIS system. "Our integrated inspection approach will help make their system more acceptable. Certainly, they can boost safety and reliability of their system with these kinds of capabilities," Nakagawa says. He adds, however, that the team's concepts are generic enough to be used by designers of other types of nuclear power systems.

"The question is, how do we reduce redundancy without compromising safety, or even while improving safety? Our answer to that question is the on-line, integrated monitoring approach," Nakagawa says. The first step of the project has been to develop the overall concept. "Of course, there have been on-line sensors — temperature gauges, and so on — but we are expanding the scope of the on-line sensor concept to the maximum," Nakagawa says.

The second component of the project is to identify the most critical areas in need of on-line monitoring and then develop NDE concepts to address each. The Ames Lab researchers are also developing sensitivity estimates for each technology. "That will tell us how much sensor output to expect," Nakagawa says.

The first area is steam generator tubing. As the name indicates, a steam generator boils the secondary water into steam that circulates outside the reactor. Even in the compact IRIS design, steam generators require a fair amount of tubing to maximize heat transfer efficiency from the core to the steam. "The tubing is very important in terms of safety inspection," Nakagawa says. One problem is magnetite deposits, black iron oxide that builds up where the coolant in a steam tube evaporates. "Bad things happen when these deposits occur," Nakagawa explains. The magnetite buildup reduces heat transfer and creates a corrosive environment.

To continuously monitor magnetite buildup, the Ames Lab team is proposing a built-in eddy current (EC) sensor. Essentially, EC sensors work by using a probe made of a wire coil. An alternating current passed through the probe generates a magnetic field around it. The probe's changing magnetic field generates current flow, or eddy currents, in the material. In turn, the eddy currents produce their own magnetic fields that generate reaction voltages in the coil. The result is a change of the coil impedance, which can be measured to gather information about the test material.

EC sensors are tough enough to survive the elevated temperatures and radiation found inside a nuclear reactor. For steam generator inspections, Ames Laboratory researchers are proposing a system in which an EC coil encircles tubes to provide a way to detect potential magnetite deposits inside the tube. One coil might even be able to monitor several tubes inside of it.

Another critical inspection job is determining the structural integrity of steam generator tubes, especially where the tubes are attached to key support points, often by welding. “We do as much as possible to not create weak points, but some level of welding can’t be avoided,” Nakagawa explains.

For these areas, the researchers are studying ultrasonic testing using an electromagnetic acoustic transducer (EMAT). Basically, an EMAT generates a static magnet field and alternating electric field inside the test piece placed nearby. The resulting force, called the Lorentz force, acts on the test material to generate sound waves that travel some distance. At the receiving end, these sound waves, in combination with the magnetic field, produce an electrical voltage that can be measured to provide information about the test material condition.

Unlike the more familiar type of ultrasonic testing (UT) used in medical applications — in which the sensor is coupled with the body via a thin layer of fluid or jelly — EMAT UT does not require that the sensor and sample be in contact. That, and the ability for EMAT coils to withstand high temperatures and radiation, makes EMAT UT an ideal NDE technology for nuclear power plants.

Moreover, EMAT UT can be used to send an acoustic wave, called a guided wave, down a tube to inspect its entire length. “Hopefully, our studies will tell us whether or not we can actually make a wave travel as far as needed, about ten meters,” says Nakagawa. The researchers are also exploring the use of EMAT UT for monitoring the reactor pressure vessel for cracking.

Another area under study is how to better monitor radiation levels in the reactor core by using radiation detectors, one more proven NDE technology. “By nature, there is radiation coming out of the system itself. We’re trying to take advantage of that activity,” Nakagawa explains. The technology may be used to monitor reactor fuel activities, the flow of primary water inside the pressure vessel and perhaps other critical events.

The concept relies on new silicon carbide sensors developed by Westinghouse. These on-chip detectors, about one-fourth the size of a dime, can withstand the high temperatures and radiation found in a nuclear reactor. The researchers are creating models to estimate gamma ray radiation intensities as functions of locations over the reactor life to determine how to best use these detectors.

Nakagawa believes the Ames Lab effort can help make nuclear power safer and more economical. “I understand people’s feeling about nuclear power,” says Nakagawa. “But, the economic pressure is there, and conserving natural resources is an important consideration. I hope people can take a long view.”

For more information: Norio Nakagawa, (515) 294-9471
nnakagaw@cnde.iastate.edu
Research funded by: DOE Nuclear Energy Research Initiative program.