Feature—EPRI's Value, Post-Fukushima

Industry Leaders Point to Research and Leadership in Four Areas

By Brent Barker

Five years ago, the Great East Japan earthquake, the second largest in recorded history, shook the islands of Japan for three minutes. The 9.0 magnitude offshore earthquake lifted the ocean and sent a tsunami racing across northeastern Honshu Island, devastating towns, killing thousands of people, and disabling and eventually destroying three operating nuclear reactors at the Fukushima Daiichi plant. Japan was thrust into a state of emergency, and EPRI and others rushed to provide critical technical assistance in managing an unfolding nuclear accident.

Fukushima raised concerns worldwide about nuclear power plants' ability to survive extreme external events that could severely damage reactor cores. To address those concerns, the U.S. nuclear industry mobilized quickly, and the Nuclear Energy Institute (NEI), Institute of Nuclear Power Operations (INPO), and EPRI spearheaded a collaboration called The Way Forward. At a time when ideas were flying in all directions, they provided focus and coordination in the United States. "We did a tremendous amount of work in a relatively short time," said Tim Rausch, chief nuclear officer of Talen Energy and chairman of EPRI's Nuclear Power Council. "The teamwork helped us to clearly articulate the problems and provide meaningful solutions, including a template for action."

The U.S. Nuclear Regulatory Commission (NRC) asked every nuclear plant to use the latest science to analyze the potential impacts of earthquakes. In response, NEI, INPO, and EPRI initiated a rigorous seismic hazard reevaluation to determine if changes were needed for earthquake protection.

"EPRI assumed a technical leadership role in this effort," said NEI Chief Operating Officer Maria Korsnick, who was chief nuclear officer of Constellation Energy at the time.

According to Dave Heacock, chief nuclear officer of Dominion Power, EPRI was instrumental in completing the multi-layered calculations required to accurately quantify earthquake effects.

In addition to seismic reevaluation, industry leaders point to three other areas of EPRI's technical leadership in the five years since Fukushima: response to the accident itself, updating the technical basis for severe accident management guidelines, and research on filtered venting to mitigate accidents.

Response to Fukushima

Immediately after Fukushima, EPRI helped Tokyo Electric Power Company with urgent needs, such as removal of cesium buildup in the cooling water of the damaged reactors. EPRI's Modular Accident Analysis Program (MAAP) was used from the outset to improve understanding of the sequence of events and observed phenomena, and to help efforts to locate the molten cores.

The Japanese government has begun funding enhancements to MAAP for use in decommissioning the plant. The code is now used by more than 70 organizations in 17 countries. As Japan's nuclear utilities conduct analyses to demonstrate that their plants can be restarted safely, they are using MAAP to evaluate plant responses to upset conditions and the progression of potential severe accidents.

"Fortunately for all of us, EPRI had built relationships of trust with the Japanese that preceded the accident, and this put EPRI in a special place," said Korsnick. "EPRI was granted unprecedented access to information, people, and conversations because they are so well trusted and have such high credibility. And their credibility helped frame the response of the U.S. nuclear industry."

EPRI applied knowledge gained through the Fukushima experience to other nuclear plants. In 2012, EPRI updated the technical basis for Severe Accident Management Guidelines developed by reactor vendors and plant operators. "This is used all over the world," said EPRI Fellow Rosa Yang. "It identifies measures that can be taken to minimize the severity of an accident at each stage, and can assist in providing the technical foundation for guidelines formulated for individual plants."

"The guidelines have positioned the industry to better prepare for and manage a severe accident," said Korsnick.

Seismic Research

EPRI worked with other experts to assist the industry through the NRC's seismic reevaluation. Fortunately, the scientific backbone had been under development long before Fukushima, according to Stuart Lewis, EPRI senior program manager.

"EPRI worked with the U.S. Department of Energy and the NRC to calculate the seismic hazard, capturing a lot of new geological data. In parallel, EPRI continued to develop and improve the methods for looking at the probability of failure as plants respond to earthquakes," said Lewis. "The result was the creation of a comprehensive seismic risk assessment model for nuclear plants at the time we needed it."

Researchers found that earthquakes east of the Rockies travel farther and vibrate at frequencies higher than those in the western United States. "The reason is that the rock in the East and Central regions of the country is older and more mature," said Heacock.

Most plants in these regions were designed based on west coast earthquake data because there was more of it. Newer data indicate that the seismic hazard to some plants in the Central and Eastern United States is greater than originally thought.

Five months after the Fukushima accident, a 5.8 magnitude earthquake in the Piedmont region of Virginia forced the shutdown of Dominion Power's North Anna nuclear plant just 10 miles from the epicenter. The earthquake—the second largest east of the Rockies since 1897—damaged the Washington Monument and was felt as far away as Florida and New York. The ground motion slightly exceeded North Anna's design standards, triggering NRC review.

"Once plants are shut down after an earthquake above a certain threshold, NRC approval is required to restart," said Dominion's Heacock. "We had to go through a formal public review to verify that the safety equipment wasn't damaged. EPRI helped with the analysis, which supported our case to the NRC."

The frequency of ground motion during an earthquake, measured in cycles per second or hertz (Hz), is critical in determining its impact on structures and equipment. The 1–10 Hz range is the riskiest for most structures, including nuclear power plants. 1–3 Hz affects plants' massive structural parts, such as containment, while 3–10 Hz affects piping systems, pumps, and other heavy equipment. Above 10 Hz, vibration primarily affects electronics, instrumentation, and relays.

NRC's reevaluation has relied heavily on seismic transport models, which calculate ground motion from the epicenter through bedrock to a location just below the structure under evaluation, and then up through the soil to the structure. Soils can amplify low-frequency vibrations and attenuate high-frequency vibrations. For structures, vibration amplitude increases with the building's height, which explains why the Washington Monument was damaged by the Virginia earthquake. For modeling earthquake impacts, each leg of the transport requires a separate calculation.

"EPRI played a huge role in determining the best way to calculate all those separate transport elements and how they work together," said Heacock.

The NRC also called for a separate analysis of impacts of high-frequency earthquakes. In the United States, EPRI took the lead to test equipment that might be affected by ground motion above 10 Hz. Researchers put switches, relays, and other potentially susceptible components through rigorous testing on shake tables, mostly in the 20–40 Hz range, though some tests went up to 64 Hz. The upshot: 75% of the components worked without problems. All the parts showing adverse impacts under high-frequency conditions also had impacts in previous low-frequency tests, indicating no unique high-frequency sensitivity.

Filtered Vent

Post-Fukushima, the NRC proposed a ruling that boiling water nuclear reactors with Mark I or II containments (similar to the damaged reactors in Japan) install large external filters on venting systems. Under normal operating conditions, operators wouldn't use the external filter. But under accident conditions, gases building up in the reactor would be vented to the filter to reduce pressure and temperature as well as scrub radioactive materials. Such systems had already been adopted in many parts of the world.

"The filter is similar to a big bubble bath," said Yang. "You bubble the gas through a large tank of water and chemicals that filter out most of the radioactive material without releasing it to the environment."

"The industry team, composed of EPRI, NEI, and INPO, opened up a wider discussion about the filters," said Korsnick. "What's the purpose? What are we really trying to do with the filter? We concluded that the purpose is to prevent releases of radioactive materials and prevent land contamination. EPRI proposed a better way to do that."

That better way consisted of flooding and injection of water into containment during an accident to lower the reactor's pressure and temperature, cool the damaged fuel, and trap radioactive particles. "Because these external filters are just tanks filled with water, the water in containment can be just as effective in cleanup," said Korsnick.

The NRC was skeptical, asking for proof of effectiveness under all possible accident scenarios—a tall order considering that there are thousands of pathways.

"We used the MAAP code to simulate accident scenarios," said Yang. "Most severe accident codes would take weeks to run a single case. But using MAAP on our supercomputer Phoebe, we could run thousands of cases overnight. In the end, we ran tens of thousands of scenarios to prove our concept."

"EPRI's work had the technical rigor that was needed to make a strong case to the regulator," said Joe Pollock, vice president of nuclear at NEI. "When presented with the MAAP runs, the NRC then ran its own independent calculations with different computer models to validate the results. EPRI's results held up, and the NRC accepted them."

Although safety and simplicity are unchanging objectives, eliminating the external filter will save an estimated $35–50 million for each of the 30 boiling water reactors in the United States. For the U.S. nuclear industry, savings could reach $1.5 billion.

"There is so much EPRI offers, in so many areas—avoided cost, cost savings, and improvements in safety, efficiency, and reliability," said Tim Rausch. "The value is a combination of savings across an entire industry and around the world, some tangible, some intangible."

Robust Design of Nuclear Plants

There is much empirical data on earthquakes' impacts on nuclear plant structures and components—what failed and what held up. One overarching observation is that nuclear plants are anything but fragile. They have been designed with exceedingly robust margins of safety and structural integrity and reinforced to ensure radiation protection. Inspections immediately after earthquakes have found little damage (see *EPRI Fukushima Daini Independent Review and Walkdown* for more details).

In Japan, earthquakes are part of life (19,000 earthquakes over 3.0 magnitude in 2011 alone), and its nuclear units have been tested repeatedly and held up well. While the tsunami triggered by the Great East Japan earthquake devastated the Fukushima Daiichi reactors, little damage resulted from the ground motion itself.

"The structures themselves are very robust, and the piping system, designed for high pressure and radiation protection, is not a problem," said Dave Heacock, chief nuclear officer of Dominion Power. "The problems are with tanks that can topple and electrical components. With high frequency vibration, relays start to chatter, and their settings change."

After Fukushima, concern arose regarding the susceptibility of spent fuel pools to earthquake damage. "An EPRI evaluation showed that spent fuel pools are also extraordinarily strong. Designed for radiation shielding as well as structural strength, they have two to three feet of reinforced concrete with a steel liner," said Heacock. "The pools have no holes except near the very top, so even if the piping system ruptured, the pool would not drain below a very high level. There would still be plenty of water over the fuel."

Key EPRI Technical Experts

Stuart Lewis, Rosa Yang