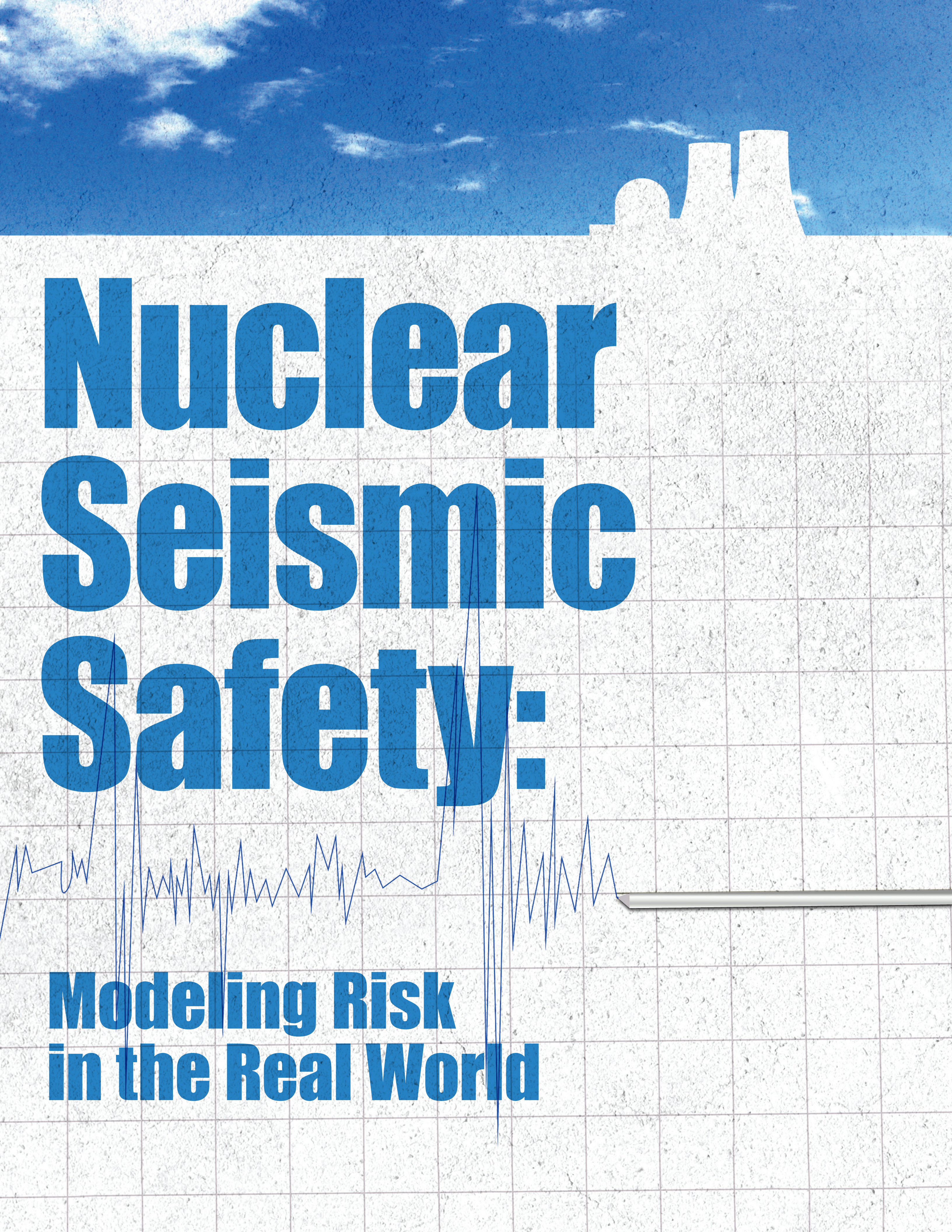

Nuclear Seismic Safety:

Modeling Risk in the Real World

On January 12, 2010, a magnitude 7.0 earthquake struck Haiti, killing more than 200,000 people. The next month, a magnitude 8.8 earthquake struck Chile. Though the Chilean earthquake released about 500 times as much energy as the one in Haiti, the death toll was only about 500. Clearly the Richter scale alone does not capture the dangers or risks posed by specific quakes.

The American poet Ralph Waldo Emerson said, "We learn geology the morning after the earthquake." It's an interesting thought from a poet, but it is not good enough for engineers, particularly where nuclear safety is concerned. To reduce the chances that seismic activity could impact nuclear plant safety, EPRI is participating in several projects to help the industry better understand seismic risks and how to minimize damage in the event of an earthquake. EPRI also is engaged in a range of initiatives with government agencies and research institutions to learn how the type and intensity of earthquakes can vary with local geology.

Despite the nearly 1,000 magnitude 5.0 or greater earthquakes that occur each year, and after more than half a century of nuclear generation, earthquakes have yet to cause a single significant safety incident at a nuclear power plant. In 2007, Tokyo Electric Power Company's 8,212-megawatt (MW) Kashiwazaki-Kariwa Power Station was hit by a magnitude 6.8 earthquake—a temblor that significantly exceeded the plant's design level—and all operating reactors were shut down safely (see "Damage Assessment: A Case Study," page 16). Continued development of procedures and protocols for the construction and operation of power plants can maintain that unblemished record.

THE STORY IN BRIEF

Researchers know—and recent events have demonstrated—that the risks and challenges posed by earthquakes go beyond a simple magnitude number on the Richter scale. Ground motion and its effects on buildings and other structures depend on the type of fault, vibration frequency, local geology, and other factors. EPRI and the nuclear power industry are developing new data and advanced analytical tools to create a more accurate picture of seismic risk at nuclear plants.

Assessing Risk

Seismic research has dealt primarily with ensuring that plants can withstand earthquakes characteristic of the Pacific Rim. Other parts of the world may be subject to earthquakes of a different character.

"The earthquakes west of the Rockies and along the Pacific Rim are vastly different from those east of the Rockies," said EPRI senior project manager Bob Kassawara. "Earthquakes in the West are powerful in the frequencies of concern for nuclear power plants—up to 15 Hz. East of the Rockies, nuclear plants are designed for those same kinds of earthquakes, but the ones that occur there are typically at a higher, less dangerous, frequency."

EPRI is working with the U.S. Department of Energy (DOE) and the Nuclear Regulatory Commission (NRC) on the Central and Eastern United States Seismic Source Characterization for Nuclear Facilities Project. This is the first comprehensive look at earthquakes and their effects on nuclear power plants in that part of the country in more than 20 years. The final report is expected by the end of 2010.

"The central and eastern United States has a lot of seismic activity, although this is not commonly recognized because much of the most damaging activity occurred many years ago," said Jeff Hamel, EPRI program manager. "Documenting the historical activity and understanding what it has to say about future seismic risks is front and center for our project. This is a great example of a truly collaborative effort by the nuclear industry."

The study will replace a 1989 EPRI study, reflecting updated research and generating a new model of seismic activity that can be used to assess risks at existing and proposed plants. The project has brought together experts from industry, government, and academia to analyze previous earthquakes in the central and eastern United States and produce an updated earthquake catalog that will be made available to the public.

"Drawing from this broad pool of experts, we have gathered a great deal of information and gained consensus on key technical issues," said Hamel. "Observers from South Africa, Japan, France, Switzerland, Germany, and other countries are interested in how we're conducting the project so they can apply the process to seismic assessments in their countries."

For new plants, the NRC requires a site-specific probabilistic seismic hazard analysis for plant licensing. The analysis quantifies seismic risks posed by the site under various conditions. Seismic source characterization—the first step in such an analysis—estimates the magnitude of the earthquake at its source, the type of fault, and the site conditions. By incorporating relevant data from thousands of earthquakes

Damage Assessment: A Case Study

Tokyo Electric Power Company's 8,212-MW Kashiwazaki-Kariwa Nuclear Power Station is the world's largest. Four of TEPCO's seven units were operating on July 16, 2007, when a magnitude 6.8 earthquake hit the area. Although the operating reactors were shut down safely, there was some damage to nonsafety equipment and structures: a transformer caught fire, pipes broke, part of the fire suppression system failed, and air ducts were damaged.

"This earthquake was up to three times the design level of the plant, and they experienced no safety-related issues," said EPRI senior project manager Bob Kassawara. "This shows a tremendous amount of margin in the design and what it is actually capable of resisting."

EPRI technical executive Ken Huffman happened to be en route to Tokyo at the time of the earthquake, touching down in Japan about two hours after it struck. At TEPCO's request, he met with TEPCO senior technical management and provided input on a plant assessment strategy, as well as U.S. postearthquake evaluation practices contained in EPRI documents. In September an EPRI review team inspected the structures, systems, and components for earthquake damage.

"EPRI had an established evaluation process for conducting postearthquake walkdowns to assess the condition of the plant," said Huffman. "These existing guidelines included what critical equipment to look at and what features to evaluate."

EPRI found that the safety equipment was all intact and that the nonsafety systems had minimal damage. Although there was no visible damage to safety equipment, questions remained about damage that might not be apparent from plant inspections. Because the earthquake exceeded the plant's design basis, the case had to be made that the units could operate safely. EPRI assisted TEPCO in devising a restart strategy that involved both inspections and testing to ensure that the equipment was undamaged and would operate successfully.

The effort benefited from a knowledge base on plant equipment and structure vulnerabilities, which EPRI had compiled over the years from field observations made at numerous nonnuclear facilities following earthquakes and from seismic equipment qualification laboratory tests.

EPRI reviewed and provided input to analytical studies conducted by TEPCO to calculate the loads resulting from this earthquake, which then were compared with seismic acceptance standards to demonstrate that the equipment could operate safely or to guide prudent structural reinforcement. "EPRI's peer review and presentations at international conferences were especially important to us, as they showed that the methods we developed to check the integrity of our facilities were valid and rational from the point of view of an independent third party," said Kazuyuki Nagasawa, deputy manager in TEPCO's Nuclear Asset Management department.

Following the inspections, analytical modeling, structural reinforcement, and tests, TEPCO received approval to start bringing the reactors back on line. The two largest reactors—Unit 7 and Unit 6—were restarted in May and August 2009, and as of June 2010, Unit 1 was undergoing functional tests prior to returning to commercial operation. Evaluations, inspections, and seismic reinforcement are under way on the other units in anticipation of returning them to service.

over the past 20-plus years with advanced seismic modeling, the Seismic Source Characterization Project will result in a more accurate representation of earthquakes that could affect a given site.

The second step in creating a probabilistic seismic hazard analysis is to look at attenuation—how the energy from a seismic event is transferred from the source over distance, through different rock and soil layers, to create motion at the plant site. "Seismic attenuation models enable you to estimate how a given earthquake would have been felt at your plant site," said Kassawara.

Also in this area, EPRI is participating in research conducted by the Pacific Earthquake Engineering Research (PEER) Center at the University of California at Berkeley. In 2008, the center completed a next-generation attenuation model for the western United States, and in 2010, it launched a corresponding program for the central and eastern United States, to be completed in 2014.

"The West experiences very frequent, shallow earthquakes," said PEER Executive Director Yousef Bozorgnia. "The central and eastern United States experiences infrequent but occasionally very large magnitude earthquakes. Since there are so many nuclear power plants in the central and eastern United States, this is of concern to the nuclear industry."

In addition, the characteristics of the rock, soil, and sediment are different in the East and West, affecting the way earthquake energy is transmitted to the surface. For its attenuation project, PEER has assembled experts and researchers from many U.S. states, Europe, and Australia. Nuclear power plant owners and operators are participating through EPRI. The NRC, DOE, and the U.S. Geological Service also are participating in the project to ensure they will have more robust models to use when evaluating applications for new nuclear plants.

Although the research also will be available for assessing risks to bridges, buildings, and other infrastructure, it aims primarily to help the nuclear industry improve plant safety and to support an efficient, effective permitting process. All of the publications and attenuation models will be available free of charge, and PEER will create and place on its web site a database of recorded and simulated ground motion.

Sharing the Wealth

With the renewed interest in nuclear power plants worldwide, EPRI is conducting the research needed to build and operate plants safely and economically. "Much of our research has focused on evaluating whether seismic regulations are commensurate with real seismic hazards," said Kassawara. "Nuclear power plants are designed conservatively for large western earthquakes. An analysis is performed for each site to ensure that the design is adequate for the earthquakes that actually could occur at that site, according to the hazard analysis."

In addition to the work discussed above, EPRI has assembled a range of data and models on soil-structure interaction to study how plant buildings themselves—hundreds of thousands of tons of steel and concrete—affect the ground motion beneath them, and how individual pieces of equipment are affected by these modified motions. Taken together, these findings can help ensure integrity and operability of plant components.

Historically, the safety of plant buildings and components is assured by giving them strength adequate to resist the motions and forces resulting from earthquakes without becoming overstressed, damaged, or inoperable. Office buildings, bridges, and other conventional structures rely on seismic isolation, which involves building the structure on flexible devices, or isolators. These shift the vibration frequency of the combined system downward, below the frequencies of the damaging ground motions. Because isolators absorb energy and change the nature of seismic motion, a structure and its interior components are subjected to significantly gentler, relatively slow swaying motions.

So far, two nuclear plants have used seismic base isolation: the Cruas plant of Electricité de France (EDF), near Montelimar, France, and Eskom's Koeberg Power Station, near Cape Town, South Africa. At these plants, each reactor sits on 1,800–2,000 neoprene pads, which measure about 2 feet on a side and several inches thick. Seismic isolation concepts have improved since these plants were built in the 1980s, and EPRI is evaluating further study of seismic isolation's wider use in the design and construction of nuclear plants.

Experience has proven that current methodologies have resulted in safe nuclear plant designs with effective margins for earthquake risk. It is also clear that opportunities exist to advance our understanding of earthquake risks and impacts and to give plant location and geologic variables more weight in calculating appropriate design requirements. EPRI is pursuing both conventional and advanced design and analysis concepts to inform rule making and to ensure that nuclear plants will continue to respond safely to seismic events.

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Jeffrey Hamel, program manager of Advanced Nuclear Technology, oversees research on near-term deployment of advanced light water reactor plants, development of GEN IV technology, and technical and commercial support for an integrated spent fuel management strategy. Prior to joining EPRI in 2007, he worked at General Electric as the manager of specialty projects and was responsible for leading new growth for GE's nuclear business. Hamel received a B.S. degree in marine transportation from the Massachusetts Maritime Academy and an M.B.A. from Santa Clara University.

Ken Huffman is a technical executive specializing in plant technology issues, including equipment reliability, instrumentation and controls modernization, risk and safety methods, and development of long-term plant operation solutions. Before joining EPRI in 1991, he served at Westinghouse, leading activities associated with nuclear component design and manufacture. Huffman holds a B.S. degree in mechanical engineering from the University of Nebraska.

Robert Kassawara is a senior project manager in the Nuclear Power Sector's Risk and Safety Management program. His research activities focus on seismic issues for operating and planned nuclear power plants, seismic qualification of equipment, performance-based fire-protection engineering, and physical plant security issues. Before joining EPRI in 1985, he worked at Impell Corporation and at Combustion Engineering. Kassawara received a B.S. in civil engineering from the Polytechnic Institute of Brooklyn and M.S. and Ph.D degrees in civil engineering from the University of Illinois.