We tend to think of infrastructure as roads and bridges, water mains and sewers. But power plants are every bit as much infrastructure. And the decision of whether to maintain or replace, which must be made when bridges or tunnels reach the end of their lives, is a necessary one to determine with the power infrastructure as well.

The United States has a fleet of 100 nuclear power plants that provide nearly 100,000 megawatts of nameplate capacity and about 20 percent of the net generation. That nuclear fleet has provided many benefits: It is the most reliable source of electrical generation with stable generation costs. Nuclear plants emit no carbon dioxide, and they have a small land footprint compared to other carbon-free energy sources.

Most of those nuclear plants were built in the 1970s and 1980s and each was given a forty-year operating license from the U.S. Nuclear Regulatory Commission. Because of proactive efforts to create and comply with the existing License Renewal Rule (for 40 to 60 years of plant operation), some 53 reactors that reach their 40 years of licensed life by 2020 can now be kept online representing 45,000 MWe of generating capacity (equivalent to the total electrical generation from all sources in 2010 of California and New York). Similarly, the existing License Renewal Rule supports the potential for an additional 45 reactors to reach 40 years of licensed life by 2030 and then continue to produce electricity representing another 51,000 MWe of generating capacity (equivalent to the total electrical generation in 2010 of Pennsylvania and Alabama). Two more have licenses that expire after 2030.

The question to maintain or replace this nuclear generating capacity is complicated by the difficulty in building new plants. New plants are multi-billion-dollar investments. It has been difficult to convince capital markets to make that money available at reasonable costs. (The generating capacity that has been added in the U.S. in recent years has been in the form of natural gas and wind power facilities, which are smaller and easier to finance.)

With increasing carbon restrictions and the growing demand for electricity, reliable, carbon-free baseload electricity generation is more important than ever for the United States.

Nuclear's next 40 years

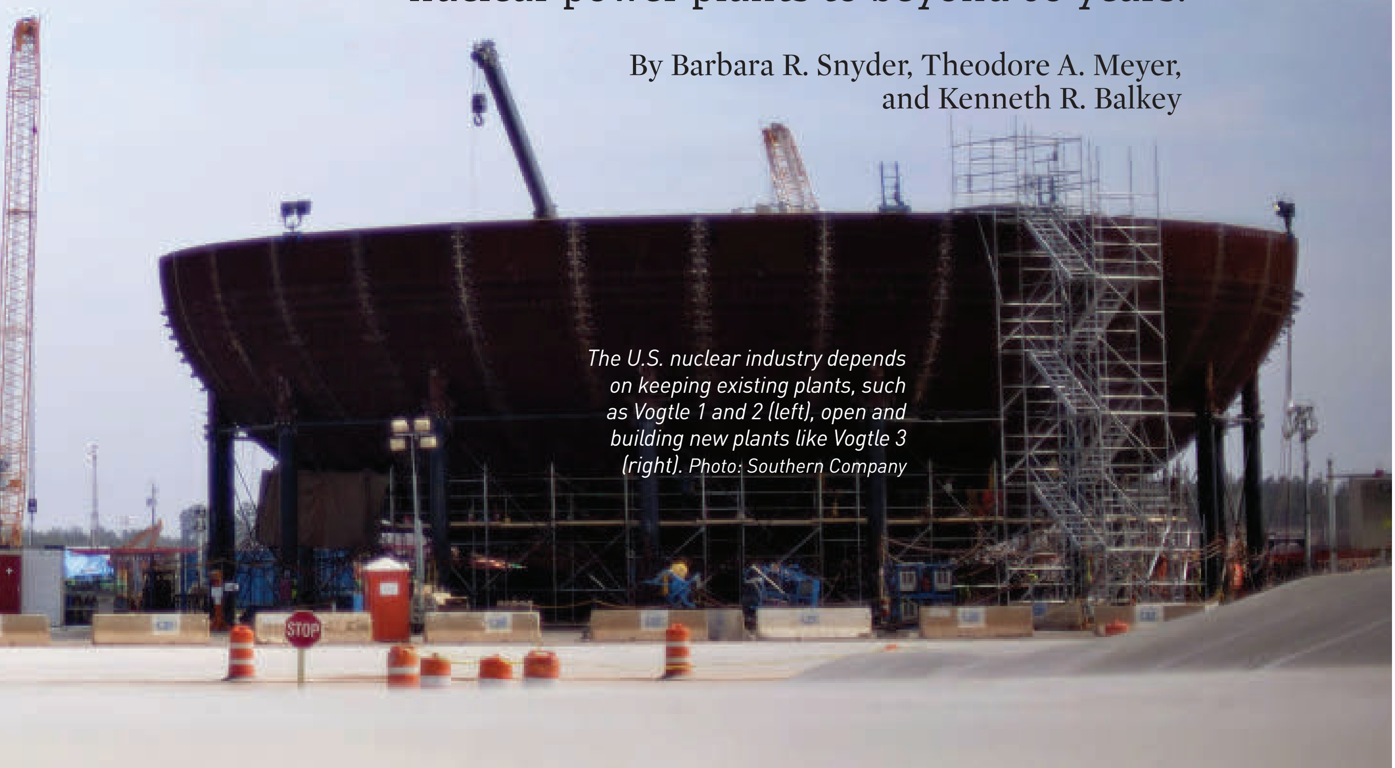
Nuclear energy, which currently supplies 20 percent of the nation's electricity, is the only electricity source that can fulfill that need. Because of the long lead times for new nuclear installations, we must look to our current nuclear operating fleet, which has been providing energy safely for decades, to meet those energy demands while also considering how additional nuclear plants can bolster our nuclear energy supply into the future.

With the expiration of their 40-year licenses imminent, most commercial nuclear plant owners either have requested or are expected to request a twenty-year extension for their operating permits. Seventy three units have already had their licenses renewed.

But looking farther into the future, it is becoming clear that an extension of 20 years is not sufficient. To continue to have

To ensure a reliable source of electric generation, we must take steps to continue to operate nuclear power plants to beyond 60 years.

By Barbara R. Snyder, Theodore A. Meyer, and Kenneth R. Balkey



The U.S. nuclear industry depends on keeping existing plants, such as Vogtle 1 and 2 (left), open and building new plants like Vogtle 3 (right). Photo: Southern Company nuclear power as part of the energy mix, stakeholders in the U.S. nuclear industry must begin to take steps to ensure that plants are able to operate for at least 80 years, which is called long-term operation. Some of the lessons learned by the U.S. nuclear industry in preparing plants to operate out to 80 years can be applied to other plants in other parts of the world.

To receive their 20-year license extensions, nuclear power plants had to address a number of challenges. In particular, there were questions about how material properties change as structures age in difficult environments. Such materials-related questions included metal fatigue, the effects of borated water on stainless steel components, the integrity of welds, especially the reactor vessel, and the potential for corrosion in the containment liner.

Fortunately, the nuclear industry began working on the outstanding questions concerning license renewals well in advance. Indeed, while the first license extension was approved only in 2000, the initial generic assessment of life extension was completed by the Electric Power Research Institute in 1979 and the first pilot plant life-extension project—for Dominion Generation's Surry plant in Virginia—was completed by EPRI in 1986. After this work was completed, the initial License Renewal Rule (to 60 years) was issued by the U.S. NRC in 1991, and after four years of substantial interaction with the nuclear industry, substantive changes were made to the License Renewal Rule in 1995.

While changes to the rule were pending, work began on the development of the first License Renewal Application. This was done to extend the operating license for two units at Constellation's Calvert Cliffs Nuclear Power Plant, which became the first facility to receive a renewed license.

In addition to all these steps, the pertinent ASME Section XI Boiler and Pressure Vessel Code requirements were modified to support license renewal. Similar steps, plus the development of new solutions for emerging aging issues, will need to be applied for second license renewals, extending the operating life of these reactors to 80 years. In recent years, engineers, scientists, regulators, and others have

GOING BEYOND 60

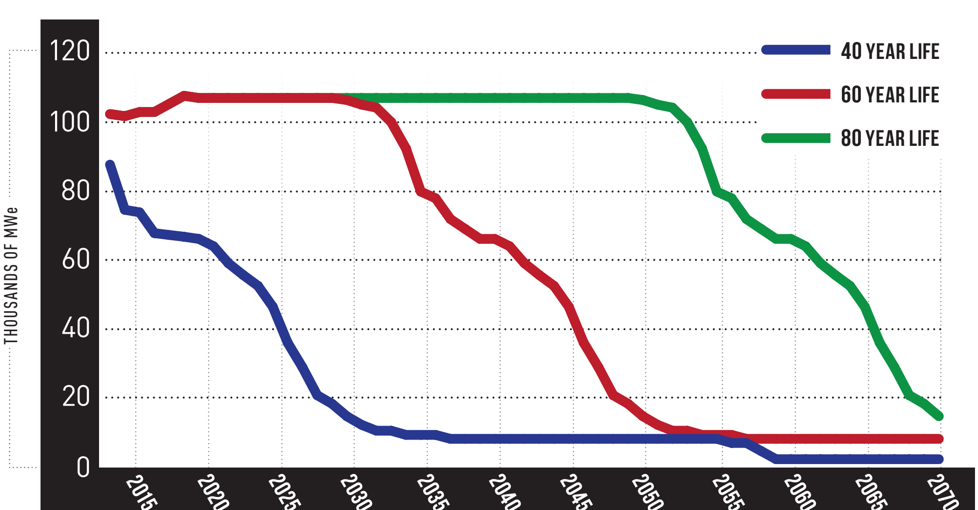
Even now, decades before long-term operations would begin, it is possible to identify questions that must be addressed.

1 **Concrete structures:** How do we demonstrate the robustness of the material?

2 **Primary components:** Do we need new technology for their inspection and repair?

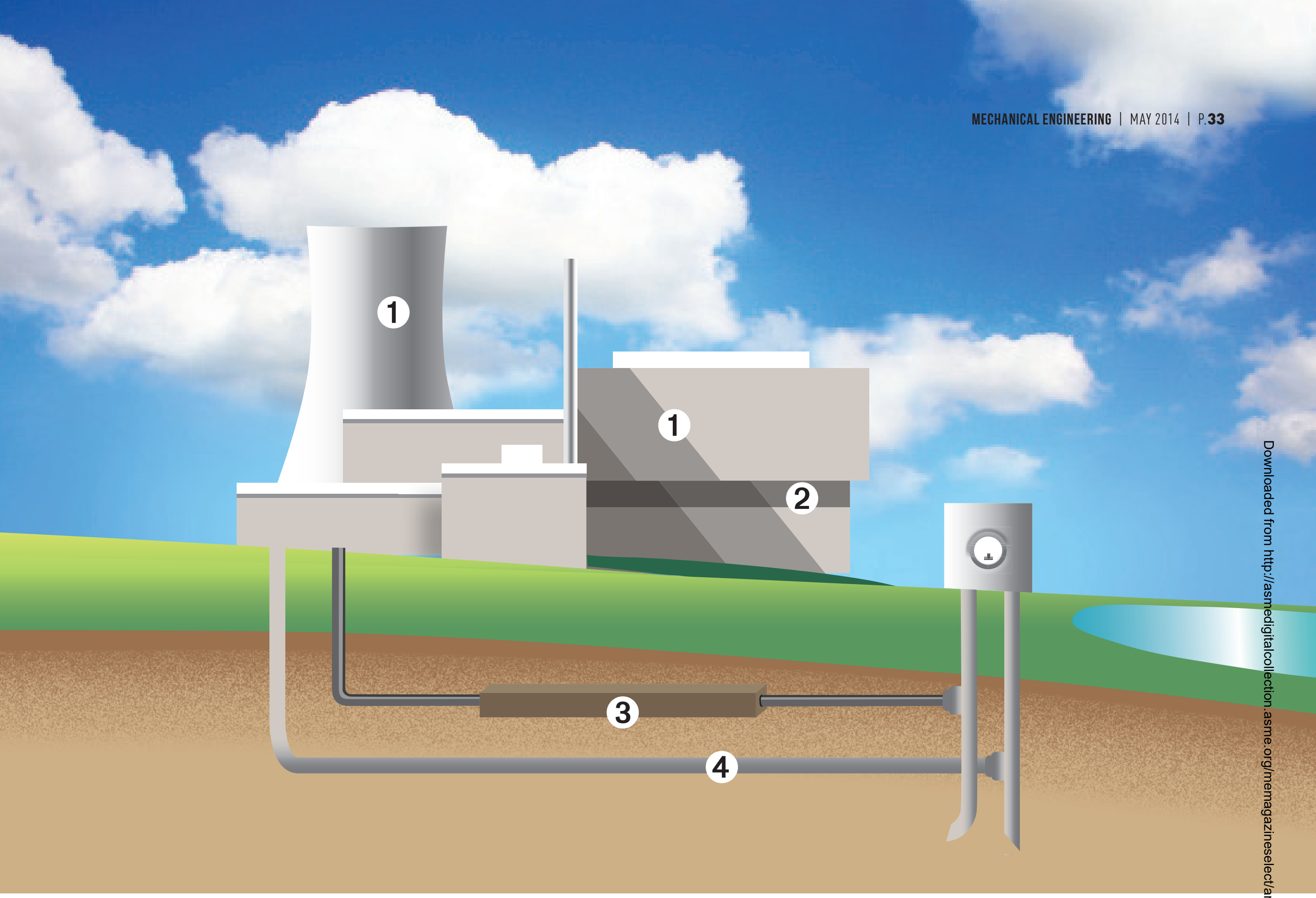
3 **Underground cables:** How can we confirm that hard-to-inspect electrical equipment is meeting requirements?

4 **Buried pipes:** What's the best way to inspect and repair buried pipes and equipment?



PROJECTED NUCLEAR CAPACITY FROM U.S. PLANTS (CURRENTLY OPERATING AND UNDER CONSTRUCTION) TO 2070

Even with existing nuclear plants operating to 60 years and starting up new plants currently under construction, the sector's capacity will decline starting in the 2030s. An 80-year life sustains nuclear power until additional new plants can be built.



begun to look at the challenges that might arise for such long-term operation. What will we need to do to keep nuclear power plants that were built in the 1970s safe and operational in the 2050s?

We need to evolve plant aging management programs to address continued and emerging aging issues. Some of the technical areas that require more focused attention than currently needed are already clear.

Even now, 20 years before long-term operations would begin, it is possible to identify some of the major questions confronting aging nuclear plants.

■ *What new technologies are required for the inspection, repair, or replacement of primary components?* The integrity of the reactor vessel, reactor internals, and primary side piping is an important technical area for long-term operation. These components are part of the plant's defense in depth and are exposed to both high temperatures and radiation. These components are inspected and managed under existing plant programs. Further investigation can help reduce uncertainties for long-term operation. The areas for further investigation include the development of advanced repair techniques and new materials. Ultimately, it will have to be determined whether continued inspection and potential repair of these components will be sufficient.

■ *How do we demonstrate the robustness of concrete for long-term operation?* The concrete containment building has had exposure to environments that could cause chemical interactions and induce strain. The internal support structures have had prolonged exposure to high temperatures and radiation that could impact strength. Lessons learned from recent operating experience involving concrete structures have also demonstrated the inability of a plant to continue to operate if the containment structure is damaged. Further investigation is needed for long-term operation to demonstrate the strength of concrete and the ability to inspect through concrete and rebar structures. As part of the defense-in-depth of a plant, determining the merit of inspection and repair versus replacement of concrete structures is imperative for long-term operation.

■ *How do we confirm that the requirements for electrical equipment are being met for long-term operation?* Nuclear plants have near-term license renewal commitments to develop and implement Cable Aging Management Programs to continue to operate beyond the initial license of 40 years. They also have to address submerged cables, which are typically part of electrical power cable systems that are buried underground and may be partially exposed to water or moisture. Unfortunately, some of these cables may not have been designed to be submerged, and they can be difficult to access for inspection. For long-term operation, the ability for all cables to perform their function may need to be considered. Certainly, plant operators need to confirm that the requirements for electrical equipment are being met during the extended period of operation.

What are the best ways to inspect and repair or replace buried equipment? It is imperative that underground piping systems, which typically transport cooling water, can be inspected. It is now known that damage in the corrosion-resistant piping coatings can cause small leaks. While such leaks may not have created safety hazards (because there is still sufficient cooling for the plant) those small leaks can introduce exposure to radiation, even though the levels are so slight as to be below regulatory limits. The discovery of these leaks has led to a reexamination of the buried-equipment issue to determine changes to the design, maintenance, and inspection of buried piping. In addition, companies are developing technologies for monitoring the corrosion on the soil side of the piping and installation of cathodic protection to prevent corrosion of piping and structures. The issue likely will rise to greater importance over the course of long-term operation.

How do we improve nuclear power plant performance and economics? The additional challenge of economic issues and plant performance encompasses upgrades to instrumentation and control systems. Advanced technologies for long-term operation will enhance plant workers' job performance by improving the human-system interface for the main control room, routine maintenance activities, and plant outages. Operational efficiency is important, and when prioritizing upgrades, nuclear plants place the highest priority on those that are safety related, followed by those that improve efficiency and economics.

Just as the nuclear industry began tackling the issues underlying license renewal decades in advance, the industry today is proactively addressing the technical areas for long-term operation. It should not require another 20 years before the second renewal of an operating license is approved, because the regulatory structure, for the most part, exists today, and plant owners understand the requirements for management of the aging of nuclear plants. The U.S. Nuclear Regulatory Commission expects that the first subsequent license renewal application to go from 60 to 80 years of operation will be submitted in 2018. The NRC and industry groups must assure themselves that they have identified any changes in aging issues and have defined or developed methods to manage the anticipated aging in the 60-year-and-beyond time period.

Industry resources must commit to demonstrate the necessary understanding of any significant changes in aging issues beyond 60 years. Also, the U.S. NRC must adjust its guidance for compliance with regulatory requirements to account for any industry findings regarding aging management beyond 60 years.

Therefore, it is important that industry bodies, such as the Electric Power Research Institute and utility owners groups, and suppliers—along with the individual utilities and plants that are the leading candidates for operation beyond 60 years—collectively assure themselves and the U.S. NRC that the pertinent aging issues are identified and appropriate aging management methods are defined or created. It is also important that the nuclear utility industry interact with the U.S. NRC to demonstrate that the plants can be operated safely beyond 60 years.

IT'S A TESTAMENT TO THE WORKMANSHIP EVIDENT IN THE CONSTRUCTION OF THESE PLANTS THAT WE CAN TALK ABOUT EXTENDING THEIR LICENSES TO THE 2050s.

Associated government agencies are doing their part. The Department of Energy's Light Water Reactor Sustainability initiative has a multi-year program with three pathways: materials aging and degradation, advanced instrumentation, information, and controls, and risk-informed safety margin characterization. The DOE is also collaborating with other industry programs, such as the Electric Power Research Institute Long-Term Operation Program, Nuclear Energy Institute, and the U.S. Nuclear Regulatory Commission.

ASME has a longstanding role in support

Plants such as the H.B. Robinson 2 Nuclear Station in Hartsville, S.C., are licensed to operate for 60 years. The necessity of long-term operation could see their service life extended even further.

As nuclear power plants enter long-term operations, the inspection, testing, and repair of components will be more critical than ever. Standards may need to be modified to reflect this.

of the safe operation of nuclear plants, and the society and its volunteers are working to make long-term operation a viable option.

One area that was addressed for first license renewals was the references to time frames in the ASME BPV Code Section XI requirements dealing with nuclear power plants. These requirements were put in place at a time before the need for extending the life of reactors—let alone long-term operation—was widely recognized.

But there was more to be done than just removing those references to a 40-year time frame. The ASME BPV Code Section XI Special Working Group on Nuclear Plant Aging Management was formed in the 1990s to study the technical, economic, and regulatory aspects of extending the operational life of nuclear power plants. The group was also charged with determining which changes were needed in the Section XI rules to manage the aging of systems, structures, and components of nuclear plants.

Similarly, new or modified standards or Code Cases need to be a considered for incorporating inspection, testing, and repair of components in aging nuclear plants. Several significant aging issues have already been addressed by changes to ASME Boiler Code Standards. Some examples include **Code Case N-638:** *Ambient Temperature Temper Bead Welding* and **Code Case N-722-1:** *Visual Examination Requirements for Susceptible Welds,* which provides visual examination requirements for Alloy 600/182/82 locations, requiring insulation removal. **Code Case N-770**: *Butt Weld Inspection Requirements* and **Code Case N-754:** *Optimized Overlays* address crack repair methodologies.

To support the continued operation of nuclear power plants for long-term operation, the ASME BPV Code Section XI Special Working Group on Nuclear Plant Aging Management has the charter to recommend additions or changes to current ASME BPV Code Section XI requirements.

When the existing fleet of nuclear plants was designed, it was expected that they would one day be replaced. It's a testament to the fine workmanship evident in the construction of these plants that we can even be talking about extending their licenses to the 2050s. They were truly built to last.

In order to achieve long-term operation, the reactors we have need to be taken care of, and the regulatory, standards, and management programs that govern them now need to continue to evolve. Fortunately, that work is being done, and we expect that these reactors will provide us with safe, carbon-emissions-free electricity for decades to come. **ME**

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NUGENIA engages stakeholders in the European nuclear industry to research materials aging and performance.

A global effort

The issue of long-term operation isn't limited to the United States and its unique regulatory and commercial environment. Efforts are ongoing in Europe and elsewhere.

The International Atomic Energy Agency and the Nuclear Energy Agency of the Organization for Economic Co-operation and Development have assembled working groups that span the international nuclear industry to draw conclusions related to long-term operation and aging management.

The IAEA standards provide a consistent and reliable means of ensuring the effective fulfillment of safety obligations. These standards are applied by various regulatory bodies and operators around the world to enhance safety in nuclear power generation. When addressing long-term operation, two IAEA safety standards are typically used: Periodic Safety Review of Nuclear Plants, Safety Guide and the IAEA Safety Report Series No. 57. Each has multiple sections dealing with evaluating the continued operation of nuclear power plants.

In Europe, there is a long history of collaborative efforts in materials performance and aging research and development as one technology area of **NUGENIA**—The Nuclear Generation II & III Association. The NUGENIA collaboration is supported by the European Union and engages most stakeholders in the European nuclear business. Research on reactor materials aging, cable and polymer aging, and concrete aging will support decisions for long-term operation. ■