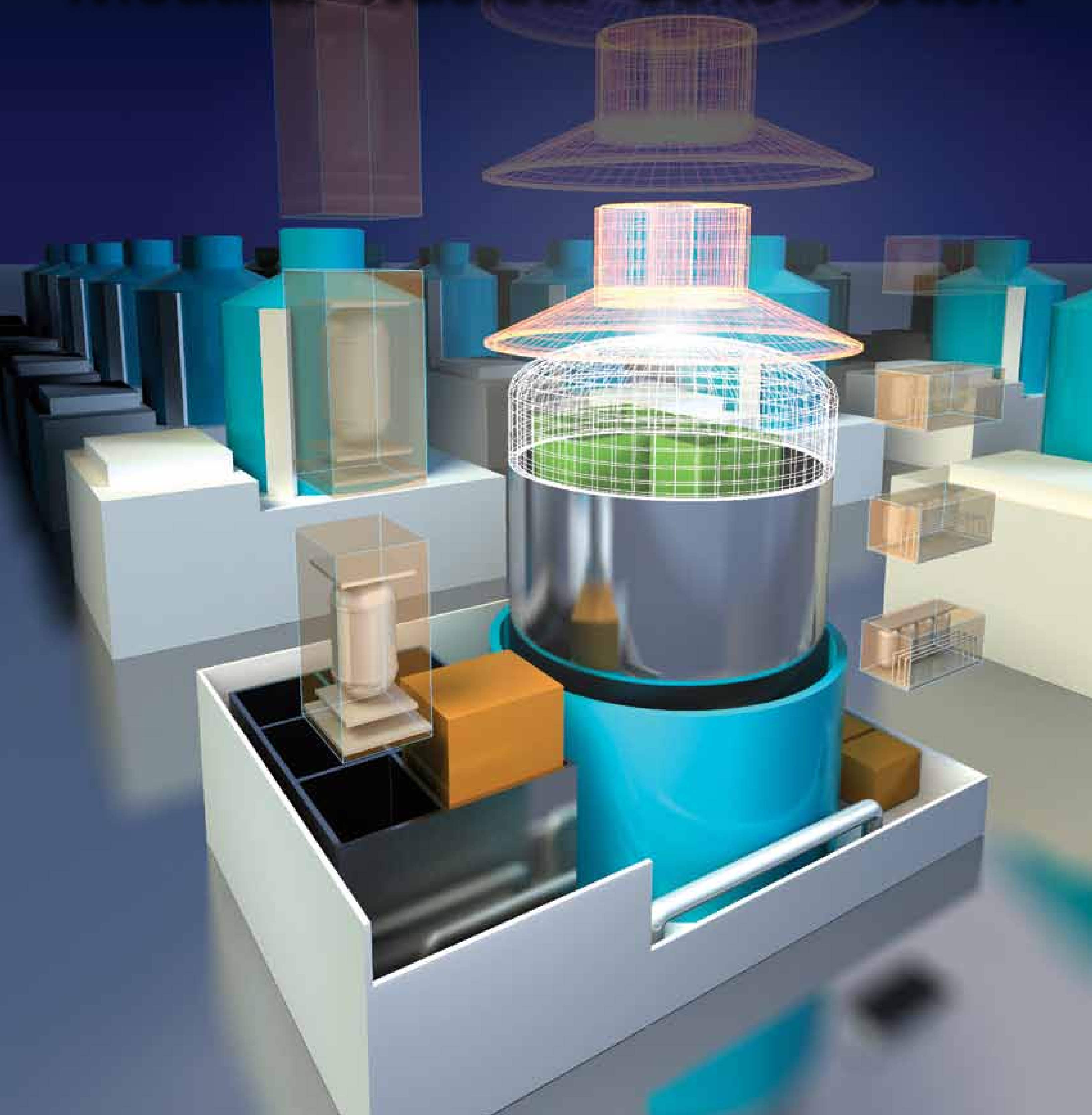
MAKING THE CASE FOR
Modular Nuclear Construction



THE STORY IN BRIEF

Builders of new nuclear plants will save substantial time and money with modular construction techniques—installing large, integrated component packages that have been tested at the factory rather than assembling and testing individual pieces at the construction site. EPRI is working with utilities and manufacturers to ensure that module inspections, tests, and qualifications will be robust and certifiable.

Interest in nuclear power is growing globally. A number of countries without any previous nuclear history—such as Egypt, Jordan, Turkey, Vietnam, Belarus, and the United Arab Emirates—are actively pursuing nuclear power plant development. Asia, which didn't experience the slowdown in nuclear power plant development that has gripped the West for the past 20–30 years, is rapidly adding to its nuclear fleet. New reactors are now under construction in Europe, and the United States will likely see the first new reactors built in three decades now that the U.S. Department of Energy (DOE) has offered conditional commitments for loan guarantees to Southern Company.

But the new generation of reactors will not be built the same way as those built decades ago. Modular construction techniques used in Japan and by the U.S. Navy are being adopted, with the result that plants can potentially be constructed much faster and at lower cost than if they were "stick-built" on site. Nuclear construction has always had modular aspects—at a minimum, the turbines, pumps, sensors, and control panels arrive on site assembled. The industry is now considering this approach for larger assemblies, which would arrive at the plant with piping, wiring, sensors, and other components already installed and tested. Nuclear submarine construction has used this process for decades.

A good part of the efficiency in modular construction lies in the possibility of doing comprehensive testing and certification of the modular components at the factory rather than in the busy, close quarters of a construction site. EPRI is working with utilities, manufacturers, and other interested parties to develop the methodology by which the Nuclear Regulatory Commission (NRC) can approve factory testing, eliminating the need for repeat testing after installation.

"The goal of the project is to provide a roadmap for the design and testing engineer," said EPRI senior project manager Ken Barry. "The roadmap reflects and compiles the world's experience with modules to ensure that inspections, tests, and qualifications conducted on the modules are not invalidated when the modules are shipped, stored, and installed."

Benchmarking Procedures

EPRI's Advanced Nuclear Technology program is leading this work as part of its ongoing focus on the development of technologies and tools needed to deploy advanced nuclear plants. The program recently released a report that benchmarked successful applications of modularization and that can be used to guide further development.

The report, *Modularization of Equipment for New Nuclear Application—Benchmarking* (1019213), is based on visits to three companies that have been involved in modularization for years through U.S. Navy submarine construction or power plant projects in the Far East: General Dynamics Electric Boat, Hitachi-GE Nuclear Energy, and Mitsubishi Heavy Industries. The report details the types of modules each company makes, the testing procedures used, and how to make sure the modules arrive on site without damage.

Electric Boat and Hitachi-GE both report achieving significant time savings and reduced project risk by using modularization. Electric Boat reports that the first Virginia-class submarine took 18 million worker-hours to build; the fifth, 11 million hours. The target for the thirtieth is below 8 million. Hitachi-GE said that since 1990, construction time for its projects has been reduced by nearly 20%, and site construction worker-hours, by nearly 40%.

"The three companies that we benchmarked had more experience and knowledge with modules than we anticipated, and they readily shared this knowledge with the benchmarking team," said Barry. "Because they need to conduct design work much earlier in the project to support module construction, problems are also discovered earlier, at the fabrication facility. This eliminates issues later in the project that could impact costs and schedules."

Developers of next-generation plants are excited about these results: "I would anticipate almost all new construction being modular-type construction," said Leonard J. Azzarello, engineering manager at Duke Energy's Lee Nuclear Project, which is scheduled for completion in 2021. "You can get quality as good, if not better, by using modular construction, and you can get it much more efficiently."

"We need to make sure the NRC understands the efficiencies we hope to gain by doing much of the inspection and testing on the modules at the factory, before they come to the site," said Azzarello. "EPRI's activities help us understand how to maintain the qualification and testing that was done at the factory so that the inspection doesn't need to be redone. If we have to redo the inspections and tests with everything in place on site, then we won't achieve the benefits we had hoped for."

Modularization Benefits

While it is more complex and more expensive at the design stage, modularization can speed up the construction process and reduce overall costs. In the initial construction stages, modularization shortens the critical path on site, allowing the plant to begin commercial operation sooner.

Unlike stick-built plants, where each step requires the completion of the previous one, several modules can be assembled simultaneously in factories while concrete is being poured and other preparation work is being done at the site. This allows for better on-site resource leveling, since more work is being performed off site by vendors. Conducting work in the controlled factory environment enables a more systematic approach to safety and quality, with improved results.

"Regardless of how you construct, you must always achieve a quality product," said Azzarello. "There is simply no other option in the nuclear industry. It is just more difficult, more time-consuming, and therefore more costly to do that testing and inspection on site."

Other factors favor off-site fabrication facilities. Manufacturers can better control assembly by using crews that are specialized for specific tasks and that gain experience with multiple reactors. There is less need for scaffolding and temporary construction materials, and centralized fabrication offers a cleaner, better-lighted environment for assembling critical components. Factory workspaces also enable the use of more productive and efficient assembly techniques, such as down-hand welding. And off-site fabrication provides for more efficient testing and qualification, enabling earlier detection and correction of defects.

Finally, standard modules offer the potential for economies of scale in manufacturing, faster design, and easier permitting.

For very large modular structures, such as the CA-20 auxiliary building, submodules can be shipped to the site separately and assembled in an area close to the plant.

One of the world's largest cranes lifts the finished CA-20 module into place at the Sanmen AP1000 reactor site in China's Zhejiang province. (Photos: SNPTC)

Vendor Acceptance

Given these advantages, it is no surprise that nuclear plant vendors and suppliers are pursuing modularization. Duke Energy's proposed Lee Plant, for example, will use the Westinghouse AP1000 advanced light water reactor—the only Generation III+ reactor yet to receive design certification from the NRC. Westinghouse projects that an AP1000 plant can be built in 36 months from first concrete pour to fuel loading, in part because of its modular construction. The largest module is a four-story, 700-metric-ton (772-ton) unit that comes with rooms that are already piped, wired, and painted.

Other nuclear plant designs are being developed using modular engineering and design principles. Mitsubishi developed its advanced pressurized water reactor (APWR) design as part of Japan's Third Phase Improvement Standardization Program for Light Water Reactors. The first two plants based on this design are undergoing licensing in Japan and are scheduled to be built by 2016. A version for the U.S. market, the 1700-MWe US-APWR, is expected to achieve NRC design certification in 2011. Pending approval, the first two units will be installed at the Comanche Peak Nuclear Power Plant in Texas.

Hitachi-GE, meanwhile, has been building with modules since the 1980s. A plant built in 1985 used 18 modules, and the current plant design includes 193 modules, ranging from 5 metric tons (5.5 tons) to 650 metric tons (717 tons). Hitachi-GE uses seven types of modules in its plants: piping blocks, piping modules, platform modules, equipment modules, cable tray modules, special modules, and civil modules.

Addressing Unanswered Questions

While the advantages of modularization are clear, work remains to be done toward facilitating broader use. In the United States, where the NRC focuses primarily on safety and not on speed of construction, the nuclear power industry must make the case that items assembled and tested in the factory can be as safe and reliable as those built and tested on site. "The efficiency and effectiveness of modular submarine design and construction can be adapted to commercial nuclear power plants," said Tom Lyon, quality manager, commercial nuclear programs, for Electric Boat. "We design, build, test, and have sailors train on modules before we even integrate the modules into the submarine, saving millions of hours of construction time while improving quality and safety."

"We have found there is a 1-3-8 rule," said Lyon. "Something that would take me one hour to do on the factory bench would take me three hours to do on a module and eight hours if I had to do that same job on the ship. The more work I can push back to the bench or the module, the more man-hours I save."

One challenge is to maintain the integrity of the module after it leaves the fabrication facility so that it doesn't need to be inspected and tested again at the site. Fortunately, the past efforts of Electric Boat, Mitsubishi, and Hitachi-GE can be applied to other plants.

"We have experience in doing this for submarines, and that experience translates pretty directly into commercial nuclear work," said Lyon. Electric Boat does most of the hydrostatic and electrical continuity testing before shipping the modules, as well as some of the motor testing and flow balances on ventilation and piping systems. To make it easier to conduct hydrostatic testing, the systems are designed with isolation valves or mechanical joints so sections can be isolated and should not have to be retested after final assembly.

Electric Boat also uses environmental controls during shipping, such as placing an airtight blanket over the equipment and purging it with nitrogen, and uses humidity sensors to detect whether any moisture has gotten inside. When bolts are torqued, they are marked with tape or Torque-Seal—a lacquer put on the bolt after tightening. If the seal is cracked, the bolt must be retightened.

Because of the nuclear power industry's emphasis on quality control and assurance, rigorous procedures must be followed to ensure that testing information is transferred along with the work. An inspection is conducted after the module arrives at its destination, and if there is any evidence of damage, the testing is redone; otherwise the test results done in the factory are considered adequate.

"As the project team considered all the possible tests that could be performed and all the possible ways to invalidate these tests, the matrix became very large," said Barry. "This project makes the complexity manageable for the design engineer by distilling the relevant industry experience captured during the benchmarking visits."

The other issue is the size of the modules that can be shipped and lifted into position. While Electric Boat creates modules up to 2,500 tons (2,268 metric tons) for submarines, the modules can simply be loaded onto a barge at its factory on the Rhode Island coast for a 60-mile trip down to its shoreside assembly facility in Groton, Connecticut. For land-based power plants, the modules will have to be much smaller to facilitate transport and craning into position, but they can still be quite large. The AP1000 design, for example, has modules up to 700 metric tons (772 tons). The dome module on the Mitsubishi APWR weighs 500 metric tons (551 tons). Each module will have to be designed so that it can be transported and moved into position in one piece.

Modular Evolution

Modularization will continue to evolve and advance. "In the future, we will see hybrid modules combining civil/structural with mechanical/electrical modules," said Junichi Kawata, Hitachi-GE vice president and senior project manager. "This will result in shorter construction periods and better construction quality."

In order for modular fabrication and construction to be applied commercially, research will be required to gain industry buy-in and regulatory approval. The EPRI benchmarking report is one step in this direction. The final report provides the industry with details on what tests can be performed at the fabrication facility and how the chosen tests can be preserved during shipping, storage, and installation.

"The industry is not ready for full-out modularization yet in the testing area, which is why EPRI is involved," said Lyon. "Rather than focusing on what is allowed, EPRI is looking at where it can go in the future. This sets the bar high and lays the foundation for broader application."

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