As seen in the December 2014 issue of **Nuclear News**

The Westinghouse SMR: Simpler, smaller, and safer

by Kristofor Paserba

The Westinghouse Small Modular Reactor (SMR) represents the next step in the evolution of simplicity and advanced passive safety for new, smaller-footprint advanced light-water reactor designs. This innovative, compact design incorporates the safety features and principles of its predecessors—the AP600 and AP1000—providing safety, resiliency, and certainty in licensing, construction, and operations. By applying new ideas to a defined set of functional requirements, Westinghouse is planning for the final SMR design to achieve performance levels that exceed those of any nuclear power plant design currently certified by the U.S. Nuclear Regulatory Commission.

With a capability of producing 800 megawatts of thermal power and more than 225 megawatts of electric power, the Westinghouse SMR produces more power per volume of building materials than any other SMR design to date. It is also designed for delivery as a stand-alone unit with no shared systems, eliminating susceptibility to failures that can cascade from one unit to another in a multi-module station.

The entire power plant is completely self-contained on a compact 15-acre site. By comparison, 160 times more land would be needed for an equivalent solar power plant, and 4,000 times more for an equivalent wind power plant. An entire Westinghouse SMR generating station is designed for 100 percent modular construction within an 18- to 24-month project schedule, with all components shippable by rail, truck, or barge.

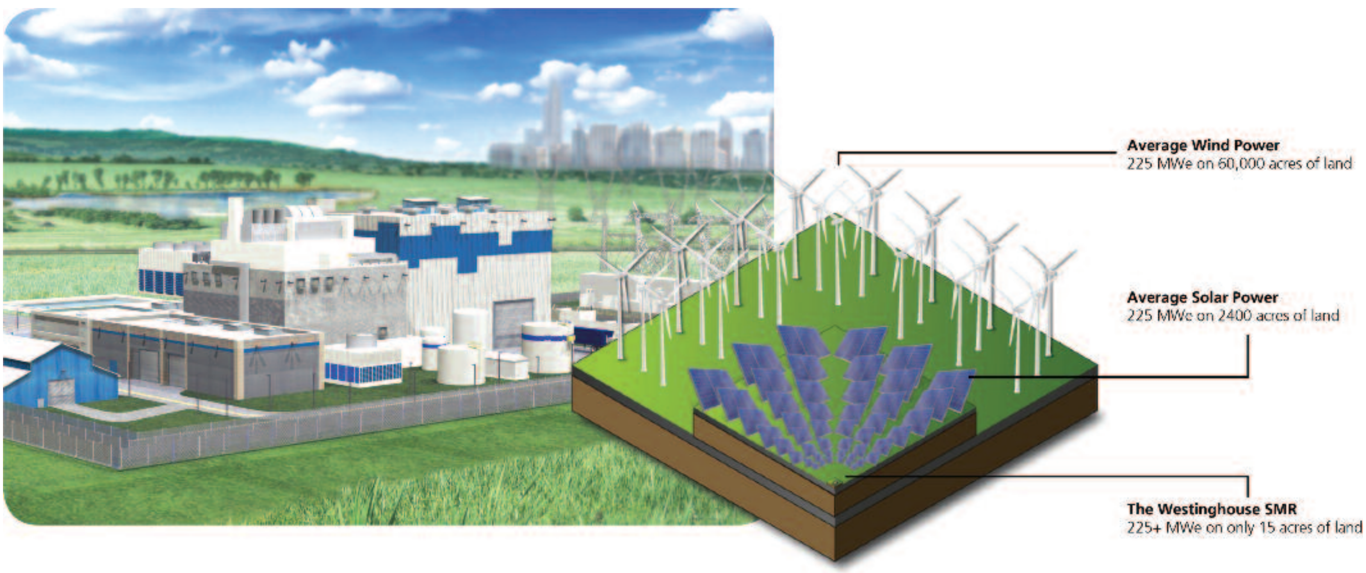
Compact design

The Westinghouse SMR is an advanced passive plant, with the safety systems designed to mitigate accidents through reliance on the natural driving forces of gravity and natural circulation, as well as on condensation. The plant would not rely on AC power or other support systems to perform its safety functions, and on-site water inventory would provide seven days of passive heat removal; more water could be added, for indefinite cooling. If off-site power were lost, safe shutdown would be maintained for at least seven days without operator action; at currently operating reactors, a three-day minimum coping time is expected.

Design features have been incorporated in the Westinghouse SMR to minimize or eliminate the effects of postulated accidents. The reactor core, steam generator, reactor coolant pumps, and pressurizer are all housed in the same pressure vessel. The small size and low power density of the reactor limit the potential consequences of an accident relative to a large plant. The integral reactor design eliminates large-loop piping and potential large-break loss-of-coolant accidents (LOCA), and significantly reduces the flow area of postulated small-break LOCAs.

The nuclear island is divided into five distinct and physically separate sectors, all located below grade. The sectors house a radiological control area, including the reactor vessel, high-pressure containment vessel, and spent fuel pool, as well as all safety-related

Kristofor Paserba is Manager of Westinghouse SMR Systems & Components.

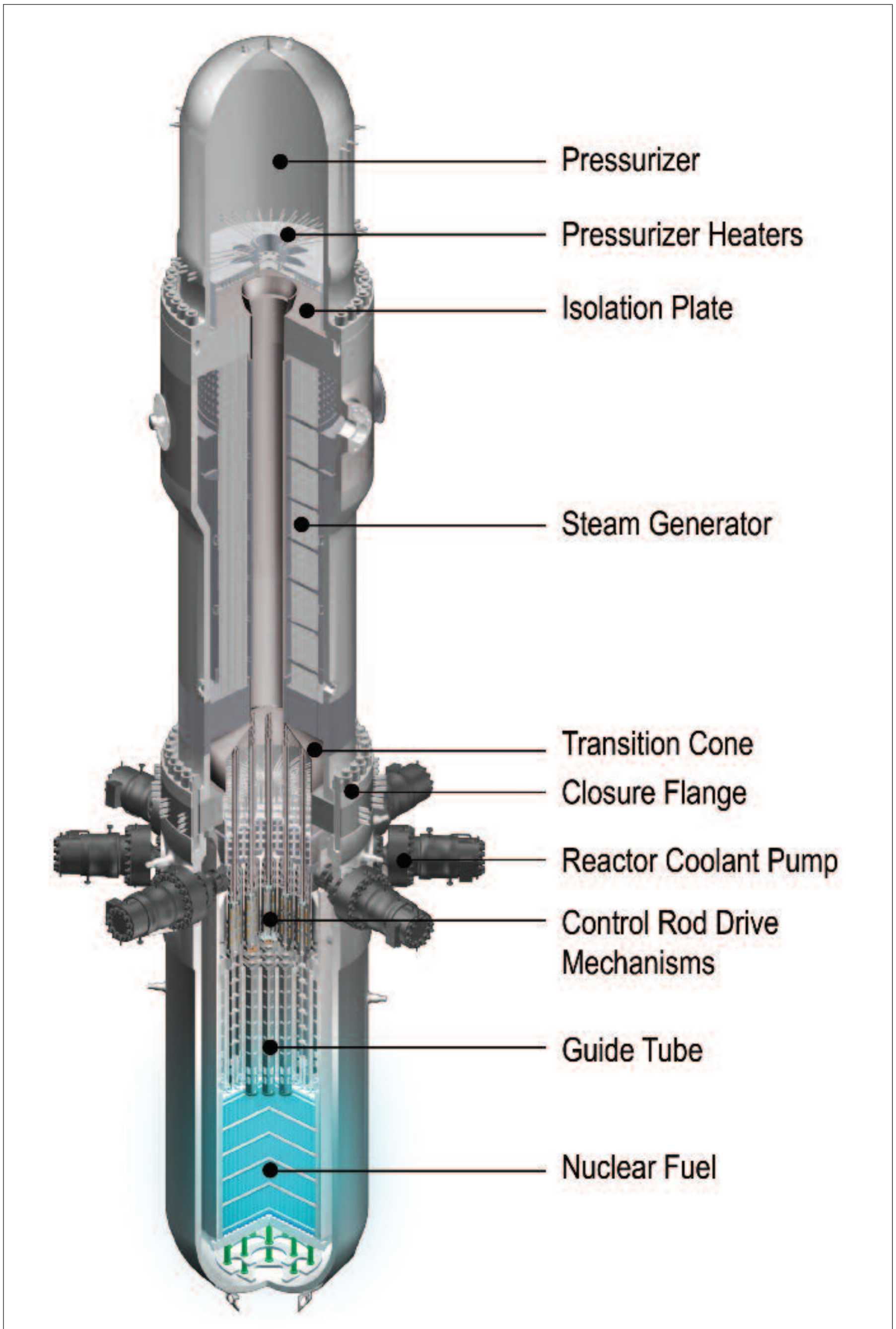


Westinghouse SMR conceptual site layout and land usage requirements for 225-MWe equivalent power. The solar plant needs 160 times more land, and the wind plant 4,000 times more land, than the Westinghouse SMR's 15 acres.

systems, including safety-related DC power and instrumentation and control (I&C) systems. No piping, wireways, or passageways traverse between these independent sectors. Access to each sector is instead controlled above grade. This protects against external threats and natural phenomena hazards. As an additional safety measure, the containment vessel is not accessible during power operation.

The Westinghouse SMR's main control room is also located completely below grade. In addition, there are multiple security monitoring stations located in separate sectors. With these enhanced security features, it is expected that the security forces required to protect the Westinghouse SMR can be much smaller than those required for existing plants.

The Westinghouse SMR incorporates three diverse decay heat removal methods: natural circulation cooling by gravity feed from the steam drum through the steam generator; cooling by passive decay heat removal heat exchangers; and passive cooling by continuous bleed and feed methods, including a two-stage automatic depressurization system, water injection, and gravity-fed boric acid water makeup. In effect, the Westinghouse SMR would be fully capable of withstanding extreme natural phenomena hazards and beyond-design-basis accident scenarios, including long-term station blackout.



The Westinghouse SMR is compact, with innovative integral reactor vessel packaging of proven components.

Proven technology concepts

The Westinghouse SMR reactor core is based on the licensed and long-proven Westinghouse Robust Fuel Assembly design and uses 89 standard 17×17 fuel assemblies with an 8-foot active fuel height and Westinghouse Optimized ZIRLO cladding for corrosion resistance. A metallic radial reflector is used to achieve better neutron economy in the core while reducing enrichment requirements to less than the existing statutory limit of 5.0 weight percent uranium-235. Approximately 40 percent of the core is replaced every two years, resulting in an efficient and economical operating cycle of 700 effective full power days, which coincides with existing regulatory surveillance intervals.

Wireless instrumentation, consisting of hardened electronics and reactor control rod drive mechanisms (CRDM), is based on proven AP1000 designs but has been modified to allow for placement within the harsh environment of the reactor pressure vessel. This eliminates CRDM penetrations through the pressure vessel head, to prevent postulated rod ejection accidents, as well as potential nozzle cracking. The upper internals of the pressure vessel support 37 of these high-temperature–resistant internal CRDMs, for reactivity control during load follow and similar operations.

The Westinghouse SMR design incorporates eight sealless canned motor pumps, mounted horizontally to the shell of the pressure vessel just below the closure flange, to provide forced reactor coolant flow through the core. A central primary riser directs the coolant flow as it exits the core to the steam generator; the reactor vessel downcomer acts as the channel for delivering the coolant flow from the reactor coolant pumps to the core inlet.

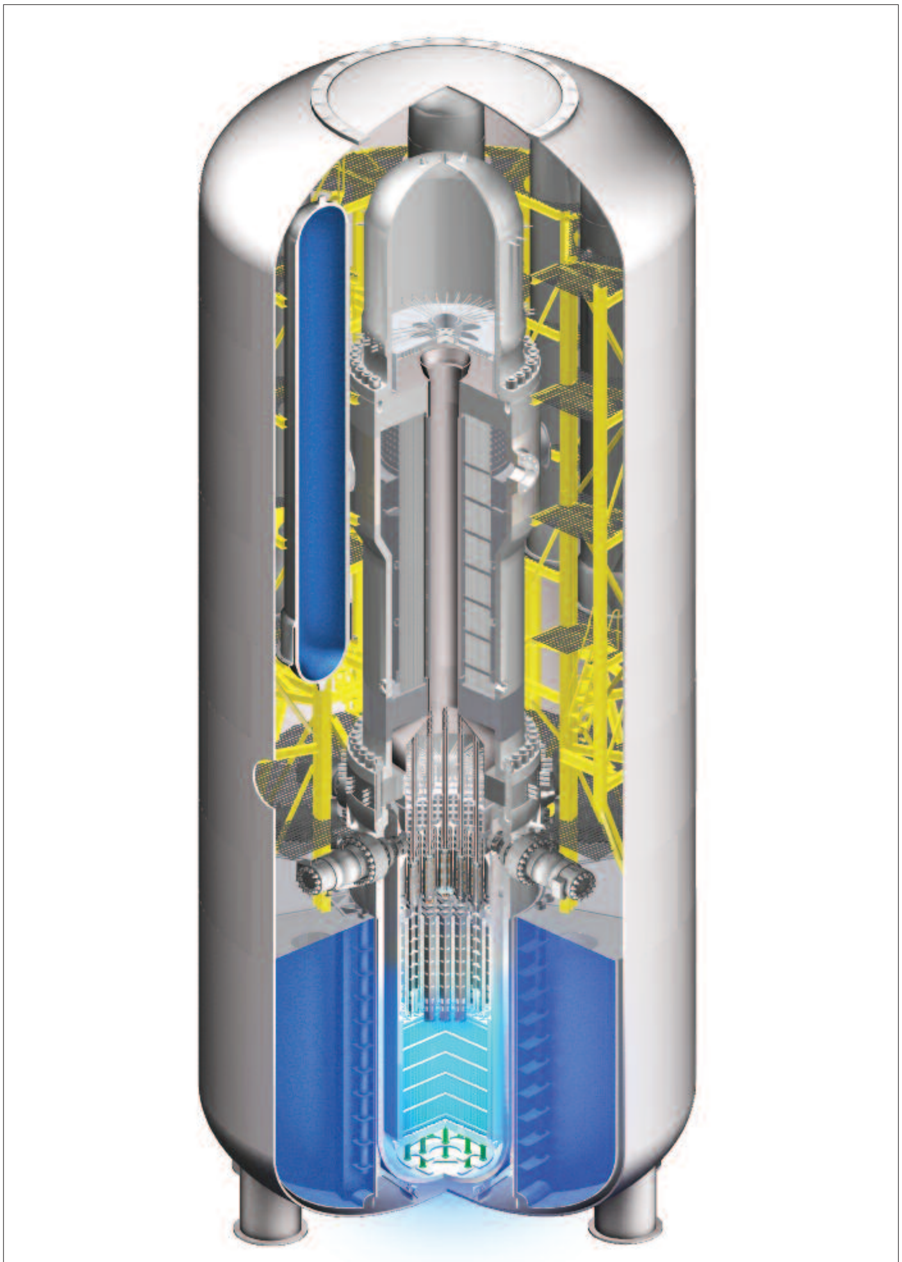
The steam generator itself is configured as a straight tube with the primary reactor coolant passing through the inside of the tubes and the secondary coolant passing on the outside. An integral pressurizer is located within the pressure vessel, above the steam generator, to control pressure in the primary system. In the Westinghouse SMR design, the moisture separation functions typically performed in the steam generator occur in a separate steam drum located outside of containment, reducing the reactor and containment vessel heights by approximately 20 feet. The steam generator/pressurizer assembly can be removed for refueling operations through a bolted closure flange near the top of the integral reactor vessel.

Both the reactor vessel and the passive core cooling system are located within a compact, high-pressure steel containment vessel located below grade. An equipment hatch is located in the top head of the containment vessel to accommodate maintenance. The containment vessel operates at a vacuum, and is designed to be fully submerged in water to facilitate heat removal during accident events while providing an additional radionuclide filter.

The Westinghouse SMR uses soluble boron in the reactor coolant for normal reactivity depletion, and control rods for load follow and plant shutdown. The reactor coolant system is serviced by a number of auxiliary systems, including the chemical and volume control system, the normal residual heat removal system, the steam generator system, the primary sampling system, the liquid and gaseous radioactive waste systems, and the component cooling water system. Safety injection, passive boration, and heat removal are provided by the passive core-cooling system and the ultimate heat sink system.

An Ovation-based digital I&C system controls the normal operations of the plant. The protection and safety monitoring system (PMS) detects off-normal conditions and actuates appropriate safety-related functions as necessary to achieve and maintain the plant in a safe shutdown condition. The plant control system controls nonsafety-related components that are operated from the main control room or from a remote shutdown workstation. A nonsafety-related diverse actuation system provides an alternate means of initiating a reactor trip and actuating selected engineered safety features. Each of these control and protection systems is based on those that the NRC approved for use in the AP1000 plant design.

The Westinghouse SMR on-site power system consists of a main AC power system and a DC power system. The main AC power system is a non–Class 1E system and does not perform any safety-related functions. The plant DC power system is composed of independent Class 1E and non-Class 1E DC power systems. Safety-related DC power supports reactor trip and engineered safeguards actuation. Batteries are sized to provide the necessary DC power and uninterruptible AC power for items such as PMS actuation; control room functions, including habitability; DC-powered valves in the passive safety-related systems; and containment isolation. There are two diverse, nonsafety AC power backup systems: One uses diesel-driven generators to power defense-in-depth electrical loads, and the other is driven by decay heat to power the plant following a reactor trip.



Cross-sectional view of the Westinghouse SMR containment vessel and integral reactor pressure vessel, which, along with the rest of the nuclear island, is located below grade.

Modular efficiencies

Westinghouse is the first reactor vendor in the United States to license and apply modular manufacturing processes to a nuclear power plant design. Increased control of cost and quality are the two primary benefits of modular plants. The entire Westinghouse SMR, including the nuclear island and all of the balance-of-plant systems, structures, and components, is 100 percent modular; this is the direct result of continued technology development in design and implementation of structural modules, and has never before been accomplished on any licensed nuclear power plant design.

The Westinghouse SMR nuclear island, for example, is divided into a set of 12 large supermodules that can be assembled on-site and lifted and set in place by crane. Each supermodule is further divided into smaller submodules that are completely outfitted with systems and components. These submodules will be fabricated, tested, and inspected at off-site facilities, shipped to the plant site, and assembled into supermodules in the designated assembly area. Inspections and integrated testing will also take place in the assembly area. Once the supermodules are placed, any remaining work, such as connecting them and conducting their final inspections and testing, would be done.

Module manufacturing is based on maximum size envelopes for rail, road, and barge transportation. Westinghouse can adjust module shipment size configurations to the preferred form of transportation for a particular site. Module weight restrictions have been established based on crane capacity (lifting limits) used and demonstrated for AP1000 modules.

The concept of modularity revolutionizes the construction process and enables the economic viability of a small reactor by reducing the construction schedule and plant construction costs; improving site construction safety; permitting extensive supermodule outfitting and extensive pre-assembly/construction testing; providing significantly higher levels of quality control; allowing for all elements of the plant to be

Concept art illustrating rail shipment of the Westinghouse SMR integral reactor pressure vessel. Module shipment size configurations can be adjusted to the preferred form of transportation to a particular site.

shipped without requiring any transportation infrastructure modifications; and removing the historic long-lead procurement items (such as the reactor vessel) from the critical path construction schedule.

Testing and validation

Westinghouse has more than 250 proprietary, NRC-approved topical reports containing company-developed and -owned methodologies and technologies that the company will use when pursuing licensing for the Westinghouse SMR design. Combining the experience and knowledge this long-gained resource represents, with the proprietary knowledge derived from already completed testing of the licensed passive safety features of the AP600 and AP1000, simplifies the testing program and licensing process for the Westinghouse SMR. Since 2010, Westinghouse has invested in developing its SMR design-specific testing and analysis plans and programs that will address the remaining certification requirements associated with the design. These include testing associated with the high-temperature environment of CRDMs, testing of the SMR fuel assemblies, and preliminary test plan development associated with integral effects and separate effects testing. The Westinghouse Fuel Fabrication Facility in Columbia, S.C., has completed manufacturing and testing of two full-scale fuel assemblies for the Westinghouse SMR.

Westinghouse, as an experienced reactor vendor, has successfully certified reactor designs under 10 CFR Part 52, and has a history of productive and successful interactions with the NRC and with regulators around the world. This experience will prove to be advantageous for its customers in the initial deployment of a Westinghouse SMR.

Economics, regional benefits

Because SMRs are not in competition with other nuclear plants, but are in competition with other generating sources, the economics associated with any SMR is primary to its success in the market. The Westinghouse SMR maximizes power output while maintaining the total cost within the capabilities of most domestic and international utilities. Simplification, standardization, and use of the existing global supply chain that serves Westinghouse will combat the potential economy-of-scale penalties associated with smaller nuclear power plants.

Westinghouse has significantly reduced construction, fabrication, and deployment costs of the plant through innovative design features. The use of a compact, high-pressure steel containment vessel reduces the size of this high-cost structure to approximately one-twenty-fifth that of the AP1000 containment (while maintaining a power output that is still one-fifth that of the AP1000 plant). The need for a large and costly shield building is eliminated by the underground placement of the entire containment (which also reduces security costs). The passive safety systems are simplified through the combination of the functions of passive residual heat removal, diverse shutdown, and high-head injection into a single set of components. The factory-assembled and -tested plant modules will offer increased cost-effectiveness, reduced schedule, established and well-documented procedures, a stable workforce, and controlled environmental conditions. The site footprint and building volume are comparatively small in relation to the power output on a per-MWe-generated basis. In applying these and other simplifications and innovative approaches to the design and fabrication of the plant, the economy-of-scale penalty is overcome, allowing delivery of the Westinghouse SMR for the same price or less on a per-MWe basis as currently licensed gigawatt-sized nuclear plants.

Westinghouse continues to leverage its extensive knowledge of the economics of currently operating nuclear power plants, and of the AP1000 plants now being constructed, to maximize the potential market for the Westinghouse SMR. Capital investment, construction duration, production cost, and resource utilization considerations all have helped shape the design of the plant, making the Westinghouse SMR an option for safe, reliable, and affordable large-scale and low-carbon-output electricity.

Looking forward

The Westinghouse SMR has been developed to a point where the technology concepts and engineering design are mature and viable, and the company will make additional investments in the program when market conditions, and external interest and support, dictate doing so.

Westinghouse is currently considering a number of business models for successfully deploying the Westinghouse SMR globally. Most of these models assume varying levels of sharing of first-of-a-kind development and licensing costs with an industry consortium and/or government partners, to advance the Westinghouse SMR toward early site permits and design certification. In parallel, Westinghouse continues to participate actively in the SMR community. When the market demands it, the Westinghouse SMR technology will be ready.

For further information on the Westinghouse SMR, please visit Westinghouse's website at <http://westinghousenuclear.com/New-Plants/Small-Modular-Reactor>. NN