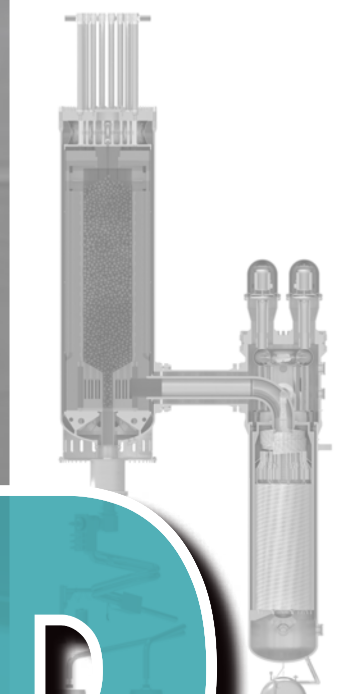
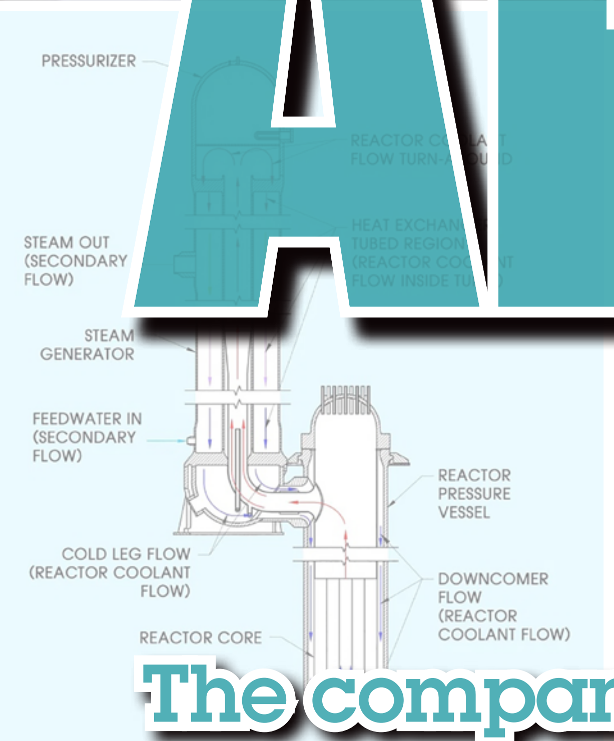
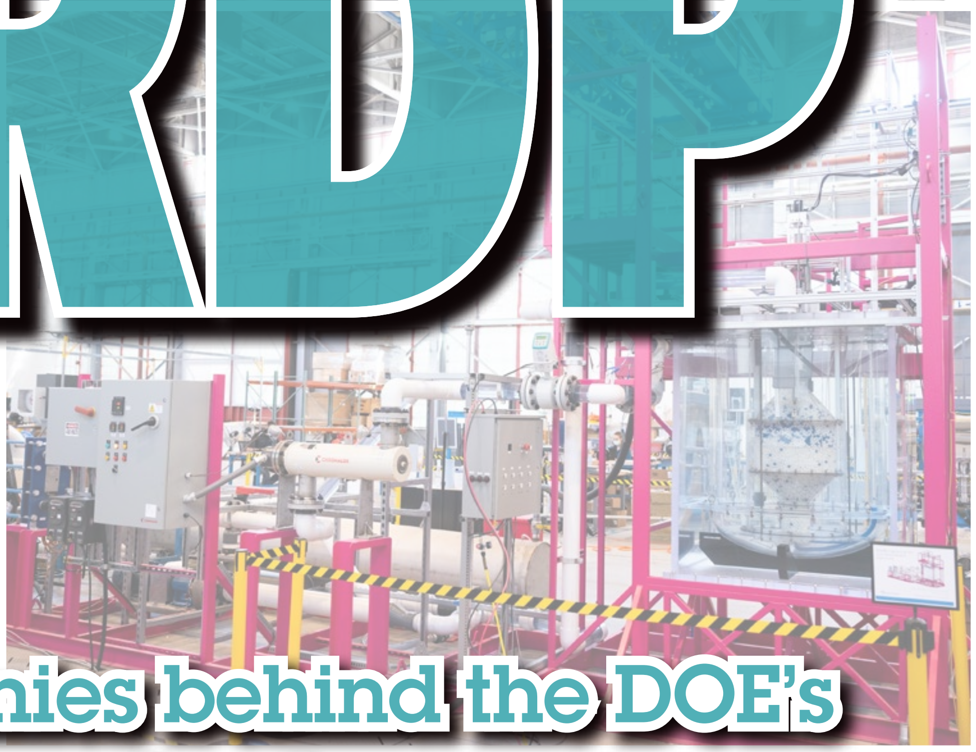
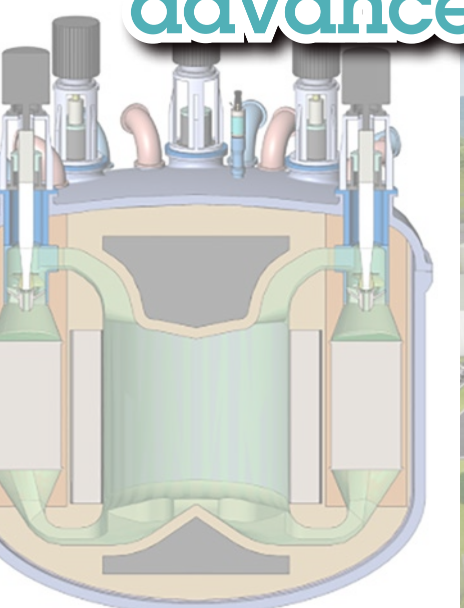


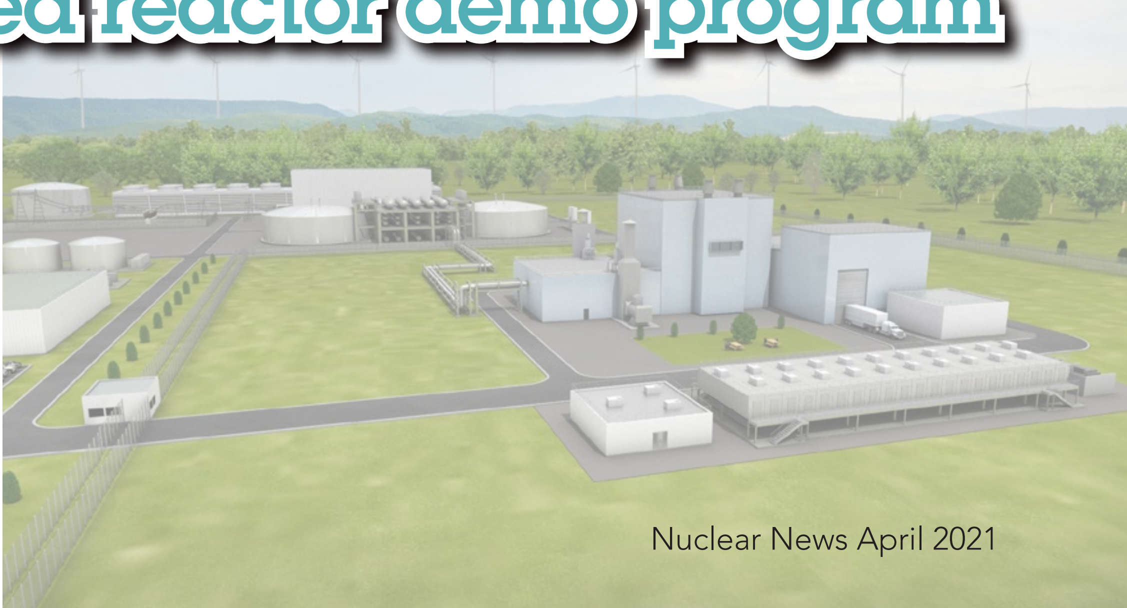
ARDP





The companies behind the DOE's advanced reactor demo program





The Department of Energy's Advanced Reactor Demonstration Program (ARDP) is one way that the federal government is making targeted investments in advanced nuclear technologies featuring coolants and fuels backed by decades of DOE research. The ARDP serves as a road map to federal cost-share funding for both near-term advanced reactor technology demonstrations and for the research and development required to support future demonstrations.

The DOE launched the ARDP in May 2020 to provide access to national capabilities and funding for selected commercial partners at different levels of funding, depending on development readiness. The ARDP leverages national research capabilities through the National Reactor Innovation Center, and commercial partners will be evaluated for satisfactory progress at program milestones based on their technological merits.

In October 2020, the DOE announced that it had selected TerraPower's Natrium sodium-cooled fast reactor and X-energy's Xe-100 high-temperature gas-cooled reactor for full-scale demonstrations within seven years. Congress appropriated $160 million in initial funding for the two projects, with plans for a total federal investment of $3.2 billion over seven years, to be matched by TerraPower and X-energy.

In December 2020, the DOE named five U.S.-based teams that had been selected for Risk Reduction for Future Demonstration awards: BWX Technologies, Holtec, Kairos Power, Southern Company, and Westinghouse. The goal of the risk reduction program is to design and develop safe and affordable reactor technologies that can be licensed and deployed over the next 10 to 14 years, with a focus on resolving technical, operational, and regulatory challenges. The DOE expects to invest approximately $600 million over seven years, with its industry partners providing at least 20 percent in matching funds.

Nuclear News invited X-energy, TerraPower, and the five risk reduction award recipients to share details of their advanced nuclear plans. Read on to see what they had to say, and for information about three other reactor concepts—from ARC Clean Energy, General Atomics, and the Massachusetts Institute of Technology—that have been selected to receive Advanced Reactor Concepts-20 funding from the DOE over the next four years.

Continued

TerraPower: Natrium

An artist's rendering of Natrium. Image: TerraPower

TerraPower and GE Hitachi Nuclear Energy combined their decades of experience and expertise to develop the Natrium technology, which joins a sodium fast reactor and a gigawatt-hour-scale thermal energy storage system that can be optimized for specific markets.

As a sodium-based technology, the reactor offers natural, inherent safety characteristics and high efficiency and has significant, existing operational performance data. Compared to conventional nuclear technologies, the Natrium reactor will operate at higher temperatures and lower pressures. The high boiling point of sodium means that the reactor can operate at atmospheric pressure. This eliminates the need for large, pressure-retaining equipment and civil structures.

Sodium also offers exceptional heat transfer due to its thermal conductivity, which is three times higher than that of stainless steel, the structural material of the reactor. This heat transfer results in high power density. When combined with the inertia of the sodium pool configuration, the high power density permits a smaller heat supply and passive heat removal systems. The high heat transfer of the reactor coolant, even under natural circulation, enables direct heat removal from the surface of the vessel by air. This passive heat removal design allows for a major reduction in equipment and structures compared to previous nuclear technologies.

The high-temperature capability of the sodium also enables process heat applications that currently rely on fossil fuels—such as desalinating water; providing district heating; or producing hydrogen, petrochemicals, or steel—without generating carbon emissions.

The Natrium technology features a compact atmospheric pool reactor system with passive vessel cooling. This system significantly reduces the space and the amount of nuclear-grade concrete required. In fact, on a per megawatt-electric basis, a Natrium reactor would use 80 percent less nuclear-grade concrete than existing large reactors. The separation of major structures and a unique approach to nuclear plant architecture and construction result in a design that is as simple as possible, helping to reduce complexity, cost, and construction time.

The Natrium system uses a combination of sodium, molten salt, and water to transfer and store heat and create electricity. The reactor core is cooled by liquid sodium circulating within the reactor vessel. The heat is removed from the reactor vessel through a heat exchanger, where the sodium transfers its heat to molten salt, which then transfers the heat to thermal storage, to the steam generation system, or both. The steam generation system then produces high-pressure, superheated steam for conversion to electrical power by the steam turbine generator.

While the reactor runs at full power around the clock, heat will be stored in Natrium's molten salt storage tanks during times of low power demand. When demand for power increases or wind and solar sources are unavailable, the turbine can utilize the stored heat and ramp up to produce approximately 150 percent of the nominal reactor power (about 500 MWe) for more than five and a half hours when needed.

TerraPower is demonstrating the Natrium reactor and its integrated energy storage system with technology codeveloper GE Hitachi and engineering and construction partner Bechtel. Numerous utilities, including Energy Northwest, Duke Energy, and PacifiCorp, a subsidiary of Berkshire Hathaway Energy, will provide their expertise in the areas of licensing, operations, maintenance, siting, and grid needs.

The Natrium technology will be demonstrated at full commercial scale, avoiding the need to transition from a small-scale prototype to a commercially viable reactor. At the end of the project, the demonstration will be a Nuclear Regulatory Commission–licensed, grid-scale reactor entering commercial service.

X-energy: Xe-100

X-energy is working on a pebble bed, high-temperature gas-cooled reactor—the Xe-100—that could be available in the market by the late 2020s. Through the ARDP, X-energy will demonstrate a four-unit, 320-MWe plant within the next seven years.

The Xe-100 is an advanced modular reactor that is designed to produce around 76 megawatts. The reactor core is filled with graphite pebbles containing high-assay low-enriched uranium enriched to 15.5 percent uranium-235. Each pebble (roughly the size of a billiard ball) contains thousands of specially coated tristructural isotropic (TRISO) uranium fuel particles.

The TRISO coating creates an airtight seal around the uranium kernel. This helps retain the fission products and gases produced during operations and would allow a plant to be sited about one-third of a mile (500 meters) away from factories or urban areas.

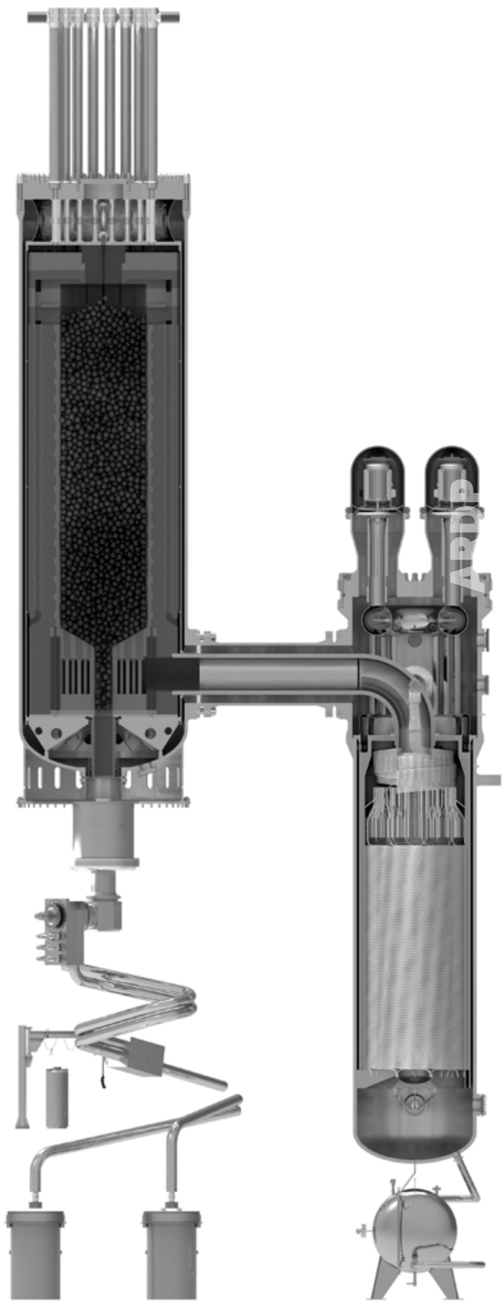
The reactor continuously refuels by adding fresh pebbles at the top as older ones are discharged from the bottom of the core. Fresh pebbles are loaded into the reactor, and helium is pumped down through the pebble bed to extract the heat to a steam generator that produces electricity. Each pebble remains in the core for a little more than three years and is circulated through the core up to six times to achieve full burnup. The spent pebbles are then placed directly into dry casks and stored on-site, without the need for interim or active cooling.

The reactor concept can be designed to incorporate passive cooling through natural conduction, thermal radiation, and convection in the case of a loss of helium coolant, meaning that it doesn't have to rely on large local water sources, pumps, or safety systems to prevent fuel damage. The plant can also load follow, from 100 percent to 40 percent power within 20 minutes, making it able to maintain a stable load on a grid that includes renewables.

X-energy is aiming to have its basic design completed by 2021, and it has successfully fabricated its first fuel pebbles using natural uranium at a pilot-scale fuel facility, on-site at Oak Ridge National Laboratory.

The only company in the United States to actively produce TRISO fuel, X-energy was awarded additional DOE assistance to design a commercial-scale TRISO-X fuel fabrication facility and submit a license application to the NRC by mid-2021.

The company plans to complete the construction of the TRISO-X facility by the mid-2020s. Since the TRISO uranium particle is the basis for multiple advanced reactor fuel designs, the TRISO-X facility could become a key enabler for the deployment of the U.S. advanced reactor industry over the next several years.



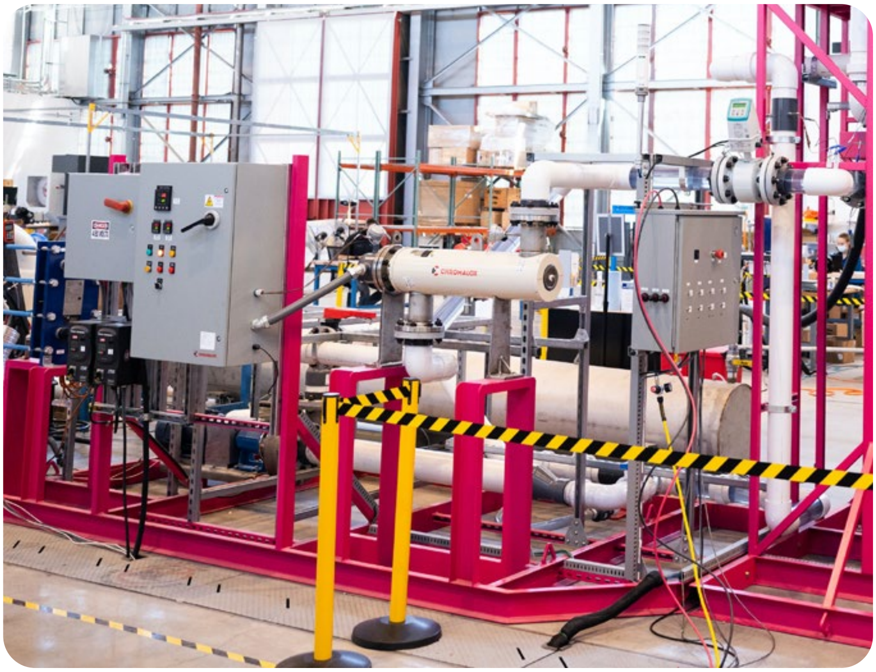
A cross-section view of X-energy's Xe-100 reactor. Image: X-energy

Continued

Kairos Power: Hermes

The Kairos Power fluoride salt–cooled high-temperature reactor (KP-FHR) is a novel advanced reactor technology that aims to be cost-competitive with natural gas in the U.S. electricity market. It is targeted for commercial deployment by 2030 or earlier.

The Hermes reactor is a reduced-scale, low-power (<50 MWt) demonstration reactor that will prove the capability of the KP-FHR design to deliver low-cost nuclear heat and to function as a platform for future KP-FHR fuel and material development and qualification tests.



The Engineering Test Unit Demonstration Experiment (ETUDE) test stand validates integral hydrodynamics performance and pebble fuel recirculation methods. Image: Kairos Power

Kairos Power's fundamental technology is a high-temperature, TRISO-fueled reactor with molten fluoride salt coolant, operating at near atmospheric pressure. The coolant is a chemically stable, low-pressure molten fluoride salt mixture, Li_2BeF_4 (Flibe), with a boiling point of 1430°C. This combination of extremely high temperature–tolerant fuel and low-pressure, single-phase, chemically stable coolant enables Kairos Power to simplify the reactor design and minimize the required number of safety systems. The intrinsic low pressure of the reactor and associated piping, along with functional containment provided by the TRISO fuel and coolant, enhances safety and eliminates the need for high-pressure, low-leakage containment structures.

Operation of Hermes will provide a complete demonstration of nuclear functions, including reactor physics, fuel and structural materials irradiation, and radiological controls for KP-FHR development. The deployment of Hermes is a pivotal step in Kairos Power's development program, which utilizes nonnuclear and nuclear hardware on the pathway to delivering commercial KP-FHRs.

Kairos Power's design approach leverages sequential, rapid hardware deployment cycles, beginning with reduced-scale surrogate fluid and molten salt compatibility testing in its Alameda, Calif., laboratory facilities. The Engineering Test Unit (ETU), the major hardware iteration that directly precedes Hermes, will be commissioned this year. ETU is a nonnuclear, isothermal Flibe test that will be located at the Component Testing Facility, now under construction in Albuquerque, N.M. ETU will demonstrate Kairos Power's ability to design, build, and operate large-scale Flibe systems.

Hermes is the ancient Greek messenger of the gods, renowned for speed. This name indicates the desired speed of the project. The Hermes reactor will be sited on the former K-33 gaseous diffusion plant site at the East Tennessee Technology Park, located in Oak Ridge, Tenn., and will be operational in 2026.

Holtec: SMR-160

The SMR-160 is a pressurized light water thermal spectrum reactor that relies on natural circulation, eliminating the need for reactor coolant pumps during normal operation. The primary application of the SMR-160 is electricity production, with optional cogeneration equipment for applications such as hydrogen generation, district heating, and seawater desalination. The SMR-160 is capable of both black-start and island operation, making it ideal for destinations with unstable power grids and for mini-, micro-, or off-grid applications.

The SMR-160's reactor coolant loop is coupled with a simplified Rankine steam cycle optimized for load following. Passive safety systems for emergency core cooling and containment heat removal eliminate the need for AC power under all accident conditions. The reference design incorporates a lower pressure conventional steam turbine and wet cooling via a tube-and-shell condenser coupled with forced-draft cooling towers. Optionally, the plant can use dry cooling via an air-cooled condenser called HI-KOOL. The SMR-160 was designed with multiple levels of defense-in-depth and has a water volume–to–power ratio about four times larger than traditional PWRs, which results in a large heat removal buffer for postulated transients. All water required to mitigate loss-of-coolant accidents is located inside the containment in accumulators and tanks.

The SMR-160 is designed to produce 525 MWt (160 MWe net), with a footprint of approximately five acres, including interim spent fuel storage.

Multiple units can be built in a staggered parallel fashion, including in a multiunit control room configuration. Although safety systems will not be shared between units and each plant will act independently, a multiunit site offers opportunities to economize by sharing support systems, facilities, and staff.

The SMR-160 is designed to provide flexible power output and perform load following based on grid demand. The reactor is capable of quickly reducing from 100 percent to 0 percent power without a plant trip and is designed for continuous operation at low power or a return to higher power levels within the same operating day.

The plant design incorporates a spent fuel management approach that accommodates the discharge of spent fuel assemblies to underground dry storage in the HI-STORM UMAX storage system after the second reactor refueling. On-site interim dry storage within the HI-STORM UMAX system accommodates all of the spent nuclear fuel for the design life of the SMR-160 reactor.

Holtec's Jodine Jansen-Vehec provides a fuller description of the SMR-160 online at ANS's Nuclear Newswire. *Please visit ans.org/news/article-2709/overview-of-the-smr160/.*

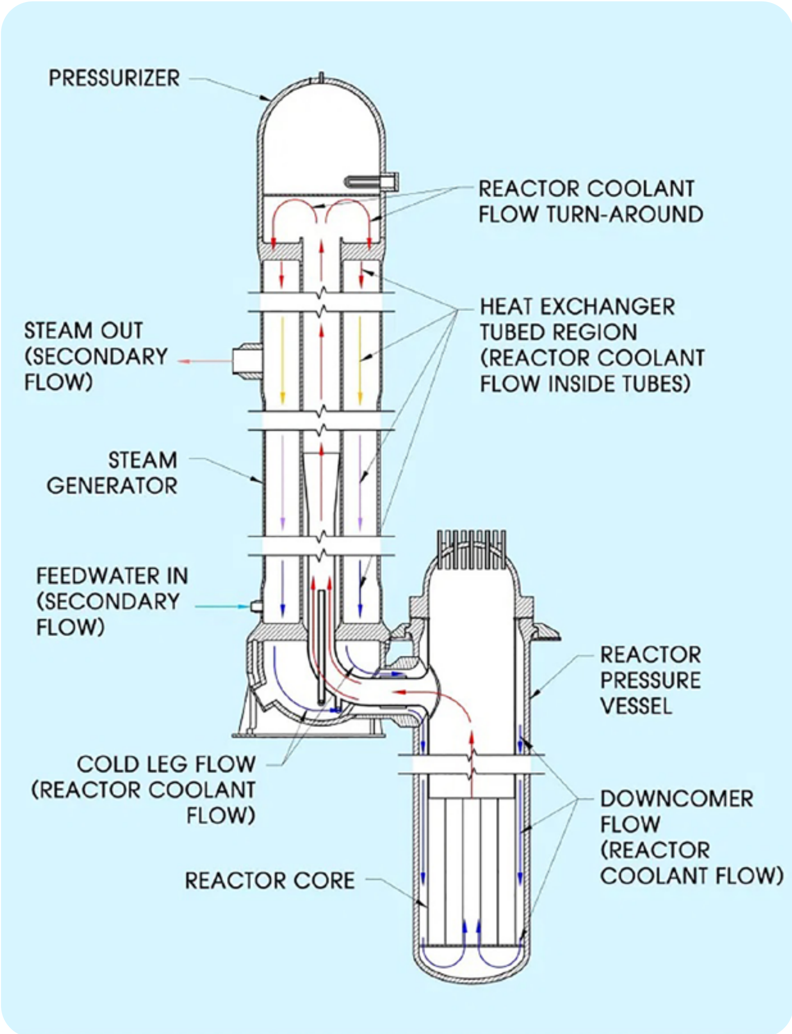


Image showing the off-set configuration of the SMR-160 reactor pressure vessel and steam generator. Image: Holtec International

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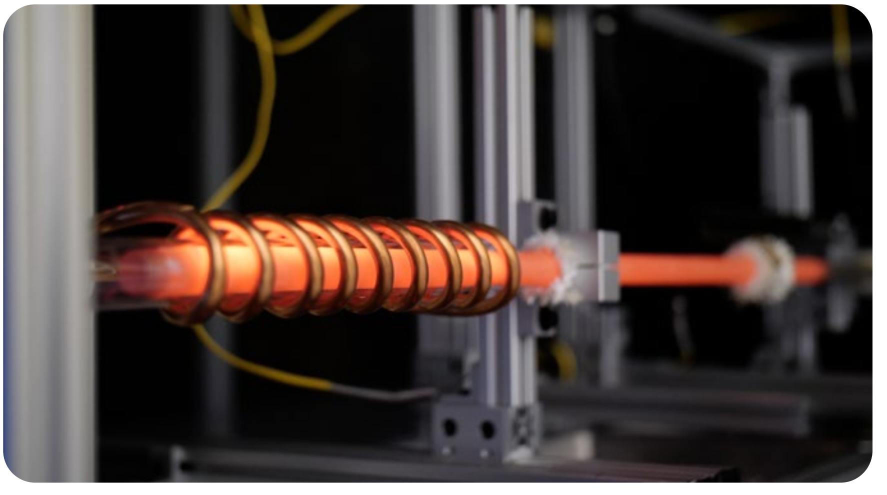
Westinghouse: eVinci

The eVinci reactor. Image: Westinghouse



The eVinci heat pipe used to cool the microreactor. Image: Westinghouse

"As a company passionate about nuclear energy, we've explored numerous reactor system configurations and sizes over the years," said Joe Halackna, eVinci senior engineering manager at Westinghouse Electric Company. "In 2015, we realized that to open the doors to a new era of nuclear power, the complexity of reactors had to undergo a paradigm shift."

Westinghouse nuclear engineers brought in knowledge and experience from technology partners at Los Alamos National Laboratory and combined them with lessons learned from designing, licensing, and constructing the AP1000 light water reactor to inform the next generation in nuclear reactor design. They determined that a passive, solid-state, low-pressure reactor could provide simple, safe, and untethered energy.

The eVinci microreactor is a next-generation technology providing a highly simplified and rapidly deployable energy source. Small by nuclear standards, the eVinci reactor uses heat pipes that operate passively and rely solely on natural forces. The design features minimal moving parts, unpressurized operation, self-regulating load following capability, and autonomous operation.

The eVinci microreactor can be built, assembled, and fueled in the factory and transported to the operator's site as a turnkey system that is ready to power up. The system can be operating in a matter of days and provide continuous power around the clock for years, even in remote locations.

The baseline core design can operate for three or more years without the need to shut down for refueling. Customer-specific variations can prioritize longer life, greater power output, or lower mass for more mobility.

With the help of DOE funding, Westinghouse plans to advance the eVinci design to support a nuclear demonstration unit by 2024.

BWXT: BANR

The baseline design for BWX Technologies' (BWXT's) Advanced Nuclear Reactor (BANR) is a small, modular, factory-fabricated high-temperature gas reactor (HTGR)—a microreactor light enough to be commercially transportable via rail, ship, or truck that delivers 50 MW of thermal power. BANR employs helium as the primary system working fluid and can be coupled with a Rankine cycle for power production. The use of mature, manufacturable, and inherently safe technologies enables high core outlet temperatures (800°C) and provides flexible options for generating electricity and/or steam while eliminating greenhouse gas emissions.

The primary objective of BANR is to demonstrate the commercial viability of the reactor concept by targeting technological upgrades selected to improve system performance and reduce manufacturing costs and time to prototype. Technological upgrades within the scope of the ARDP risk reduction project include the fuel form, reactor core, reactivity control system, passive cooling for accident conditions, and reactor instrumentation and control. More specifically, the goal is to use a denser uranium nitride (UN) TRISO fuel instead of the traditional uranium oxycarbide (UCO) TRISO. This denser fuel form allows BWXT to optimize the service life and/or power output of the reactor to enhance cost viability.

The design-build-test approach provides mission-critical nuclear components and supports various DOE programs to advance reactor technology, such as additive manufacturing of refractory metals. BWXT currently manufactures UN TRISO fuel for other programs, an ability that comes from past experience with the DOE's Advanced Gas Reactor uranium dioxide and UCO TRISO qualification efforts. The BWXT BANR team will leverage the expertise of Oak Ridge National Laboratory and Idaho National Laboratory for development, characterization, irradiation, examination, and testing.

BWXT will work with commercial partners to define the market for BANR and seeks to deploy a commercially viable reactor in the early 2030s.

The BWXT Nuclear Operations Group facility in Lynchburg, Va. Image courtesy of BWX Technologies, Inc. Used with permission.

Continued

Southern Company: MCFR

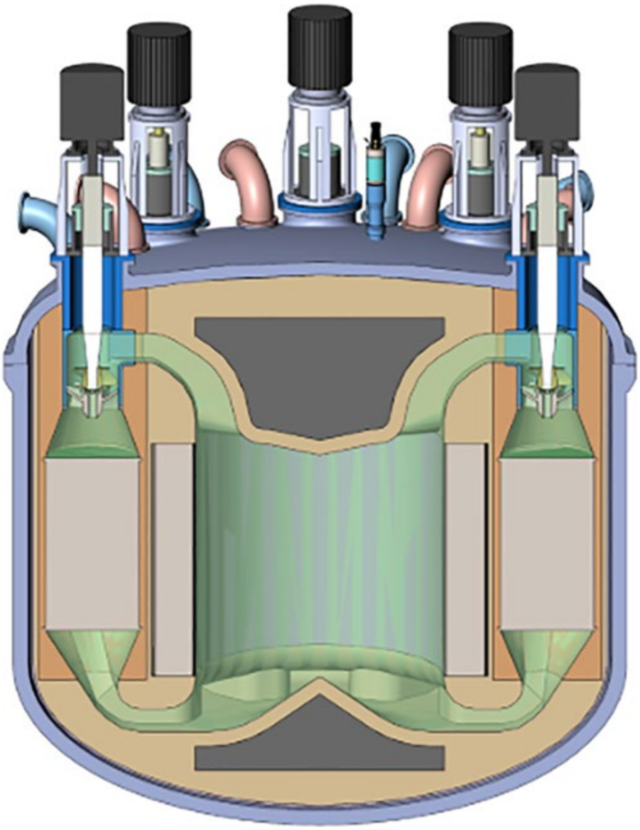
TerraPower's Molten Chloride Fast Reactor (MCFR) is a novel concept for nuclear generation, designed to combine the best aspects of homogeneous (liquid-fueled) reactors, fast reactors, and molten salt reactors, resulting in superior performance, safety, and economics compared to conventional light water reactors and advanced reactor concepts.

Southern Company will lead a team to design, construct, and operate the Molten Chloride Reactor Experiment, which will be the world's first critical fast-spectrum salt reactor and an integral part of a comprehensive technology development program led by Southern Company to directly support the commercialization of the MCFR.

This small reactor experiment is specifically designed to maintain the strong momentum being pursued by Southern Company, TerraPower, and several partners since 2015 to explore, develop, and demonstrate key MCFR technology under a DOE Advanced Reactor Concepts award. Southern Company's research and development organization will manage the effort in a collaboration that includes TerraPower and a number of private companies, national laboratories, and universities.

Designed as a less than 1-MW critical reactor, the Molten Chloride Reactor Experiment is expected to span approximately five years and provide vital nuclear data and operational experience with TerraPower's first-of-a-kind technology. The goal is to inform the design, licensing, and operation of an MCFR demonstration reactor that is expected to be operational by the early 2030s.

In addition to flexible, highly efficient clean electric power generation, which offers a complement to the increased use of intermittent renewable resources on the grid, the technology also has the potential to provide carbon-free, high-grade process heat and thermal storage for difficult-to-decarbonize industrial markets and ocean transportation sectors with high energy consumption.

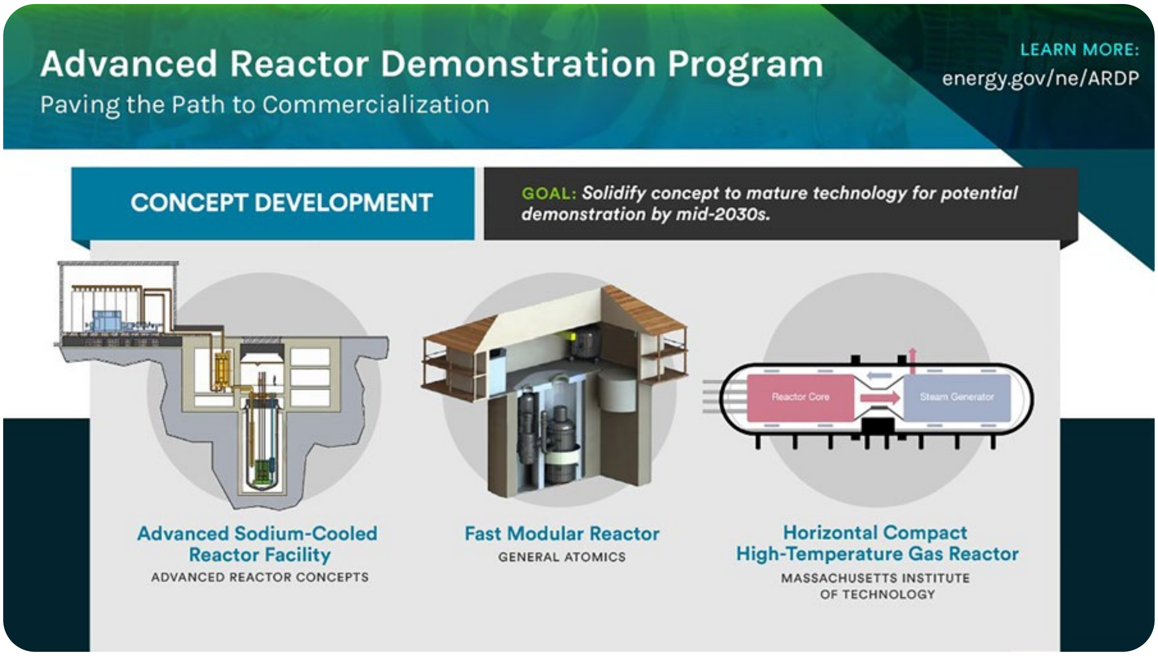


A diagram of the MCFR. Image: Southern Company

There are several key features that provide these benefits. Low-pressure operation reduces concrete and steel requirements for the facility. The attractive heat capacity of molten salts enables high-temperature operation and, therefore, better thermodynamic efficiency in the power cycle. The salts are not chemically reactive, and they provide for inherently stable operation via thermal expansion and natural circulation. The MCFR can be refueled while on line and can load follow at rates similar to a natural gas combined-cycle power plant. This modern design capitalizes on advances in automation and construction techniques.

Advanced Reactor Concepts-20

The goal of the ARC-20 program is to assist in the maturation of advanced reactor concepts in their earliest phases, supporting innovative and diverse designs with the potential to commercialize in the mid-2030s. The DOE selected three U.S.-based teams to receive ARC-20 funding under the ARDP, led by ARC Clean Energy, General Atomics, and the Massachusetts Institute of Technology. The DOE expects to invest a total of approximately $56 million over four years in the ARC-20 projects, with industry partners providing at least 20 percent in matching funds.



ARC Clean Energy

ARC Clean Energy (formerly Advanced Reactor Concepts) will deliver a conceptual design of a seismically isolated advanced sodium-cooled reactor facility that builds upon the initial preconceptual design of a 100-MWe reactor facility. Total award value over three and a half years: $34.4 million, with a DOE share of $27.5 million.

General Atomics

General Atomics will develop a fast modular reactor conceptual design in collaboration with Framatome, with verifications of key metrics in fuel, safety, and operational performance. The design will be for a 50-MWe fast modular reactor. Total award value over three years: $31.1 million, with a DOE share of $24.8 million.

MIT

The Massachusetts Institute of Technology will mature the modular integrated gas-cooled high-temperature reactor concept from a preconceptual stage to a conceptual stage to support commercialization. The total award value over three years: $4.9 million, with a DOE share of $3.9 million.