

eVinci™ Micro Reactor

By Yasir Arafat, and Jurie Van Wyk,
Westinghouse Electric Company LLC.

Yasir Arafat

Yasir Arafat is a Principal Engineer and technical lead of the eVinci™ Micro Reactor program for Westinghouse. With the co-lead, he shares responsibility for the overall technical authority of the project and aligns work between design, testing, licensing and manufacturing, and the development and commercialization program.

Mr. Arafat's eight years of nuclear industry experience with Westinghouse have been focused on nuclear systems design, including for the AP1000® Nuclear Power Plant, Westinghouse Small Modular Reactor and fusion power plant design. Mr. Arafat has been co-patent author of multiple patent disclosures filed for full patent applications. His broad exposure to technologies in product, systems and process design, among others has facilitated his leadership work on eVinci.

Mr. Arafat has a B.S. in Chemical and Nuclear Engineering from the University of Pittsburgh and is pursuing a M.S. in Engineering Technology & Innovation Management at Carnegie Mellon University.



Our Next Disruptive Technology

“Simplicity is the ultimate sophistication.” This statement, attributed to Leonardo da Vinci, one of the greatest minds in creative, practical inventions in human history, embodies the guiding principles of the Westinghouse eVinci™ micro reactor design. The eVinci design is based on demonstrated technology that can revolutionize how remote locations access clean, reliable energy.

In co-development arrangements with national laboratories, design partners and utilities, Westinghouse is developing the eVinci micro reactor to serve remote residential, industrial and military energy consumers who are not connected to a national grid. The eVinci micro reactor employs a nuclear battery concept as the energy generator. It is being designed to deliver combined heat and power from 200 kWe to 5 MWe from a compact solid monolithic core that is surrounded by additional fission product barriers and fully enclosed in a protective canister that can be transported by road, rail and sea.

Westinghouse and the associated team are aiming to complete the design, testing, analysis and licensing to build a demonstration unit by 2022, test by 2023, and have the eVinci ready for commercial deployment by 2025. Although aggressive, Westinghouse believes it has the right strategy, skillset and lessons learned from previous experience in deploying first-of-a-kind nuclear technology to meet this target.

In addition, the company is working closely with Los Alamos National Laboratory (LANL) to expand on LANL's successful development of heat pipe reactor technology. LANL has successfully implemented this technology for space applications, such as Kilopower, which was later re-conceptualized for a terrestrial application, called Megapower.

The eVinci Micro Reactor design leverages the combined forces of LANL's heat pipe technology and Westinghouse's expertise in commercial reactor design, licensing and manufacturing. The resultant product will address some of today's most challenging nuclear safety considerations, such as primary coolant loss, positive reactivity injection due to water entering the core, high-pressure eruptions and ejections, positive reactivity injection due to control rod ejection, and station blackout. It is an inherently safe reactor design that does not rely on a safety-related instrumentation and control system, AC power or operator actions to achieve safe shutdown, which will be a step-change in nuclear innovation. The eVinci micro reactor's inherent safety is due to the design's foundation of physics; it does not require computer signals or mechanical actuations to operate or shut down.

Why eVinci and Why Now?

According to Navigant Research, new distributed generation power capacity is overtaking new centralized generation capacity at a growing rate and may displace approximately 300 GW of new large-scale generation by 2026.

Wanting to develop the next generation technology to address this global market trend, Westinghouse chose the alkali metal heat pipe technology at the heart of the eVinci micro reactor. Heat pipes enable a simple plant, eliminating the need for a reactor coolant pump, bulk coolant and associated equipment. Unlike a high-temperature gas reactor, a heat pipe reactor is not pressurized but can operate at temperatures greater than 650OC. Although heat pipes are passive (naturally driven), they can self-adjust the amount of heat transferred. The self-regulating behavior of the heat pipes and the solid core enables inherent load following. The resultant product can deliver reliable, affordable, flexible and clean energy, with a new level of safety and operability.

With the notion of creating a nuclear battery, the eVinci micro reactor is envisioned to be built and fueled within a factory and transported fully assembled

to site. A plug and play interface allows onsite installation in less than 30 days. The reactor is capable of operating multiple years without refueling and in island mode, with black start capability. These attributes are of interest to those in the energy industry seeking great resiliency and energy security. Westinghouse is also applying its expertise in instrumentation and controls to design the eVinci micro reactor to operate autonomously.

The eVinci design is also planned to deliver combined heat and power with smart load-follow capability via a micro-grid interface subsystem. High-grade heat – up to 600°C – can be used for industrial heating applications such as desalination, hydrogen generation and onsite liquid fuel production. Low-grade heat can be used for district heating or greenhouse applications.

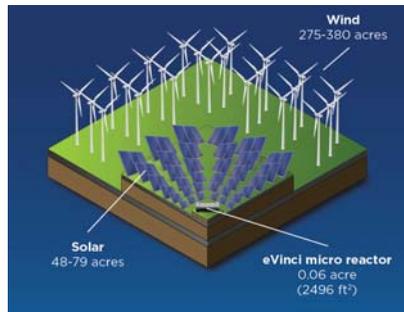
Autonomous clean energy power and heat production can help meet increasing demand while also playing a positive role concerning our climate and environment with the eVinci micro reactor. The eVinci micro reactor also requires far less land area than other sources of clean energy to generate equivalent power while providing energy independence and security.

The Technology and How it Works

The eVinci micro reactor is a high-temperature heat pipe reactor. This technology's groundbreaking safety features stem from the simplicity of its design. The core design is unique: It is comprised of a solid monolithic block with three types of channels that accommodate fuel, neutron moderators and heat pipes. There are no moving or mechanical parts, except for reactivity control drums, which surround the monolithic block and allow absorber material to passively turn inward toward the core if power is lost, as well as on demand. A thick radial neutron reflector surrounds the monolithic core block and reactivity control drums, which, in turn, is surrounded by a neutron shield, followed by a gamma shield. A canister encases the entire core and each of these fission product barriers. The reactor core is itself subcritical; it cannot achieve criticality without both the neutron moderator and the neutron reflector.

Each heat pipe contains a small amount of sodium liquid as the working

fluid to move heat from the core to the heat exchanger, and is fully encapsulated in a sealed pipe. Unlike traditional sodium-cooled reactor designs, in which large volumes of sodium are pumped around the core, the eVinci requires very small amounts of sodium to serve as the coolant, almost all of which is entrained in the wicks of the heat pipes. It is relatively benign in terms of chemical reaction kinetics. There are no mechanical pumps, valves or large-diameter primary loop piping. The heat pipes replace the reactor coolant pump, reactor coolant system, primary coolant chemistry control and all associated auxiliary systems. The size of the overall reactor product is very compact with few components.



eVinci compared to other energy sources.

In its current development status, each fuel channel is adjacent to three heat pipes for efficiency and redundancy, achieving an overall 1:2 fuel channel to heat pipe ratio. Designing this large number of heat pipes in the core is intended to increase reliability and safety.

Thermal to power conversion is being designed to accommodate the range

Jurie Van Wyk

Jurie van Wyk is a Principal Engineer and technical lead of the eVinci™ Micro Reactor program for Westinghouse. With the co-lead, he shares responsibility for the overall technical authority of the project and aligns work between design, testing, licensing and manufacturing, and the overall development and commercialization program.



Mr. van Wyk's 19 years with Westinghouse have

been focused in areas of new advanced reactor development, including the Pebble Bed Modular Reactor and the Westinghouse Small Modular Reactor. Mr. van Wyk has been co-patent author of multiple patent disclosures filed for full patent applications. His experience in evaluating new advanced reactor designs for economic feasibility has shaped the vision for the eVinci design that paved the way for a new nuclear application in remote power generation.

Mr. van Wyk has a B.S. in Mechanical Engineering and a M.S. in Aeronautical Engineering from the University of Stellenbosch.

of electric power output goals of specific eVinci micro reactors. Two mature power conversion technology options are being considered to generate electricity. Neither requires cooling water since the final heat rejection is envisioned to be by air and not by water.

Fuel

Westinghouse has evaluated multiple fuel options for the eVinci micro reactor; including options for uranium in oxide, metallic and silicide form. Working with LANL and Idaho National Laboratory (INL), both of which are uniquely qualified to conduct fuel performance tests, Westinghouse and its strategic

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eVinci™ Micro...

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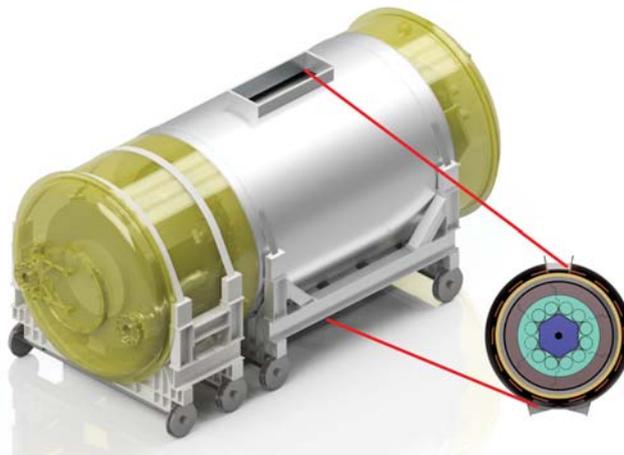
partners will determine which fuel option is most feasible.

Within the reactor core, Westinghouse is incorporating structure and materials to reduce neutron leakage in the design, while including a quantity of fuel to be initially loaded that avoids any need to reload fuel for the operating life of the system. Westinghouse is also designing the fuel channels and plenum to accommodate fuel swelling and other irradiation effects, as well as fission gas releases and enhanced heat transfer that accommodate the fuel burnup process for the life of the system. The solid monolith isolates the fuel and acts as a heat transfer medium between the heat pipes and fuel channels.

Site Implementation and Arrangement

There are three main systems that will be located onsite: the eVinci micro reactor system; the power conversion system; and the instrumentation, control and electrical system. Offsite, there is a remote monitoring system that can be used to monitor and operate either a single or multiple eVinci micro reactors. The eVinci design itself is scalable in power, and the overall system is scalable so that multiple reactors and supporting systems can be located on one site. This flexibility in reactor output from 200 kWe to 5 MWe with the ability to readily add and increase electricity generation are perfect for remote and potentially growing communities or military bases. Since the eVinci micro reactors can be arranged in multiple, independent but connected units, the power additions can be staged over time as power demand grows.

Depending on the application, the eVinci micro reactor can be housed either in a concrete enclosure for fixed installations or a sub-grade trench for mobile applications to utilize earth as natural shielding. The concrete enclosure will be a bunker-type structure located at ground level, which facilitates rapid installation. For either scenario,



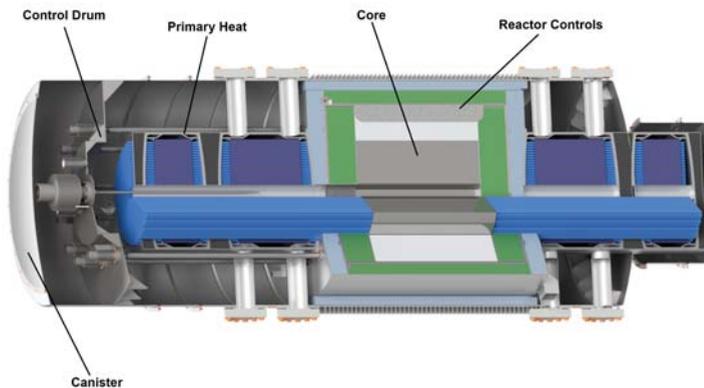
eVinci Core Configuration.

shielding, protection and airflow paths for decay heat removal will be provided. Accommodations in the concrete enclosure design are being made for piping for power conversion fluid and cabling for signal and electrical power. The piping and cabling will travel to and from the power conversion system and the instrumentation, control and electrical system. Currently, the sub-grade trench is intended for mobile power generation for

systems may then be reused for another fuel cycle after minimal inspection and maintenance. The eVinci micro reactor module can be transported back to the factory where it can be refueled and its components can be refurbished.

Continued Development

In partnership with national laboratories, universities and industrial partners, Westinghouse is continuing



eVinci Micro Reactor Overview.

defense applications only, which allows higher mobility and relocation.

When the eVinci micro reactor core has reached the end of its operable lifetime, Westinghouse plans to replace the eVinci canister, swapping the entire reactor canister with a new micro reactor unit. The concrete vault and site

development work with several funding awards. In 2018, The U.S. Department of Energy (DOE) awarded LANL and Westinghouse a \$1.5 million project to design and fabricate a first-of-a-kind heat pipe filling machine at LANL and investigate fabrication methods of the core monolith.

Later in 2018, the U.S. DOE's Advanced Research and Projects Agency-Energy (ARPA-E), separately awarded Westinghouse and its partners a \$7.8 million project under the Modeling-Enhanced Innovations Trailblazing Nuclear Energy Reinvigoration (MEITNER) program. This project is to develop a self-regulating solid core block that employs solid materials to inherently self-regulate the reaction rate in a nuclear reactor, focusing on key high-risk technologies, such as heat pipes, moderator, fabrication, instrumentation and control and factory design. In addition, as part of this project, a separate resource team was funded nearly \$1 million to utilize the Nuclear Energy Advanced Modeling and Simulation (NEAMS) program capability in coupled modeling and simulation tools to demonstrate the solid core block's self-regulating ability. This program will also utilize the Advanced Test Reactor (ATR) facility at INL to perform accelerated irradiation testing. Another complementary ARPA-E fund, called OPEN, of \$3.5 million was awarded, with LANL as the lead, to



Site plan for single eVinci in a fixed installation– planned for 0.6 acres.

investigate alternate monolith and core designs.

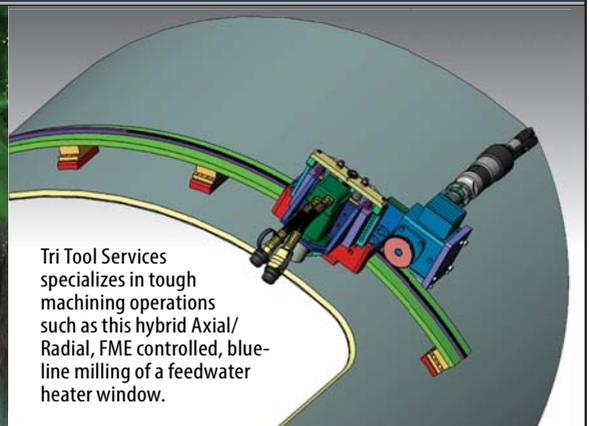
Most recently, the U.S. DOE, under the First-of-a-Kind Nuclear Demonstration Readiness Project pathway, awarded Westinghouse and its team \$12.9 million to accelerate the design, analysis and licensing of an eVinci nuclear demonstration unit that will be ready for construction and testing by 2023.

With the self-regulating core and other inherent and passive safety features, Westinghouse anticipates that the eVinci micro reactor design will be one of the safest and most reliable nuclear reactor designs to become available.

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