Desktop Metal

CASE STUDY

Ultra Safe Nuclear

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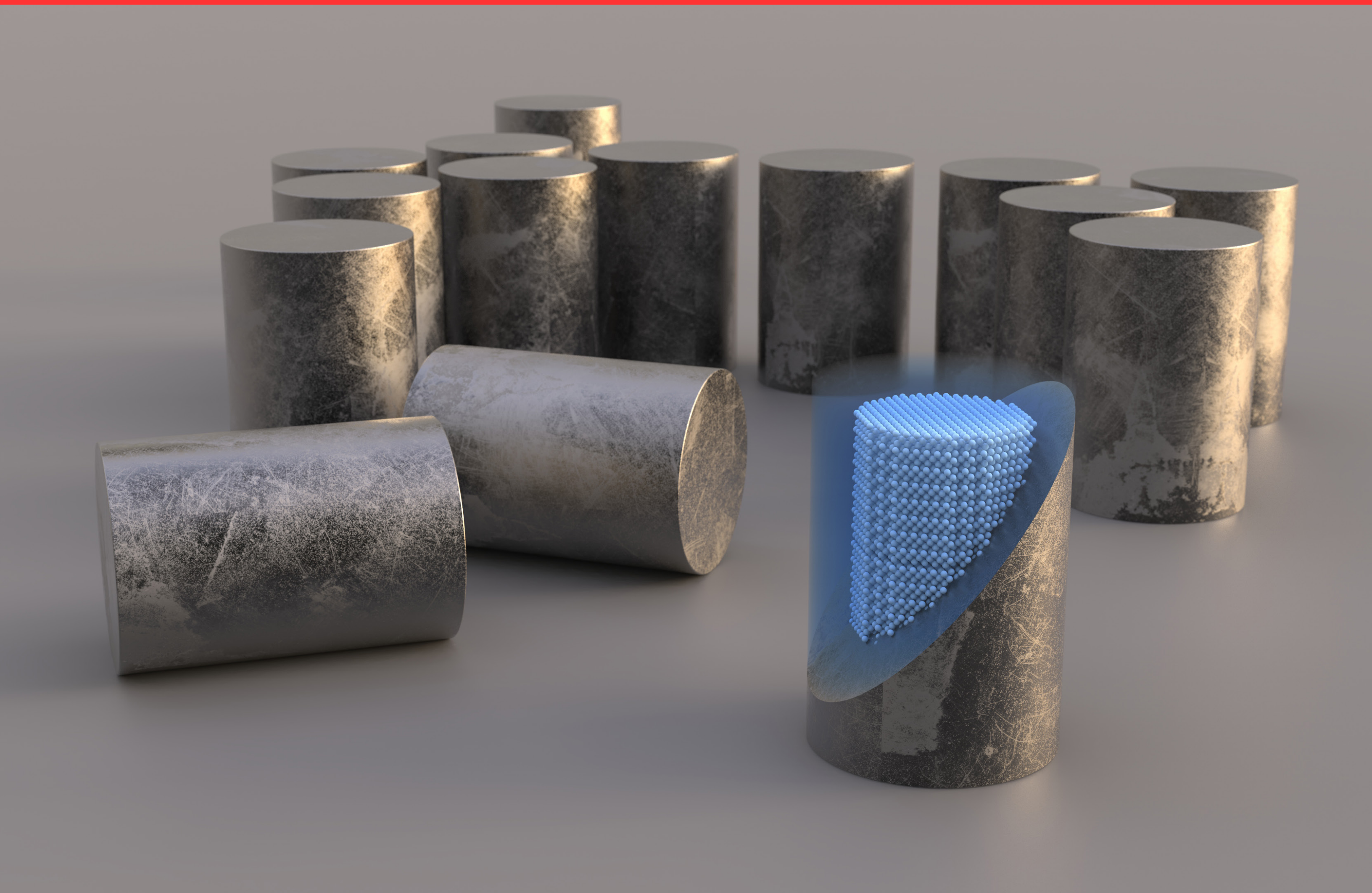
Binder jet 3D printing a new nuclear future with silicon carbide



Customer
Ultra Safe Nuclear Corporation

Location
Seattle, Washington

Industry
Energy

Application
Nuclear Micro Modular Reactors

Machines
InnoventX, X25Pro, X160Pro

Material
Silicon Carbide

Website
www.usnc.com

Introduction

Ultra Safe Nuclear Corporation (USNC), a wholly U.S.-controlled corporation headquartered in Seattle, is a global leader in the deployment of micro reactors, and a strong vertical integrator of nuclear power technologies. The company is committed to bringing safe, commercially competitive, clean and reliable nuclear energy to power markets throughout the world. USNC is demonstrating MMR Energy Systems at the Canadian Nuclear Laboratories in partnership with Ontario Power Generation and at the University of Illinois, and has started new projects to further deploy its technology in the United States, Canada, and Europe. The company adheres to strict inherent and intrinsic safety principles through technological innovation in fuels, materials, and design. USNC is Reliable Energy. Anywhere.

Creating next-generation nuclear to power the future

More than a dozen countries around the world are now collaborating in a global race toward Generation IV – next-generation concepts in nuclear energy seen as vital to supplying carbon-free energy to a world with ever-increasing demands for electricity.

While renewable sources such as solar and wind continue to grow, a conventional wisdom has taken root in energy circles that nuclear stands alone as a reliable baseload energy source, one that is to operate continuously to meet the minimum level of power demand 24/7 without negative environmental consequences.

In this environment, Seattle-based Ultra Safe Nuclear Corporation (USNC) is blazing the way for a group of innovative companies working to bring advanced nuclear concepts to market, and where new methods of

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Dr. Kurt A. Terran, Executive Vice President, USNC's Core Division, works with advanced techniques like binder jet 3D printing to manufacture innovative nuclear reactor components

manufacturing, such as 3D printing, are often necessary to deliver all-new designs that deliver optimal performance in unique materials.

Internationally recognized nuclear fuel expert Dr. Kurt A. Terrani, the former National Technical Director at Oak Ridge National Laboratory (ORNL), joined the team at Ultra Safe Nuclear (USNC) in February 2020 to advance the company's mission of producing safe, controlled, and reliable nuclear energy on demand, anywhere in the world. He said small and advanced reactors, which run on different fuels and coolants while operating in different ways than the gargantuan nuclear facilities of the past, will deliver a paradigm shift in nuclear energy, one that the world especially needs now.

"Ultra Safe Nuclear is on the bleeding edge of nuclear fuel and reactor design, pioneering new advances in safety and performance," he added. "Powering up a new generation of micro reactors represents a watershed moment in zero-carbon energy production in the U.S. and worldwide."

Born out of crisis: USNC and manufacturing innovation

USNC's journey started in 2011, the same year an earthquake hit Japan. The Fukushima Daiichi nuclear power facility shut down operations as designed. Fifty minutes after the quake, however, the facility was hit with a tsunami, flooding and destroying all but one of the power generators used to keep cooling water circulating, leading to a meltdown and the subsequent explosion of three reactors.

The tragic accident also hit the nuclear industry at an already-tough time. The high cost of traditional reactors, in addition to other high-profile accidents such as Chernobyl, had already been slowing their development and escalating their decommissioning in many countries. At the same time, many governments were beginning to come to the incongruent conclusion that nuclear is actually one of the most reliable, portable, and green baseload energy sources.

The United States, EU, Canada, Japan and many other states and countries now view nuclear power, which generates no CO2, as vital as world electricity consumption continues to escalate.

Leading nuclear experts, such as Terrani, had known for some time there was a better way to execute safe nuclear energy. The technologies used in facilities such as Three Mile Island and Fukushima dated back to the 1950s and 1960s, when advanced and safe materials and their methods of manufacture weren't available.

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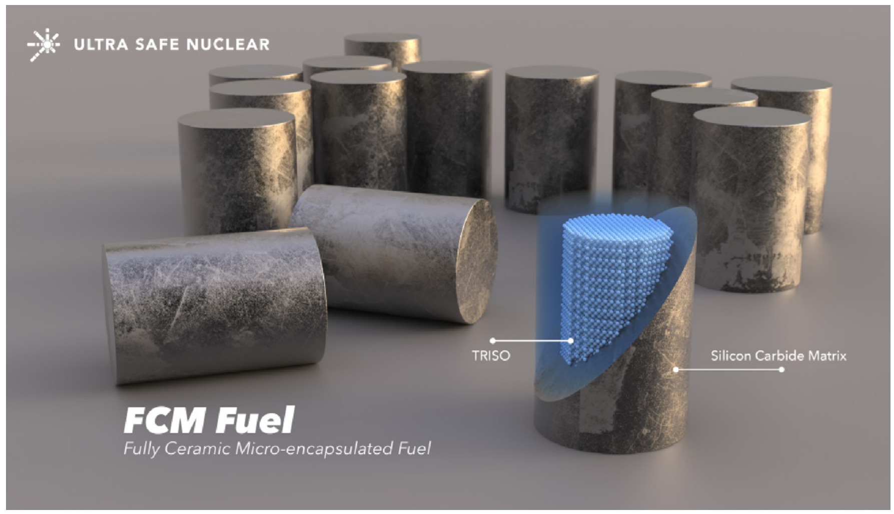
USNC's innovative Fully Ceramic Micro-encapsulated (FCM) Fuel is made possible by binder jetting silicon carbide matrix designs to keep radioactive material safely enclosed and contained at all times.



While calls to phase-out nuclear power were growing louder, the founders of Ultra Safe Nuclear knew that walking away completely would pose dire consequences in the fight against climate change and the resilience of global electricity systems.

Instead, they chose to focus on Generation IV Nuclear Energy and a technology that would allow them to control nuclear fission and prevent accidents altogether.

Innovative approach requires innovative manufacturing

The key to their approach is Fully Ceramic Micro-encapsulated (FCM) fuel, the manufacturing of which is enabled by Desktop Metal innovative binder jet 3D printers and their ability to 3D print silicon carbide heat-resistant ceramic particles in unique geometries that can safely surround a standard type of nuclear fuel particle known for its safety.

Today, USNC is using the novel approach to fuel its extremely reliable and safe micro modular reactor (MMR™) energy systems. Application of Desktop Metal binder jet 3D printers facilitates a key step in manufacturing of USNC's fuel, which is vital to executing the organization's underlying innovation.

Their approach is gaining momentum, with testing of USNC's FCM fuel underway by the Nuclear Research & Consultancy Group in the Netherlands (NRG Petten). Separately, USNC, through its joint venture Global First Power

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About Modular Reactors

- Small Modular Reactors (SMRs) are defined as producing up to 300 megawatts (MW) of power, while Very Small Modular Reactors (vSMRs) or microreactors produce up to 20 MWs of power per module
- A single MW powers about 800 average U.S. homes for a year
- Microreactors are highly transportable and will likely power future bases on the Moon and Mars, as well as orbiting space stations

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USNC's micro modular reactor (MMR) units can be linked as needed and harmonize with renewables to help meet 100% of demand around the clock to provide power to remote locations. "Complex systems like modular reactors for on-demand power, together with renewables, brings about a reliable and highly cost-effective power source," Terrani said.

is also working to deploy its first-of-a-kind MMR at Chalk River Laboratories, a site owned by Atomic Energy of Canada Limited and managed by Canadian Nuclear Laboratories. Currently, an effort is underway seeking a License to Prepare Site from the Canadian Nuclear Safety Commission (CSNC).

"Small modular reactors represent one of the most exciting areas of new nuclear innovation in Ontario and are a potential game-changer for the energy industry," said Todd Smith, Minister of Energy. Small reactors "with their versatility and ability to generate clean, low-cost energy, could provide the perfect solution for unique energy challenges, such as powering remote communities and mines that currently rely on expensive diesel power."

Shifting the nuclear paradigm

To deliver its innovation, USNC focused on combining a highly advanced and safe reactor system design with a highly advanced and safe fuel system. This combined approach, leveraging breakthroughs such as advanced manufacturing, yielded approaches that could take a six-decade-old technology and transform it to deliver a safer, more efficient reactor in the 21st century.

"When you do that, through exploiting fundamental laws of nature, we've created a design for a passively safe reactor, so you don't need a concrete dome, exclusion zone, or big water reservoir because it's inherently safe," Terrani said, explaining the idea behind USNC's approach. We're leveraging a high-temperature resistant fuel with multiple inherent barriers to radiation release at the center of our reactor system. That is the essence of the Ultra Safe Nuclear approach."

Capitalizing on a technology dating back to the 1960s, Ultra Safe Nuclear produces smaller-scale coated fuel particles, or micro encapsulated spheres, known in the industry as TRISO, a tristructural isotropic particle fuel seeing a resurgence in the race to deliver Generation IV nuclear reactors.

"That's quite a mature technology shown to provide extreme resistance to radionuclide release under a whole host of conditions," Terrani said. Traditionally, these fuel microspheres would be put into a soft graphitic matrix. However, these were not structurally strong and served as a poor barrier to radionuclide release.

USNC's answer was to replace this graphitic matrix with a refractory ceramic: silicon carbide (SiC). SiC is a technical ceramic material with extreme environmental stability that is often used in aerospace, armor, plasma shield, and high-temperature applications. The conditions within a nuclear reactor are some of the harshest in all of industry, yet SiC doesn't shrink or excessively swell like the traditional graphitic matrix and has a very high resistance to oxidation and corrosion, offering unique stability under all the demanding conditions of the nuclear reactor core.

The problem with SiC, however, is that it's an incredibly cumbersome material to manufacture or form into complex parts. For decades, despite the industry's desire to work with silicon carbide, there was no viable or affordable manufacturing process to transform highly pure, crystalline, nuclear-grade SiC into the shapes and forms needed for nuclear applications. Not until 3D printers began processing the material, anyway.

Desktop Metal binder jet 3D printing enables innovation

Highly similar to paper printing, binder jet 3D printing is widely regarded as the fastest method of 3D printing for high-volume output. The technology inkjets a binder into a bed of powder particles such as metal, sand, or ceramic to create a solid part, one thin layer at a time. Importantly for 3D printing SiC, the whole process is carried out at low temperatures.

"There was a whole host of additive manufacturing methods out there, but a large portion of those rely on a high-temperature process during deposition," Terrani explained. "With metals they're melting the particles to connect them together, but you can't do that with the high melting point of silicon carbide. Binder jet technology is unique because it really relies on the physical characteristics of the powder, and it's essentially highly agnostic to the chemical and phase structure of the material. So, we can select highly pure, highly crystalline carbide feedstock powder, nuclear grade powder, and then form these really complex geometries, and that just wasn't previously possible."

Binder jet 3D printing directly from digital design files without the need for tooling allows the USNC team to iterate their designs quickly and create unique shapes not otherwise manufacturable.

The 3D printed SiC fuel forms may have complex geometries that act as shells for the nuclear fuel particles. Silicon carbide will often be infiltrated with silicon or other matrices for densification; however, this is not an option in a nuclear environment. "Radiation will affect one material one way and another differently, so material uniformity and homogeneity is key," Terrani said.

> **"Binder jet really shines. It is a low-cost and high-yield process** for us as a part of our complex serial manufacturing**"**
>
> Dr. Kurt A. Terrani, Executive Vice President, USNC's Core Division

By marrying binder jetting with chemical vapor infiltration to fill the porous SiC structure with more high-purity crystalline silicon carbide, USNC is able to realize highly complex, near-net shapes without the need to sinter the SiC material, apply any pressure, or introduce secondary phases.

3D printing ready for prime time

The team at USNC already had many decades of experience processing ceramics, which gave them a unique perspective in doing a full lifecycle analysis of their production, including costs, schedule, and yields. “Binder jet really shines. It is a low-cost and high-yield process for us as a part of our complex serial manufacturing,” Terrani said of Desktop Metal’s SiC printing.

Compared to the traditional way of processing technical ceramics, including mixers to create slurries, injection molders, and furnaces, Terrani said binder jet 3D printing is simple and elegant. Most importantly to his team, he said, it’s also a “cost-effective and reliable process.”

Beyond production efficiencies, USNC’s 21st century manufacturing strategy with binder jet 3D printing allows USNC to optimize the performance of their reactors by tapping the design freedom that comes with 3D printing. Previously the team was limited to one design, mass produced from hard tooling. Because this tooling was expensive and hard to change with long lead times, designers made a single design as generic yet efficient as possible.

3D printing technical ceramics

Binder jetting specialty materials on the Desktop Metal X-Series was developed with scalability in mind to drive innovative applications from R&D and prototyping to serial production with repeatable performance across a range of machines. USNC develops applications on an InnoventX before scaling them for production on the X25Pro and X160Pro. Features of the X-Series machines like top-of-the-line piezo printheads and Triple ACT powder compaction deliver industry-leading density in a variety of materials, including hard to process powders like silicon carbide and other technical ceramics.

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X160Pro binder jet system ramps up applications developed on the innoventX or X25Pro to mass-production volumes

"With binder jetting we have the design freedom to have unique parts – we don't need to make the same thing," Terrani said. This design freedom allows shapes, wall thicknesses, and cooling channels to be tailored to each USNC reactor for operational efficiency and optimal safety.

> **"Binder jetting allows us to create a new paradigm of safe, reliable, carbon-free nuclear energy** for use by industry and remote communities**"**
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> **Dr. Kurt A. Terrani, Executive Vice President, USNC's Core Division**

Beyond performance, the ability to create unique designs en masse with 3D printing allows USNC to add an additional layer of quality assurance to its mission of safe, responsible nuclear energy. "We print an ID on these parts, so from the moment of birth we track the reactors' manufacturing DNA throughout production, operational lifetime, and upon their discharge," Terrani said. "Binder jetting allows us to create a new paradigm of safe, reliable, carbon-free nuclear energy for use by industry and remote communities."

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About Desktop Metal Inc.

Desktop Metal, Inc. is accelerating the transformation of manufacturing with end-to-end metal 3D printing solutions. Founded in 2015 by leaders in advanced manufacturing, metallurgy, and robotics, the company is addressing the unmet challenges of speed, cost, and quality to make metal 3D printing an essential tool for engineers and manufacturers around the world. In 2017, the company was selected as one of the world's 30 most promising Technology Pioneers by the World Economic Forum, and was recently named to MIT Technology Review's list of 50 Smartest Companies. For more information, visit www.desktopmetal.com.