BWXT

NASA's Nuclear Thermal Propulsion Engine System, for which BWXT is providing support for reactor and fuel design and analysis.

The promise of nuclear thermal propulsion

BWXT is using advances in manufacturing and fuel to develop the technology to power a mission to Mars.

By Jud Simmons

The United States is pursuing the objective of landing humans on Mars, more than 100 million miles away, and nuclear power has the potential to be a key technology in getting them to the Red Planet and providing power while they are there. Specifically, nuclear thermal propulsion (NTP) is a promising approach that could enable astronauts to travel from Earth's orbit to Mars and back in a fraction of the time, and with greater safety, than is possible with other options.

NTP technology development is under way at BWX Technologies (BWXT) in Lynchburg, Va., where NASA Administrator Jim Bridenstine and a number of his staff members recently visited. "When we plant that American flag on Mars," Bridenstine said, "it is very likely that that mission is going to go through Lynchburg, Virginia, because of BWXT."

The technology

NTP is not a new concept. It has been researched over a number of years for multiple space programs.

"The concept behind nuclear thermal propulsion is pretty straightforward," said Jonathan Witter, BWXT's chief engineer for its NTP program. "Nuclear power, using a low-enriched uranium fission power source, quickly heats super-cooled liquid hydrogen supplied from a propellant tank. As that hydrogen expands rapidly at high pressure, it is directed via a nozzle out of the spacecraft with a specific impulse approximately double that of a chemical liquid rocket engine. That gives the vehicle a tremendous amount of thrust as it leaves Earth's orbit and heads to Mars, and then later makes the return trip."

Of course, other technologies can be used for the same purpose, but NTP has a number of important advantages. Using NTP, a spacecraft traveling to Mars can get there faster, reducing the astronauts' exposure to cosmic radiation. What's more, each reactor would be roughly the size of a 55-gallon drum, which is another key consideration given that every cubic foot counts on a spacecraft.

NTP is not a scientific novelty. Rather, it is recognized as a promising technology at the highest levels of the U.S. government. When

Jud Simmons (<hjsimmons@bwxt.com>) is Director of Media and Public Relations at BWX Technologies.

BWXT

BWXT's Uranium Processing Services facility in Lynchburg, Va., has provided all phases of uranium downblending and uranium recovery.

BWXT's president and chief executive officer, Rex Geveden, testified last year before the National Space Council, both Bridenstine and Vice President Mike Pence were listening.

"America has the nuclear technological capabilities right now to push the boundaries of human exploration on the moon and further on to Mars," Geveden said. "Many space exploration and operations problems require that high-density power be available at all times or on call, and there is a class of such problems for which nuclear power is the preferred, if not the only, solution. Technology is rapidly evolving to make relatively low-cost nuclear reactors that are not just attractive alternatives to other space power options, but also the means to accomplish things that were not possible before."

BWXT

BWXT's president and CEO Rex Geveden (right) talks to employee Dudley Raine about the company's laser welding capabilities to support nuclear thermal propulsion work.

Manufacturing challenges

The environment of space is harsh, and the technical requirements for a propulsion system are considerable. In order to ensure that its systems would work as designed, BWXT's Advanced Technologies

Program is using specialized manufacturing techniques to support NASA's mission needs.

"The theory of nuclear thermal propulsion is well understood, but that doesn't mean design or manufacturing is easy," said Jonathan Cirtain, president of the BWXT Advanced Technologies team that is responsible for the development of novel technologies that can be utilized for manufacturability. "For example, the thermal requirements of the system may require us to use high-temperature refractory metals like molybdenum and tungsten," he said. "It's not something you do every day, but our experts have figured out how to work with these metals, and it's just one example of the challenges we will have to overcome if nuclear thermal propulsion is going to work."

Cirtain also explained that BWXT uses a specialized furnace to perform stress-relieving operations on new refractory metal alloy materials prior to machining and cutting operations for fabrication of high-temperature performance parts and components.

"This furnace also provides us a method to remove contaminants from metal parts to ensure high-quality welding operations and provides the capability to heat-treat parts to relieve thermal stresses following welding operations," Cirtain said. "This is particularly important when welding refractory materials that can crack if not stress-relieved in a timely manner."

BWXT has been working hard to overcome other challenges as well. With a little over $20 million in funding from NASA since 2017, BWXT has focused on reactor design, fuel development, and reactor fabrication development. The company's engineers and scientists are using a variety of advanced technologies, such as additive manufacturing, to tackle the unforgiving requirements of space travel.

BWXT

In its Specialty Fuel Facility, BWXT is producing uranium solutions for high-temperature nuclear fuel (including TRISO) for commercial applications as the company moves forward with its previously announced plans to restart its manufacturing line and increase capacity at its Lynchburg, Va., facility.

Fueling the reactor

BWXT has a long history of development and manufacture of specialty fuels, and this experience is being leveraged at BWXT's laboratories to support the NTP effort.

"We're all very proud of our work in manufacturing naval nuclear reactors for U.S. submarines and aircraft carriers, and we're also very excited to be moving into another realm of fuel manufacturing for nuclear thermal propulsion," said Joel Duling, president of BWXT's Nuclear Operations Group, where fuel manufacturing is conducted. "We recently announced plans to restart and expand our TRISO fuel manufacturing capability, and the equipment and the facility we will use to manufacture TRISO can be used to manufacture other high-temperature nuclear fuels with direct applicability to nuclear thermal propulsion reactors."

The TRISO production line offers the capability to manufacture an array of nuclear fuel, including uranium carbide, uranium dioxide, and uranium nitride. The TRISO production line also provides the flexibility of any fuel enrichment—the facility and process is qualified to produce TRISO-coated kernels with enrichment levels from depleted uranium up to highly enriched uranium.

Many of the proposed NTP core designs call for spherical fuel kernels, such as those that BWXT has successfully made on its TRISO fuel production line. The TRISO line has been demonstrated to produce kernel diameters down to the range of 200–250 μm, with the potential to go smaller or larger. This provides the flexibility to meet potential fuel particle requirements for an NTP reactor.

Duling explained that the TRISO production line operates in batches, which offers the flexibility to run separate batches of the various fuel types with minimal transition time. This flexibility would allow NASA and others to leverage the same fuel line and pursue different fuel forms to optimize their own design and applications.

Keith Rider, one of BWXT's scientists who is helping develop the company's NTP fuel manufacturing processes, explained that NTP places demands on its fuel that are more stringent than any other application. "It's common for a pressurized water reactor used by a utility for power generation to operate with coolant temperatures of something like 580 K (~585°F)," he said. "In comparison, a hydrogen-cooled NTP reactor operates at five to eight times that temperature."

What's more, Rider said, the performance of the rocket is directly tied to the maximum operating temperature of the fuel in an environment with high thermal gradients and rapid temperature changes. "We're using a mix of off-the-shelf com-

BWXT

A Category I license from the Nuclear Regulatory Commission authorizes BWXT to manufacture a variety of specialized fuel forms at its Lynchburg, Va., facility. The equipment and the facility BWXT will use to manufacture TRISO fuel can be used to manufacture other high-temperature nuclear fuels with direct applicability to nuclear thermal propulsion reactors.

ponents and some of our own proprietary technology to produce nuclear fuel that meets NASA's performance requirements."

The administrator's visit

When Bridenstine visited BWXT's research and development labs earlier in 2020, he talked about NASA's plans for travel to the moon and Mars, and the importance of technologies such as NTP. He explained that Earth and Mars are on the same side of the sun only every 26 months, which means that using current technologies, astronauts would have to stay on Mars for an extended period of time.

"If we had the right propulsion technologies, we could do what's called an opposition class return from Mars," Bridenstine said. "In other words, Earth might be on the opposite side of the sun from Mars, and we could actually have the technology and the propulsion set to achieve a return when we're not on the same side of the sun. We could have a short-duration stay on Mars, rather than a two-year stay on Mars. That is a significant advantage. That's why the investments we're making right now in the research and development for nuclear propulsion matter. Because, ultimately, it's about achieving more for less cost and preserving the lives and safety of our astronauts. The bottom line is, the faster we go, the safer it is, and that's why nuclear propulsion is so important."

Bridenstine also made the point that this is a long-term vision for NASA. "We

BWXT

BWXT's Specialty Fuel Facility can fabricate the fuel required to support the development of advanced reactors.

TRISO

BWXT recently announced plans to restart and expand its TRISO fuel manufacturing capability. The equipment and the facility that will be used to manufacture TRISO can be used to manufacture other high-temperature nuclear fuels with direct applicability to nuclear thermal propulsion reactors.

TRISO refers to a specific design of uranium nuclear reactor fuel for advanced reactors and microreactors. It can withstand extreme heat, and it has very low proliferation concerns and environmental risks.

BWXT

Artist's rendering of TRISO-coated kernels.

TRISO is a shortened form of the term TRIstructural-ISOtropic. TRIstructural refers to the layers of coatings surrounding the uranium fuel, and ISOtropic refers to the TRISO-coated kernel being the same size in each direction, since it takes the shape of a sphere. This three-layer coating system acts as a miniature pressure vessel, providing containment of the radionuclides and gases generated by fission of the nuclear material in the kernel.

TRISO fuel consists of a very small kernel of uranium coated with a variety of silicon- and carbon-based materials. Due to this design, radionuclides are retained within multiple barriers. Each TRISO-coated kernel is about 1 mm in diameter—about the size of the tip of a ballpoint pen. About 100,000 of them could fit in a standard tube of lip balm.

are building a sustainable program so that when my children and my grandchildren are my age, we are still going to the moon sustainably and going to Mars," he said. "That's what we're trying to achieve, and BWXT is likely to be a big part of that, given the capabilities that reside here."

Beyond NTP

While BWXT is continuing its work to develop NTP technologies, the company's work could also translate into providing power systems for operations after a spacecraft lands, a scope of work that goes beyond NTP. Not only could nuclear power get astronauts to Mars, but it could also provide the power needed to explore the planet's surface and communicate back to Earth.

Ken Camplin, BWXT's president for nuclear services, who has overall responsibility for BWXT's space nuclear technology development efforts, said, "Nuclear power is one of several technologies that are options for propulsion to Mars and sustainment of life once we arrive, and BWXT is working hard every day to demonstrate that it can be a go-to choice for NASA. If this becomes a chosen technology for getting humans to Mars and powering their work while they are there, it won't be just a victory for BWXT—it will be a victory for everyone in the nuclear industry." NN