The astronauts pass their days in darkness. After several months of living on the moon, they’re still adjusting to the endless night. The crew’s habitat at the lunar south pole sits in a shadowed crater—chosen for its promise of ice—that has not been touched by a single ray of sun for billions of years.

Fortunately, the nearby nuclear reactor is unfazed by the lack of light. Connected to the astronauts’ base camp by a kilometer of cables cautiously tracing the lunar surface, the reactor provides an uninterrupted supply of electricity for recharging rovers, running scientific instruments, and, most importantly, powering the air and heating systems that keep the astronauts alive.

This is one vision of what human exploration could look like on the moon. In fact, NASA has plans to make some version of this scene a reality—and soon.

The agency aims to send a human mission to the moon by 2024 in an effort named the Artemis project. Congress has allocated more than $6 billion of NASA’s 2020 fiscal budget for space exploration programs including the Space Launch System launch vehicle, the Orion spacecraft, exploration ground systems, and research and development. The agency estimates that it will cost $35 billion to land a crew on the lunar surface, including the first woman to step foot on the moon. After 2024, NASA hopes to move to launching one human mission each year and reach sustainable operations on the moon by 2028.

The lessons learned in that phase will be crucial in preparing for future trips to Mars. One major effort will involve figuring out which power systems—including ones that have never been tested on the lunar surface, such as nuclear power—would best support future settlements.

**Nuclear reactors might be the best electricity source for colonies on the moon and Mars.**

NASA is developing a nuclear reactor (shown in this artist’s rendition) that could power a human settlement on the moon. Credit: NASA.

Whether the necessary materials can be brought safely to the moon—and whether systems such as nuclear fission can run reliably under such harsh conditions—are central questions that must be answered as engineers weigh their options.

**Going nuclear**

Choosing a power source depends on the particular mission’s needs, says Michelle A. Rucker, an engineer at NASA’s Lyndon B. Johnson Space Center who has researched possible architectures for space settlements. Electricity may come from nuclear reactors, solar panels, batteries, fuel cells, or some combination of these technologies.

Published: April 13, 2020
connected in a power grid, she says. “I’m a big fan of all the
types of power.”

But each power source has distinct pros and cons to
consider. Solar arrays have reliably delivered renewable
power in space for decades but are useless in places that
never get any light, like the potentially resource-rich craters
on the moon. And on the windy, dusty surface of Mars, solar
panels may struggle to collect enough light, making them
a risky option for powering life support systems, Rucker
says. Batteries and fuel cells have limited lifetimes for now,
relegating them to supplementary power sources at best.

One type of nuclear device that has been used to power
spacecraft is a radioisotope thermoelectric generator, which
runs on the heat produced by the decay of plutonium-238.
These generators have been used since the 1960s in Mars
rovers and space probes sent to the outer edges of the solar
system, such as the Voyager vehicles and Cassini. Despite
being the workhorses of scientific missions, the generators
provide only several hundred watts of power, just enough to
send radio signals back to Earth or power a camera.

On Earth, the nuclear technology used by power plants is
nuclear fission, which splits uranium-235 atoms via bombard-
ment with neutrons to generate heat that’s captured to pro-
duce electricity. Nuclear fission holds the potential to provide
a continuous, reliable source of power for a small space
settlement designed to last for several years.

In the 1960s, many scientists thought fission reactors for
space would follow on the heels of radioisotope generators.
In 1965, the US launched a small nuclear fission-powered
satellite named SNAP-10A, but electrical issues caused it to
fail a mere 43 days after launch; it’s still in orbit, now just
another piece of space junk. The Soviet Union launched
31 nuclear fission-powered satellites over the next 2 decades.

But the development of new nuclear fission reactors for
space stalled during that time because of design problems
and ballooning budgets. Engineers wanted advanced per-
formance from these systems right away, which led to com-
licated and expensive designs, says David Poston, a nuclear
engineer at Los Alamos National Laboratory. He and
Patrick McClure, who specializes in reactor safety at Los
Alamos, have worked at the lab for the past 25 years and
recall the days when nuclear fission had fallen out of favor.

“Pat and I were sitting around just kind of demoralized,”
Poston says, “because we had gotten to the point where
NASA wasn’t really interested anymore because the impres-
sion was that it was going to be too expensive and too hard
to develop a fission reactor.” But the pair were convinced
their team could come up with a design to dispel the funk
that had settled around fission power for space.

In the early 2010s, they got their chance: researchers at Los
Alamos, and later the NASA Glenn Research Center and the
U.S. Department of Energy, began work on a joint project
called Kilopower, now renamed the Nuclear Fission Power
Project. The goal is to develop a new nuclear fission power
system for space that would be capable of producing 10 kW
of electrical energy.

Designing the reactor

Four of these reactors could easily provide the 40 kW of
power that Rucker estimates a six-member crew would need
to live on Mars. The project’s modular, compact design is
lightweight enough for space exploration, in which every
kilogram counts. Previous hypothetical fission-power con-
cepts required a payload of 12–14 metric tons (a 6–7 t
reactor plus a backup), whereas a single Kilopower reactor
would weigh an estimated 1.5 t, she says.

The team decided to approach the reactor design anew,
putting one priority above all: simplicity. This meant not only
maintaining a simple mechanical design but also looking
for opportunities to simplify safety approvals and project
management. As an example, McClure says, the team made a
conscious choice to limit the size of the nuclear core to a container already being used to test nuclear materials instead of fabricating a new one.

“I hate to call it an innovation because it’s not that complicated. But it’s an innovation that we said, ‘Why don’t we just do it the simple way that we know is going to work?’” Poston says. “We knew it was going to work, but the world didn’t.”

The nuclear core, which is about the size of a paper towel roll and weighs 28 kg, comprises a solid alloy of about 8% molybdenum and 92% highly enriched uranium. The nuclear material is surrounded by a beryllium oxide reflector that bounces neutrons into the core to drive the fission reaction. Lodged inside the core is a rod of pure boron carbide that absorbs neutrons, quenching fission reactions.

When the boron carbide rod is slowly removed, neutrons start to strike uranium atoms, occasionally splitting them, creating more neutrons and releasing energy as heat. Once the number of neutrons lost equals the number of neutrons being produced, the reactor becomes self-sustaining. The fission-generated heat travels through sodium-filled heat pipes to a set of Stirling engines. Designed in the early 1800s, these simple piston-driven engines convert heat to electricity. Finally, the team’s reactor design includes a radiator to remove the excess heat, sloughing it off into space.

“We wanted to show not only the world but ourselves that we can still do something real because we had gotten away from actually testing real fission systems,” Poston says.

In a proof-of-concept test called DUFF, the team showed that the hardware worked to produce electricity. Then, in 2018, the team successfully tested a prototype of the reactor at the Nevada National Security Site. During the months-long KRUSTY experiment, researchers tested each of the reactor’s components and its ability to withstand various failures. (The experiment names were inspired by The Simpsons TV show.) The reactor also successfully passed a 28-h test, in which it ramped up to full power, peaking at about 5 kW, operated at a steady state, and then shut down safely.

The team hopes that with more optimization, such as by increasing the size of the nuclear core, it can meet its goal of producing 10 kW per reactor.

Of course, some people look at highly enriched uranium with skepticism, given its potential to harm humans and its role as a material for nuclear weapons. But McClure says transporting uranium to the moon and working alongside a reactor can be done safely. Uranium emits weak alpha particles, which can’t penetrate a piece of paper or skin, so the shielding that surrounds the nuclear core would prevent astronauts from any radiation exposure. Burying the reactor a few meters into the ground or putting it behind a big rock feature could also help keep astronauts safe from radiation when the reactor is on. Once the reactor has run its course, the radioactive waste will likely be shielded and left alone.

The worst-case scenario for such a system would involve the entire reactor blowing up mid-launch, aerosolizing and dispersing uranium particles. Even then, a person a kilometer away might receive a dose in the millirem range—less than the dose you get from solar radiation when you take a plane flight, McClure says.

Ultimately, the fission reactor’s future will not only depend on technical success but sufficient funding. Dionne Hernández-Lugo of the NASA Glenn Research Center and deputy project manager for the Nuclear Fission Power Project, says the proposed budget puts the team “on the path to build and send a surface power system to the moon.”

“It’ll be really exciting to test [the reactor] on the moon and get some experience under our belts before we go to Mars,” Rucker says. “On the moon, you’re close to home, so if something fails, it’s a fairly close trip to get back home, whereas on Mars, your system better be working.”

Los Alamos’s Poston says designing the fission reactor with McClure and others is “definitely the highlight of our careers.” He adds that there’s still a lot to do. In addition to passing more safety and reliability tests, which haven’t been decided on yet, the reactor will need to be “flight qualified,” meaning it would have to survive the gravitational forces experienced at launch and the extreme temperatures seen on the moon. Although the ground tests were a great accomplishment, Poston says, he and his colleagues won’t be satisfied until they see the reactor operating in space. And when—or more cautiously, if—that day comes, the whole world may be watching.

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