How NASA prepares spacecraft for the harsh radiation of space

11 June 2019, by Lina Tran

The long-term radiation dose tests at the Radiation Effects Facility take place in a small room walled by four feet of concrete. Each part of every NASA instrument destined for spaceflight goes through radiation testing to ensure it can survive in space. Credit: NASA's Goddard Space Flight Center/Genna Duberstein

In a small, square room walled by four feet of concrete, the air smells as if a lightning storm just passed through—crisp and acrid, like cleaning supplies. Outside, that's the smell of lightning ripping apart oxygen in the air, which readily reshuffles into ozone. But belowground in one of the rooms at NASA's Radiation Effects Facility, the smell of ozone lingers after high-energy radiation tests. The radiation that engineers use to test electronics for spaceflight is so powerful it shreds the oxygen in the room.

Each part of every NASA instrument destined for spaceflight goes through radiation testing to ensure it can survive in space. It's not easy being a spacecraft; invisible, energetic particles zip throughout space—and while there are so few that space is considered a vacuum, what's there packs a punch. Tiny particles can wreak havoc with the electronics we send up into space.

As NASA explores the solar system, radiation testing becomes ever more crucial. The Radiation Effects Facility, housed at NASA's Goddard Space Flight Center in Greenbelt, Maryland, helps inspect the hardware that enables NASA's exploration of the Moon, the Sun and our solar system—from missions seeking to understand the beginnings of the universe to the Artemis program's journey to the Moon much closer to home.

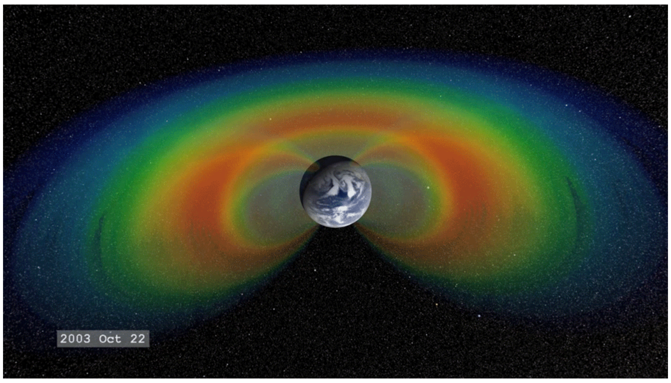
"We will be able to ensure that humans, electronics, spacecraft and instruments—anything we are actually sending into space—will survive in the environment we are putting it in," said Megan Casey, an aerospace engineer in the Radiation Effects and Analysis Group at Goddard.

The exact conditions a spacecraft encounters depends on where it's headed, so engineers carefully test and select parts catered to each spacecraft's destination. Earth's magnetic field, for example, traps swarms of particles in two doughnut-shaped bands called the radiation belts. Other planets have radiation belts too, like Jupiter, whose belts are 10,000 times stronger than Earth's. Generally, the closer to the Sun, the harsher the wash of solar particles known as the solar wind. And galactic cosmic rays—particle fragments from exploded stars far outside the solar system—can be encountered anywhere.

Timing is a factor too. The Sun goes through natural 11-year cycles, swinging from periods of high to low activity. In the relative calm of solar minimum, cosmic rays easily infiltrate the Sun's magnetic field, streaming into the solar system. On the other hand, during solar maximum, frequent solar flares flood space with high-energy particles.

"Based on where they're going, we tell mission designers what their space environment will be like, and they come back to us with their instrument plans and ask, "Are these parts going to survive there?"" Casey said. "The answer is always yes, no, or I don't know. If we don't know, that's when we do additional testing. That's the vast majority of our job."

Goddard's radiation center—along with partner facilities throughout the country—is equipped to mimic the gamut of space radiation, from the constant irritation of the solar wind to the blazing radiation belts and brutal blows of solar flares and cosmic rays.



Earth's radiation belts are filled with energetic particles trapped by Earth's magnetic field that can wreak havoc with electronics we send to space. Credit: NASA's Scientific Visualization Studio/Tom Bridgman

The Effects of Space Radiation

Engineers use computer models to determine what a spacecraft's destination will be like— how much radiation it will encounter there—and what kinds of tests they need in order to mirror that environment in the lab.

Radiation is energy in the form of waves or tiny, subatomic particles. For spacecraft, the main concern is particle radiation. This radiation, which includes protons and electrons, can impact their electronics in two ways.

The first kind, known as single event effects, are immediate threats—quick bursts of energy when a solar particle or cosmic ray pierces through a circuit. "Highly energetic particles dump energy in your electronics," said Clive Dyer, an electrical engineer at the University of Surrey's Space Center in England. "Single event effects will mess up your computers, scrambling your data—in binary code—from 1's to 0's."

Many spacecraft are equipped to recover from these skirmishes with particles. But some strikes can upset the programs spacecraft run on, impacting communications or navigations systems and causing computer crashes. At worst, the result can be catastrophic. Years ago, astronauts' laptops on the space shuttle crashed while they passed through particularly hairy parts of the radiation belts, and NASA's Hubble Space Telescope preemptively turns its science instruments off when it passes through the region.

And then, there are effects that worsen with time. Charged particles can collect on a spacecraft's surface and build up a charge within hours. Much like walking across a carpeted room and turning a metal door knob, charging triggers static that can damage electronics, sensors and solar panels. In April 2010, charging disabled the Galaxy 15 satellite's communications systems, sending it adrift for eight months.

Spacecraft must weather radiation throughout their entire lives. Long-term radiation—known as total dose—wears material down, gradually reducing instrument performance the longer they're in orbit. Even relatively mild radiation can degrade solar panels and circuitry.

Tucked in an adjacent room a safe distance away from the radiation, engineers at the testing facility pelt instrument components with a medley of energetic particles, looking for signs of weakness.

Generally, the effects of their tests aren't visible. A jump in temperature or electric current might indicate a single particle struck a circuit. On the other hand, during total dose tests, the engineers watch for slow, graceful degradation, a side-effect of space travel most missions can live with given they have enough time to complete their science goals.

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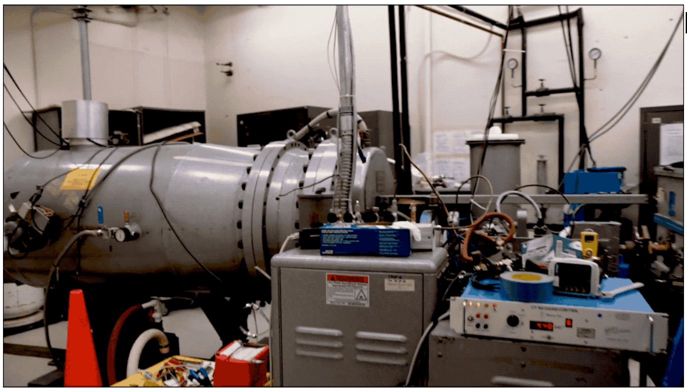

A particle accelerator at the Radiation Effects Facility hurls high-energy particles at instruments, mimicking the solar wind or galactic cosmic rays. Credit: NASA's Goddard Space Flight Center/Genna Duberstein

"The worst case is a destructive single event effect, when you see a catastrophic failure because an instrument has shorted out," Casey said. "It's bad news for the mission, but those are the most fun for us to test. Sometimes there's so much energy, you actually see something happen—light or a scorch mark in some cases."

Weathering the Radiation Storm

So, how do engineers protect spacecraft from the constant hazards of space radiation? One tactic is to build parts that are hardened against radiation from their very foundations. Engineers can select certain materials that are less susceptible to particle strikes or charging.

Spacecraft designers rely upon shielding to defend their instruments from long-term effects. Layered aluminum or titanium slow down energetic particles, preventing them from reaching sensitive electronics. "Right now, we assume that all missions will have a shielding thickness—how thick the walls of the spacecraft or instrument are—of about a tenth of an inch," Casey said.

After their tests, engineers make specific recommendations for shielding if the environment demands it. Shielding adds bulk and weight, which raises fuel needs or costs, so engineers always prefer to use the least amount possible. "If we can better our models and more tightly refine what the radiation environment looks like, we can maybe thin those walls out," she said.

Gathering observations from a diverse range of space environments is a key step in improving models. "Refining our models of space radiation ultimately helps us make better selection of devices," said Michael Xapsos, a member of the Project Scientist Team for NASA's Space Environment Testbeds mission, which is dedicated to studying the effects of radiation on hardware. "With more data, engineers can make better trades between risk, cost, and performance in the electronic devices they pick."

The most energetic particles are impossible to avoid, even with heavy shielding. After testing for single event effects, the engineers calculate a prediction for how often such a blow could occur. It may be, for example, that a spacecraft has a chance of a particle strike once every 1,000 days. These are isolated events that are as likely to occur on a satellite's first day in space as on its 1,000th day—and it's up to mission designers to decide how much risk they can bear.

A common strategy against single event effects is equipping an instrument with multiples of the same part that work together simultaneously. If one computer chip is temporarily disabled by a particle blow, its counterparts can pick up the slack.

Engineers can plan and develop such mitigation strategies—but it's best done when they truly understand the space environment a satellite is traveling through. Missions like Space Environment Testbeds, or SET—scheduled to launch at the end of June—and modeling efforts at the Radiation Effects Facility ensure they get that information.

Provided by NASA's Goddard Space Flight Center