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November 2009

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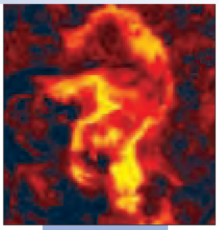
A PUBLICATION OF THE AMERICAN INSTITUTE OF AERONAUTICS AND ASTRONAUTICS



Phantom Torso takes solar blasts for science

THE PHANTOM TORSO IS BACK, AND HAS quite a story to tell.

"He" is an armless, legless, human-shaped torso, a mannequin resembling a mummy wrapped in bandages. Scientists at ESA call him Matroshka, and like his NASA counterpart, Fred, this mannequin is an intrepid space traveler. Now that Matroshka has spent four months on the ISS, scientists are learning about the space radiation he endured there.

Lessons learned from Fred and Matroshka have major implications for NASA's plans to set up a manned outpost on the Moon and, eventually, to send people to Mars. Protecting astronauts from the harmful effects of space radiation will be a critical challenge for these extended missions. In order to design spacesuits, vehicles, and habitats with enough shielding to keep astronauts safe, mission scientists need to know how much radiation—and what kinds—humans actually absorb.

Scientists can use computers to estimate the amount, but a computer model and real life can be two wildly different things. Until now, researchers were unsure whether their models accurately predicted the radiation dose astronauts would experience in space.

That is where the Phantom Torso comes in. It has provided the real-world test needed to prove that the models are essentially correct. Francis Cucinotta, chief scientist for NASA's Space Radiation Program, and his colleagues analyzed the measurements from hundreds of radiation sensors embedded throughout Matroshka's body and found that the models are actually quite good—accurate to within 10% of the measured dose. That means it is "all systems go" for using them to plan NASA's return to the Moon or even a trip to Mars.

Fred is NASA's version of the Phantom Torso.

Gauging the danger

The most dangerous kind of radiation the astronauts encounter is galactic cosmic rays (GCR). These are bare atomic nuclei, some as heavy as iron atoms, accelerated to nearly the speed of light by distant supernovas. Because of their high velocity, high mass, and positive electric charge, GCR particles can cause tremendous damage to a person's cells. Moreover, traditional radiation shielding cannot stop GCR particles.

But understanding the danger is not as simple as merely knowing how much radiation is out there. "What matters most is how much radiation actually hits a person's vital organs," says Cucinotta.

To reach those organs, particles of radiation must first pass through the walls of a spacecraft, an astronaut's spacesuit, and then skin and other body tissues. It is a very complex interaction. Sometimes these barriers will slow down or stop a particle of radiation. Moreover, sometimes the collision between a particle and a barrier will produce a shower of new particles called "secondary" radiation. Computer models must account for all this activity.

Space station astronauts wear sensors on their flight suits to record total radiation exposure, but there is no practical way to measure how much radiation actually reaches their vital organs. Fred has sensors just about everywhere—even on the inside.

The Phantom Torsos are made of a special plastic that closely mimics the density of the human body, sliced horizontally into 35 1-in.-thick layers. Within these layers, researchers have embedded a total of 416 lithium-crystal dosimeters, each of which measures the accumulated radiation dose at one point in the body over the course of the experiment. Fred and Matroshka also contain several "active" dosimeters located where vital organs such as the brain, thyroid, heart, colon, and stomach would be. These active sensors keep a record of how the radiation dose changes moment by moment. Together, these various sensors thoroughly document how radiation propagates through their bodies.

"The geometry and the composition of the torso mimic the human body very well," Cucinotta says. "I think it is a very good test."

Maximizing safety

So now that these computer models have been verified in the real world, what do they say about keeping astronauts safe in a lunar outpost or on Mars?

"Short lunar missions are fine," says Cucinotta, "but living in a lunar habitat for six months starts to be problematic. We are going to have to do a really good job with radiation shielding and perhaps medical countermeasures to have six-month missions."

Mars will be even tougher, these models suggest. Some scenarios call for missions that would last 18 months or more. "Right now there is no design solution to stay within safety limits for such a Mars mission," says Cucinotta. "Putting enough radiation shielding around a spacecraft would make it far too heavy to launch, so we need to find better lightweight shielding materials. And we probably need to develop medical techniques to counteract damage to cells caused by cosmic rays." One of the biggest obstacles to progress in this area, he notes, is "uncertainty in the types of cell damage deep cosmic ray exposure can cause. We still have a lot to learn."

The solar flare factor

Another key question: How do solar flares affect astronauts? Fred and Matroshka have not experienced any intense solar radiation storms during their time onboard the ISS.

"The energy spectrum of solar events and how the radiation dose changes from organ to organ will be very different from what we have seen so far from cosmic rays," says Cucinotta.

To find the answer, scientists have recreated the intense radiation from giant solar flares right here on Earth. Matroshka has been chosen as the volunteer who will experience the blast.

In 1972, Apollo astronauts narrowly escaped a potential catastrophe. On August 2, a large sunspot appeared and began to erupt repeatedly for more than a week, producing a record-setting fusillade of solar proton radiation. Only pure luck saved the day. The eruptions took place during the gap between Apollo 16 and 17, and astronauts missed the storm.

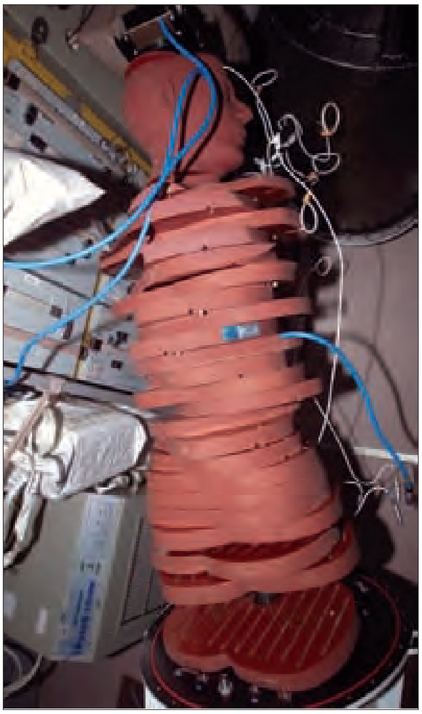
Researchers still wonder what would have happened if the timing had been just a little different. What if astronauts had been caught unprotected on the surface of the Moon?

NASA researchers are working to find an answer to that question. At Brookhaven National Laboratory in Upton, N.Y., scientists are subjecting Matroshka to a beam of protons to learn how astronauts would be affected by the type of radiation generated during the 1972 event.

"We want to know how close it comes to a dangerously acute exposure," says Cucinotta. In the parlance of radiation experts, "acute exposure" is brief but intense—the radiation would strike the body over a relatively short period ranging from minutes to hours, much as a solar flare would. This is different from the "chronic exposure" astronauts normally experience as they travel through space. Cosmic rays hit their bodies in a slow drizzle that is spread out over weeks or months. With chronic exposure, the body has time to repair or replace damaged cells as it goes along, but an acute exposure gives the body little time to cope with the damage.

"The biological effects are very sensitive to the dose rate," Cucinotta explains. "A dose of radiation delivered over a short amount of time is two to three times more damaging than the same dose over a few days."

Matroshka is usually suited up in his white travel poncho.



Sensors embedded in 35 different slices of the Phantom Torso measure the impact of radiation.

At first glance, the 1972 event would seem to fall into the acute category. It was, after all, a solar flare. However, there is a complication—it was actually a series of flares producing a radiation storm that was longer and less impulsive than normal. Radiation exposure would have been neither chronic nor clearly acute, but somewhere in between. In this gray area, details about how much of the radiation actually reaches a person's vital organs—vs. how much is blocked by a spacesuit, skin, and muscles—can make all the difference.

True blood

Matroshka is helping scientists understand these details. In addition to its hundreds of radiation sensors, this Phantom Torso even has real human blood cells.

"We put blood cells in small tubes in the stomach and in some places in the bone marrow." Some of these cells are deep within the torso while others are close to the surface where there is less "tissue" to block radiation. Among the questions they are asking is whether the less shielded parts of the bone marrow

The radiation beamline machine at NASA's Space Radiation Lab in Brookhaven, N.Y., will test the impact of protons on Matroshka.

will be much harder hit, raising the risks of leukemia and other cancers.

Using real blood cells lets scientists see how much the radiation damages the cells' DNA. High-speed particles of proton radiation can smash into DNA, breaking the string-like molecules. Cells can usually repair these breaks; however, if several breaks occur within a short period, the damage can be irreparable. At best, the cell will then self-destruct; at worst, it will go haywire and grow out of control, becoming cancerous.

To subject Matroshka to a 1972-style radiation storm, scientists have devised a way to simulate that event using a high-energy proton beam at NASA's Space Radiation Lab in Brookhaven. The beam fans out so that, at the point where Matroshka sits, it is 60 cm across—large enough to engulf the entire torso. By stepping the energy of the beam through a series of energy levels, scientists can mimic the unique energy spectrum of the protons in the 1972 event.

In the upcoming experiment, led by Guenther Reitz of the German Aerospace Center in Cologne, Matroshka's radiation sensors will reveal how much proton radiation reaches various parts of the mannequin's body. "With protons, you might have an order of magnitude difference from one part of the body to another," notes Cucinotta.

The readings will help mission planners figure out how much shielding is necessary to protect real astronauts from a 1972-style storm. The results will also point researchers in the right direction for medical treatments that might help mitigate the effects of such an event.

Unlike a real astronaut, Matroshka can withstand multiple flares with no lasting side effects. A quick transfusion of blood cells and Matroshka is ready for another blast.

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