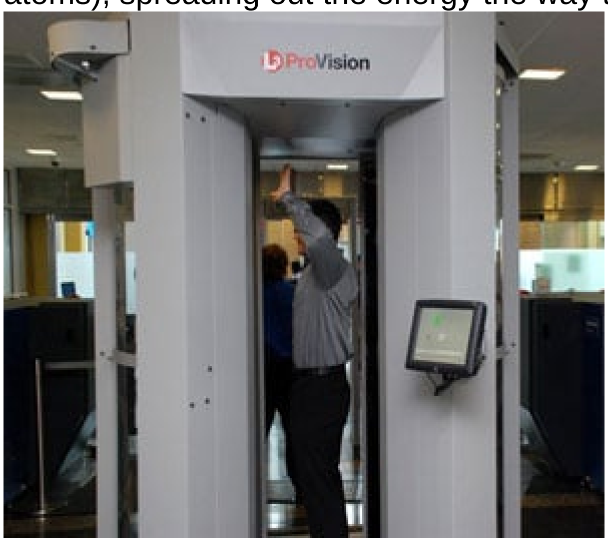
Humans on Mars? NASA must find way to protect us from radiation

We as a society have a radiation literacy problem.

In the US, X-ray body scanners are used by airport security agents to screen passengers for hidden explosives. But consider this: in 2011, the European Union banned their use in European airports. The EU said the decision was made because of radiation concerns “in order not to risk jeopardizing citizens’ health and safety”—and indeed, researchers say “there is still an alarmingly small amount of information about its potential health effects.”

Nonetheless, these scanners are thought to be harmless to passengers, because they impart an X-ray dose of just 0.1 µSv. Furthermore, because the X-rays are spread for a scattering effect, rather than focused sharply, the small amount of energy that reaches the person does not even penetrate. Although we categorize X-rays as a type of ionizing radiation (radiation that excites electrons, removing them from atoms), spreading out the energy the way these scanners do it, prevents such ionization.



One can reason that the long-term effects of this type of scanner radiation are still uncertain based on the EU’s concern about a ‘small amount of information about its potential health effects’, but based on everything we know about physics and biology, there is not even a plausible hypothesis as to why one should be concerned in the first place. Nevertheless, it has been reported –quite unsurprisingly– that these scanners, operating at such low outputs, do not even heat tissue, even slightly, even at the surface of the skin. Effectively, this is just another case of people worrying about a technology out of distrust of explanations from scientists that depend on nothing more than high school level science.

Still, the hysteria remains, particularly in Europe –which is strange because the very same travelers who avoid x-ray scans then fly on an airplane where each hour of flight exposes them to *40 times the dose* of ionizing radiation from one of these scanners. Rest assured, when you fly, there is *some* ionization of some of your cell membranes and DNA molecules, and heating of some tissues, which you do not have from the airport scanning machines. So by the EU rational, maybe you should avoid air travel, based on a lack of safety studies.

This illiteracy about science and risk underlies skewed perspectives in public discussions on matters involving radiation. Skewed perspectives and a misunderstanding of risk make it harder for us to have a rational debate on various human activities that involve radiation, from routine medical and dental care to nuclear energy–and space travel. Still, when it comes to space flight, those who support human space exploration accept the idea that astronauts are in a dangerous line of work specifically because of radiation exposure.

But as we move beyond just astronauts heading into space, whether for tourism or colonization of other planets, we need to discuss and consider the potential dangers of radiation on the human body. The topic requires perspective because it turns out that, as on Earth, dosage matters.

Radiation effects are different beyond low Earth orbit

Radiation exposure is dangerous for deep-space- travelers. Apollo astronauts have a shorter life expectancy due to increased incidences of cardiovascular disease compared with average Americans, according to a watershed study published in *Scientific Reports*. If we don't improve radiation protection, we may never be able to venture out through the Solar System. It could be bad news for prospective Mars colonists. It also could be bad news when it comes to high dosage radiation exposure in medical settings. It is clear now, if it wasn't already, that Mars and Moon colonists might have to live underground.

On the other hand, astronauts who don't travel in deep space do just just fine, despite receiving radiation doses exceeding what most people receive in the natural environment. This finding dovetails with other research that have come out in recent years that suggests that ionizing radiation in low to moderate doses may not be so bad. And so, the dark cloud threatening would-be astronauts and colonists traveling beyond low Earth orbit (LEO) could have a silver lining for those remaining on Earth.

Yuri Gagarin

Hundreds of people have blasted into space since Cosmonaut Yuri Gagarin became lifted off some 55 years ago. People in LEO receive a higher dose of radiation in a given amount of time compared with people on Earth's surface and compared with people flying in aircraft. Dozens of astronauts have spent extended periods of time in orbit, thereby receiving cumulative radiation doses significantly higher than people who have orbited for just a few days.

But only 24 people have traveled beyond LEO– on 9 Apollo missions to the moon, launched in the years 1968-1972. What's different about space travel to the Moon compared with LEO? It's the radiation. Other factors–weightlessness, isolation, life support issues–are all the same comparing LEO and missions through deep space. There are suppressive effects of long-duration stays on the production of T-lymphocytes by the thymus gland. Potentially, this can be a major problem during long-term missions into deep space, since astronauts could be at increased risk for infections that healthy immune system otherwise would fend off. But, similar to bone loss, which also occurs in LEO, T-lymphocyte decrease was not an issue for Apollo lunar missions, because the longest such mission (Apollo 17) was only twelve-and-one-half days.

Apollo 9 Astronauts, Left-to-Right: James McDivitt, David Scott and Russell Schweickart,

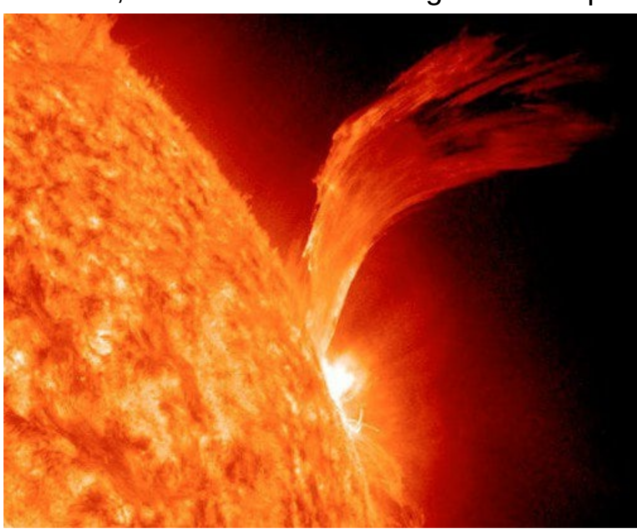
The 24 Moon travelers are a small population, but the number is large enough to produce a statistically significant difference in health outcomes when compared to other astronauts and the age-matched US population. The study revealed that the 24 lunar travelers had adverse clinical outcomes compared with everyone else, likely due to higher radiation and longer exposure time.

But, less expected, the study also showed some positive results for LEO-only astronauts. Mortality has been lower compared with the lunar astronauts, but not higher compared with the Earth-bound US population, nor compared with astronauts who never went into space at all, despite the radiation they received in LEO. In fact, both LEO astronauts and astronauts who never flew show significantly lower mortality–longer lifespan–compared with non-astronauts. It seems that being an astronaut is healthy, as long as one does not travel beyond LEO.

Categories of space radiation and layers of protection

Ionizing radiation (radiation energetic enough to remove electrons from atoms) includes rays–gamma rays, x-rays, and the most energetic types of ultraviolet light rays–as well as particles, such as atomic nuclei, or pieces of atomic nuclei, traveling at high speed. In space travel, ionizing radiation also can be categorized based on where it comes from, or where it's located.

The space radiation category of most concern during Project Apollo, and for which spacecraft shielding and emergency planning were designed, is solar particle radiation. Occasionally, the Sun shoots bursts of energetic particles into space. To an unshielded astronaut on the Moon, these solar particle events (SPEs) could impart such a high radiation dose that it would be fatal within hours. To prevent such a disaster, there were monitoring stations spread throughout Earth, which could report SPEs to NASA and
me to return to their lunar landing craft for some shielding and
ding.



While solar particle radiation happens in bursts, space is also full of what's called galactic cosmic radiation (GCR). Though not as strong as the radiation of a large SPE, GCR is present constantly, so the health concern is not acute radiation sickness that could kill an astronaut immediately, but long-term consequences, such as cancer and damage to organs, including the brain and cardiovascular system. Finally, there's a category of space radiation called trapped radiation, but to understand what that is, we have to discuss the natural shielding that the Earth provide against all radiation from space.

One layer of protection is called the geomagnetosphere. It is a region that surrounds Earth and is produced as a result of Earth's magnetic field, the phenomenon that causes a compass to point toward the North Pole. Radiation in the form of particles that have an electrical charge gets trapped by the geomagnetispere. Instead of proceeding to bombard the Earth, these particles get deflected around the planet in certain patterns. That's what the trapped radiation is, it's dangerous to space travelers, but it's present only in very specific regions, or "belts". The payback for Earth having these belts of trapped radiation is that charged particle space radiation is prevented from reaching the ground, and even from reaching spacecraft flying in LEO, including the International Space Station (ISS), which orbits at just 400 km altitude.

Now, uncharged radiation, such as neutrons and gamma rays, passes right through the geomagnetosphere, but the atmosphere also acts as a shield, resulting in fairly low doses of space radiation for people on the surface of Earth. Space radiation sources are the charged particles, the LEO environment is much safer if terms of the actual biological radiation effects.

moon-landing-hoax-59729

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Trapped radiation has been a favorite last resort argument for people believing that the Apollo Moon landings were a conspiracy. Their argument goes something like this: radiation exposure would have been fatal in the short term, due to trapped radiation hitting the astronauts as they traversed geomagnetosphere—and particularly areas called the Van Allen Belt—en route to and from the Moon. But this belief has been easily rebutted using basic information about how the Apollo flights worked, such as this:

> Flux maps of the Van Allen belts were developed, solar flare particle events were subjected to

intensive statistical analyses, and techniques were developed to calculate radiation doses behind complex spacecraft structures. Van Allen belt radiation doses were kept small by use of low-altitude Earth orbits and rapid transits to the Moon along trajectories with inclinations of about 30 degrees. Only the very large (and consequently very rare) solar flare particle events constituted a hazard for moderately shielded spacecraft.

Once on the outside of the geomagnetopshere, however, astronauts were at much higher risk compared with people in LEO. At no time was any Apollo crew subjected to SPEs that could have caused death during the mission, but the GCR is another matter. Radiation measurements taken during the missions. Also during the last two missions, Apollo 16 and 17, experiments called *Biostack* included various animals, eggs, plant seeds, and microorganisms showed that space radiation did produce biological damage notably worse compared with radiation in LEO, although it also that organisms could survive such radiation hits. But for the lunar 24 astronauts, there was always a concern about cancer and other long-term consequences. They all knew it was a possibility and with this new study we have evidence of mortality effects of space flight, but only in association with lunar travel. There's no other explanation for the lunar group of astronauts having dramatically increased mortality compared with other astronauts, except that the missions were real. Maybe the truthers will now claim it was the stress of covering the conspiracy.

Lower doses in LEO and on Earth

A long-standing practice to ensure radiation health is to do everything possible to limit dose exposure of workers and for patients getting radiation in clinical settings. This is based on the idea that if high radiation doses are terrible, and medium doses are pretty bad, then low doses must be a little less bad but bad nonetheless. Mathematically, this is called the linear-no-threshold (LNT) model of radiation exposure; there is no threshold dose above which radiation is unhealthy and below which it is harmless. Typically, this is applied all the way down to the very small doses of flat-fiim chest x-rays and dental x-rays, such that clinicians might think twice before, or even avoid, ordering an x-ray for a pregnant patient. But in terms of actual data, possible danger of medical radiation, whether for

cancer down the road or harm to the fetus, is supported only for doses in excess of 100 millisieverts (mSv). That's being conservative, and while it's in dosage region of special types of CT scans, it's many many times more than the dose of a simple chest x-ray, or dental x-ray.

How does this compared with spaceflight in LEO? Astronauts on 8-day STS-41-C mission, a typical space shuttle mission, received 5.59 mSv, which is slightly less than the dose one receives from a CT scan of the chest or spine. Most astronauts fit into this category, more or less; those who flew in LEO in the early years of the space program may have been in space for much shorter time, while certain space shuttle missions lasted two weeks or slightly longer. Then, there are the very long LEO missions. An astronaut could receive up to 160 mSv during a 6-month stay on the ISS, which is a much higher cumulative dose compared with what lunar traveling astronauts received. The *Apollo* 14 crew, for instance, received a cumulative dose of 11.4 mSv, the result of travel a little in LEO, then travel (as quickly as possible) through the safest parts of the geomagnetosphere, travel through deep space to the Moon, and then the return trip. But that dose was squeezed into just 9 days and there is growing evidence that a given radiation dose spread out over time are not as harmful as the same dose given all at once.

Even so, the Apollo doses were not that much higher per day compared with LEO doses; daily dose outside the geomagnetosphere may be less than twice that of LEO. But that difference may amount to a sea change in terms of long-term effects, so it is noteworthy that the new study on *Apollo* astronauts found that LEO is not a mortality risk. This is something that corroborates various other studies suggesting that there may indeed be thresholds, that small to modest doses may not be harmful to the body at all. Unfortunately, we don’t yet know what those thresholds are, and it’s plausible that each person may have his or her own specific threshold. But it’s tempting to speculate of a threshold *dose rate* (how much received in a given time) somewhere between the LEO daily dose and the lunar mission daily dose. This, in turn, would raise the question of how many days of the threshold dose someone would need before it

Prior to the release of the new study, Mars colonization enthusiasts already knew that shielding would be a major issue for human settlements, and the same goes for humans living on the Moon, or for that matter in free space colonies (colonies built in space from an asteroid or lunar materials). Mars currently has only a very weak magnetosphere, nothing like the strong magnetosphere of the Earth that helps shield people on the ground from space radiation.

The Mars atmosphere is much thinner than Earth's and consequently provides relatively little protection. Early settlers, or robots that precede them, thus will dig ditches into which habitat modules will be placed and thick layers of excavated dirt will be used to cover the modules. This will keep colonists fairly safe, so we can imagine a colony developing consisting of housing and urban environments all below the surface, with various interconnecting tunnels. There could be domes covering farms but don't expect the kind of city skylines sticking up in the domes that we sometimes see in artists conceptions of the first Mars colonies. Think more regarding the Washington DC metro system without the city above it. The same arrangement could develop on the Moon (perhaps down in a crater and in systems of lunar caves), and other worlds in the Solar System where we deposit people

When it comes to the space vessels, the answer is not as simple as covering the walls with a meter or more thickness of dirt of other materials. There are weight restrictions. And while there are some creative ideas to increase shielding using waste material and design the ship so that people are more on the inside and machinery, fuel, and water more on the outside, it's especially challenging to shield out what's called galactic cosmic radiation (GCR). But there are some good ideas in development for using pharmaceuticals that mitigate radiation damage, drugs that are given to patients in connection with radiation therapy, and for cocktails of the various radiation-protective compound that space travelers might ingest.

One interesting finding in this context, however, is that astronauts in the LEO-only and never-went-into-space groups have lower mortality from cardiovascular disease not only compared with the lunar traveling astronauts, but also with the general US population! How can we explain that? One might be tempting to think that the modest radiation levels in LEO have a positive effect—that's an idea called *radiation hormesis* and it's supported by a small number of studies in laboratory animals, and also somewhat by data from the Hiroshima and Nagasaki bombings. But radiation hormesis would not explain the lower mortality in non-flying astronauts, people who were admitted into the astronaut corps, but thus far have never been on an actual mission in space. So, we have to go with a more mundane hypothesis, that astronauts are simply healthier than the typical American. They exercise, they try to eat healthy foods, they certainly do not smoke, and they're not obese.

But putting everything together, one thing clear: radiation protection will have to figure prominently in human interplanetary missions. This is something that NASA plainly admits; in fact, the agency is highlighting the radiation challenge, with confidence that we will overcome it. And maybe another message humans can relax a little when it comes to lower dose sources, such as medical x-rays, radiation exposure during air travel, and living near a nuclear power plant that is functioning correctly.

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