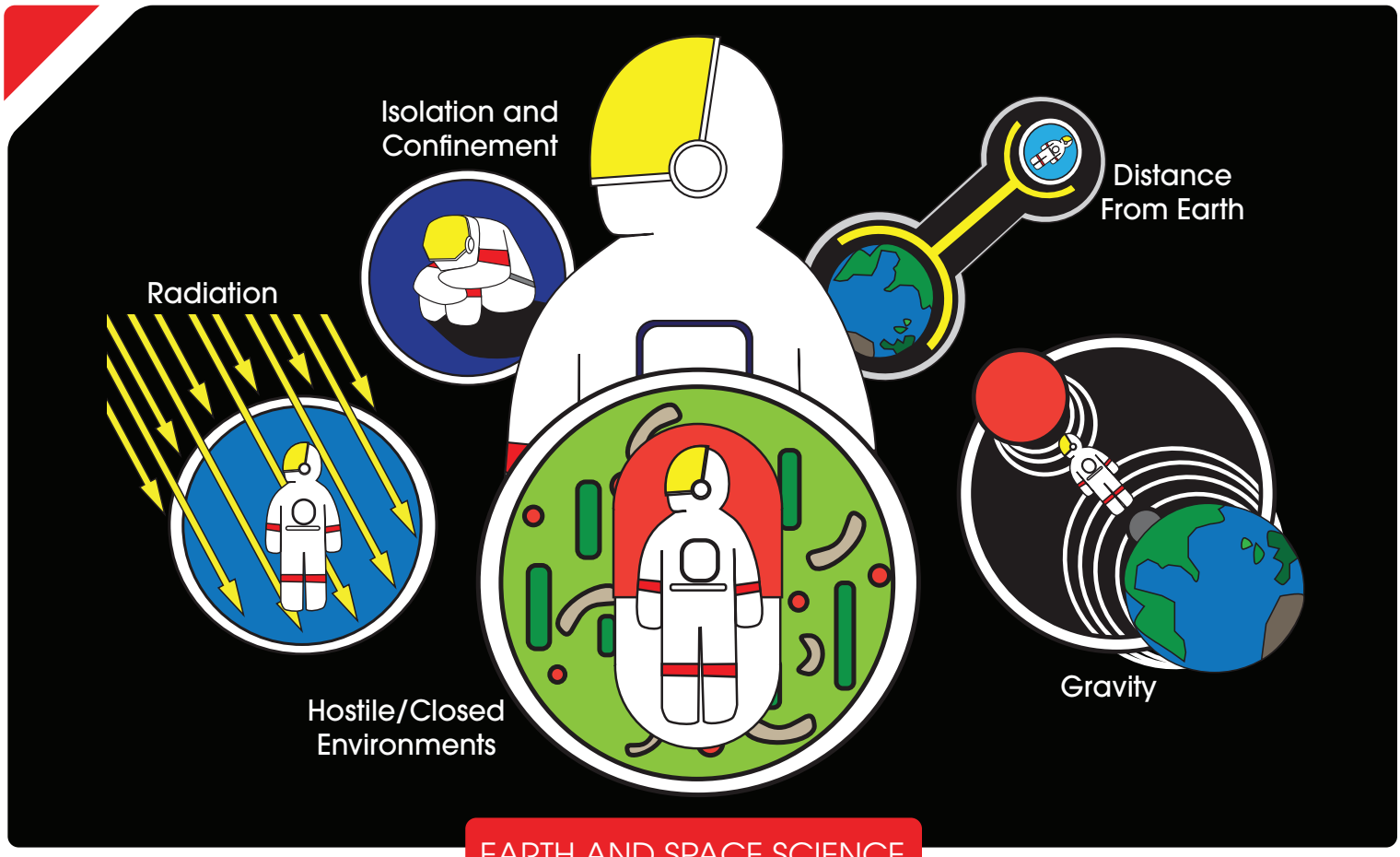
National Aeronautics and Space Administration

# Hazards to Deep Space Astronauts

## Educator Guide




EARTH AND SPACE SCIENCE

## Next Gen STEM – Moon to Mars

For more about Next Gen STEM visit https://www.nasa.gov/stem/nextgenstem/moon_to_mars

| Education Product | |
|---|---|
| Educators and Students | Grades 6-8 |

# Contents

# Preface

*Hazards to Deep Space Astronauts* was published by NASA's Office of STEM Engagement as part of a series of educator guides to help middle school students reach their potential to join the next-generation STEM workforce. The activities can be used in both formal and informal education settings as well as by families for individual use. Each activity is aligned to national standards for science, technology, engineering, and mathematics (STEM), and the NASA messaging is current as of June 2021.

# STEM Education Standards

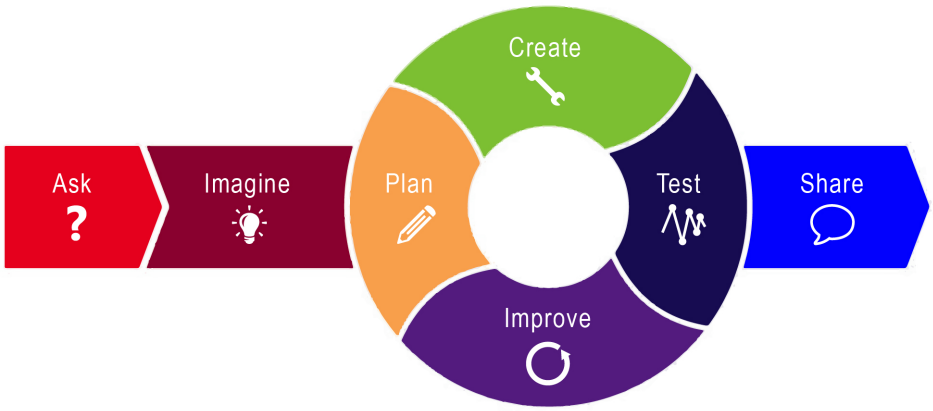
The STEM disciplines matrix shown below aligns each activity in this module to standards for teaching STEM according to four primary focus areas within each discipline. The four focus areas for science were adapted from the Next Generation Science Standards (NGSS) middle school disciplinary core ideas. The four focus areas for technology were adapted from the International Society for Technology in Education (ISTE) Standards for Students. The four focus areas for engineering were adapted from the National Science Teaching Association (NSTA) and NGSS science and engineering practices. The four focus areas for mathematics were adapted from the Common Core State Standards (CCSS) for Math middle school content standards by domain.

| Activity | STEM Disciplines | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Science | | | | Technology | | | | Engineering | | | | Math | | | |
| | NGSS Disciplinary Core Ideas | | | | ISTE Standards for Students | | | | NSTA and NGSS Practices | | | | CCSS Content Standards by Domain | | | |
| | Physical Sciences | Life Sciences | Earth and Space Sciences | Engineering, Technology, and the Application of Sciences | Knowledge Constructor | Innovative Designer | Computational Thinker | Global Collaborator | Ask Questions and Define Problems | Develop and Use Models | Plan and Carry Out Investigations | Construct Explanations and Design Solutions | Ratios and Proportional Relationships | The Number System | Expressions and Equations | Ratios and Proportional Relationships |
| Radiation | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | | ✓ | ✓ | | ✓ | ✓ | ✓ | ✓ | ✓ | |
| Isolation | | ✓ | ✓ | ✓ | | ✓ | ✓ | ✓ | ✓ | | | ✓ | | | | |
| Distance | | | ✓ | ✓ | | | ✓ | | | ✓ | ✓ | | ✓ | ✓ | ✓ | ✓ |
| Gravity | ✓ | ✓ | ✓ | ✓ | | ✓ | | ✓ | ✓ | | | ✓ | | ✓ | ✓ | |
| Environment | | ✓ | ✓ | ✓ | ✓ | | | | ✓ | ✓ | ✓ | ✓ | ✓ | | | ✓ |

# Engineering Design Process

The engineering design process (EDP) is crucial to mission success at NASA. The EDP is an iterative process involving a series of steps that engineers use to guide them as they solve problems. Students can use the seven steps outlined below for many of the activities in this guide. Learn more about the EDP with NASA's Educator Professional Development Collaborative at www.txstate-epdc.net/models-of-the-engineering-design-process/.

1. **Ask**: Identify the problem, the requirements that must be met, and the constraints that must be considered.
2. **Imagine**: Brainstorm solutions and research what others have done in the past.
3. **Plan**: Select and sketch a design.
4. **Create**: Build a model or a prototype.
5. **Test**: Evaluate solutions by testing and collecting data.
6. **Improve**: Refine the design.
7. **Share**: Communicate and discuss the process and solutions as a group.




# Problem-Based Learning Process

In the problem-based learning process, the roles and responsibilities of educators and learners are different than in a traditional classroom setting. The educator acts as a facilitator by providing students with problems to work, assisting them in identifying and accessing the materials or equipment to solve the problems, giving necessary feedback and support, and evaluating students' participation. Learn more about the problem-based learning process at www.cal.org/adultesl/pdfs/problem-based-learning-and-adult-english-language-learners.pdf.

1. **Meet the Problem**: Identify the problem, introduce new vocabulary, and discuss previous experiences with the problem.
2. **Explore Knowns and Unknowns**: Use resources to explore the knowns and unknowns.
3. **Generate Possible Solutions**: Brainstorm possible solutions based on resources and prior experience with the problem.
4. **Consider Consequences**: Examine the pros and cons of each solution to determine a viable solution.
5. **Present Findings**: Communicate and discuss the process and solutions as a team.

# Teamwork

Everyone is a scientist and an engineer! It is important that everyone on the team be able to participate and contribute throughout these activities. If one student does all the building, the other students may be very bored during the building process. If one student is the leader, other students may not have a chance to share their ideas. Here are some possible roles that students can take:

| Student Role | Description |
|---|---|
| Communications and Outreach | Takes notes of all team decisions and actions for use in a final presentation. If a camera is available, takes video and/or photos throughout the investigation or challenge for use in a final presentation. |
| Logistics | Makes sure that the team has all the resources they need, that resources are distributed fairly, and that the team knows when resources are running low. |
| Mission Assurance | Makes sure the team is following the plan. Keeps track of time and makes sure that everyone has a chance to have their voice heard. |
| Safety | Ensures all team members are wearing their safety goggles and following safety protocols. |

# Curriculum Connection

In this module, students will assume the role of researchers in NASA's Human Research Program as they study the dangers of deep space exploration. They will learn about the effects these hazards can have on the human body and what can be done to mitigate those dangers. Students will gain an understanding of the following five hazards (RIDGE):

1. Radiation exposure from a variety of sources during spaceflight
2. Isolation and the effects of loneliness from being away from family and friends or stuck in close proximity with only a few other astronauts for months at a time
3. Distance from Earth and the logistical complications that causes
4. Gravity fields and the related dangers to the human body due to long durations of time spent in microgravity
5. Environments that are hostile (such as the Martian surface) or closed (such as the space vehicle)

This guide will challenge students to work collaboratively to develop and design projects to help reduce the effects these hazards will have on deep space astronauts. Each activity suggests a variety of additional resources such as videos, podcasts, articles, e-books, or extension activities. Facilitators and educators are encouraged to explore these additional resources, because research into deep space hazards is ongoing and the knowledge gained is often applicable to inventions meant for use on Earth, which NASA refers to as spinoff technologies. The OYO® DoubleFlex exercise device and Orbital Systems' Oas shower are two examples of NASA spinoff technologies that were developed based on current research into deep space hazards.

## Weightless "Weight" Lifting Builds Muscle on Earth

Everyone should exercise, but astronauts need to dedicate a lot of time to it. They do not have exposure to Earth's gravity, which would normally require their bones and muscles to work all day just to stand up. In zero gravity, the human body quickly loses significant muscle and bone mass, making a rigorous workout schedule crucial to long-term health. Exercise during spaceflight requires special resistance-based devices because traditional exercise machines do not work without Earth's gravity. OYO® Fitness founder Paul Francis worked with NASA to develop a resistive exercise device suitable for use on the International Space Station. That exercise device eventually became a NASA spinoff, the OYO® DoubleFlex exercise device, which uniquely applies resistance to both sides of a muscle group through one motion, improving the efficiency of workouts. The DoubleFlex is also very light and easy to move; the device itself weighs just 2 pounds, but it provides up to 25 pounds of resistance. spinoff.nasa.gov/Spinoff2018/hm_4.html

NASA astronaut Garrett Reisman using a resistive exercise device that led to the innovation of several lines of exercise devices for use on Earth.

## Space-Age Water Conservation

Orbital Systems' Oas shower is the world's first water-recirculating shower. It was inspired by a university's partnership with NASA and is enabled by a filter technology NASA helped fund with an eye toward improving astronaut life-support systems. Learn more: spinoff.nasa.gov/page/space-age-water-conservation-nasa


NASA's 2021 Spinoff brochure includes information on hundreds more
NASA technologies that benefit life on Earth in the form of commercial products.
https://spinoff.nasa.gov/sites/default/files/2020-12/NASA%20Spinoff%202021%20Brochure.pdf

# Introduction and Background

Sending astronauts to Mars is one of NASA's primary 21st-century goals. In preparation for this long-duration spaceflight, NASA has been studying the health effects the trip could have on astronauts. Using various research platforms, NASA is always learning more about the hazards of deep space exploration and how to mitigate those effects. The International Space Station and upcoming Artemis lunar missions might immediately come to mind, but NASA also conducts analog missions here on Earth that simulate what living elsewhere in the solar system might be like. One such example is NASA Extreme Environment Mission Operations (NEEMO), where astronauts, engineers, and scientists study how to live and work deep in the Atlantic Ocean. NASA's Human Research Program (HRP) has organized the hazards astronauts encounter into five classifications, which allows for an organized effort to understand and overcome the obstacles that stand in the way of a deep space mission. It is important to understand that the risks do not stand alone; they are interrelated, and one hazard may exacerbate the effects of another on the human body. The five areas of research create the acronym RIDGE:

1. R—Space radiation
2. I—Isolation and confinement
3. D—Distance from Earth
4. G—Gravity (or lack thereof)
5. E—Hostile/closed environments

While these five challenges make spaceflight dangerous, they also provide opportunities for NASA to better understand the human body and, ultimately, make spaceflight safer through technological innovations.

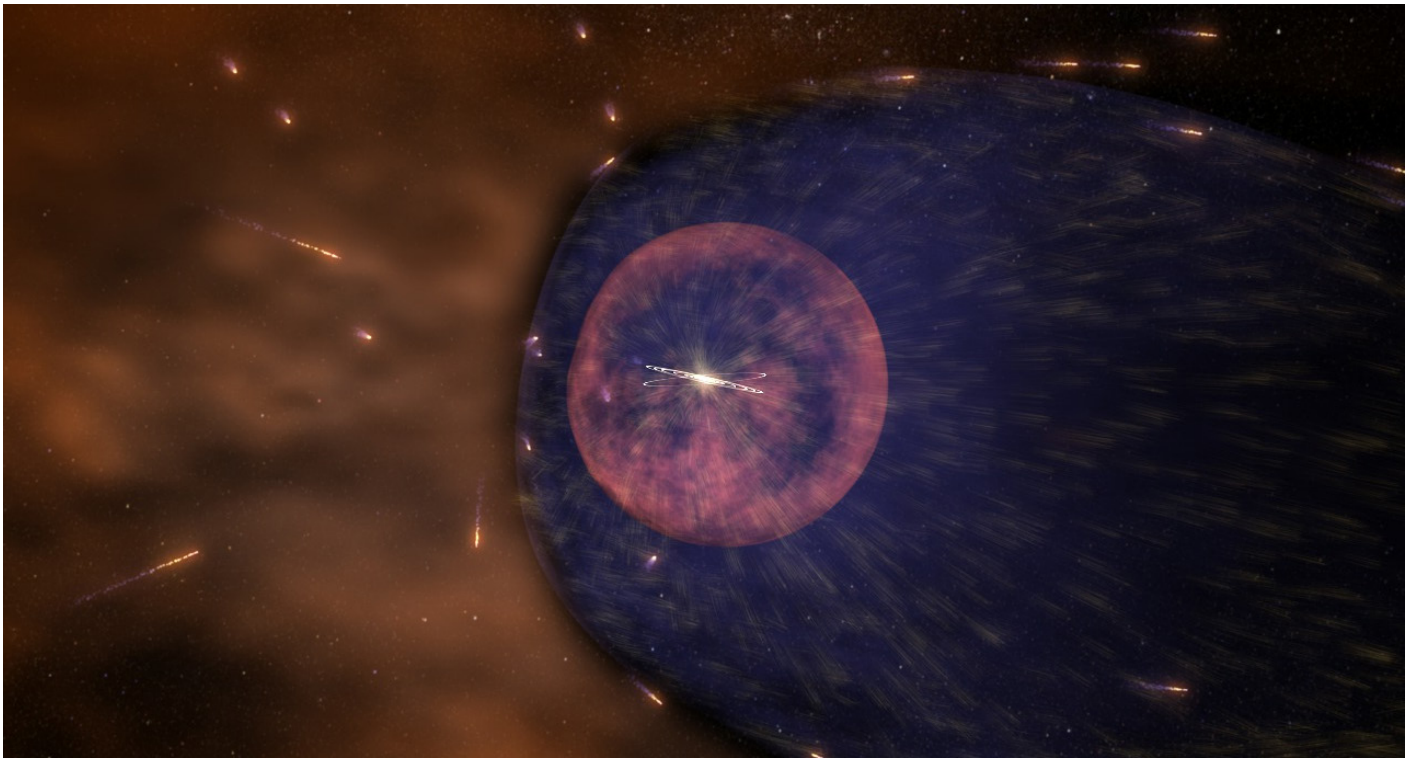

Illustration showing the top five hazards of human spaceflight. (NASA)

## RIDGE

In this activity guide, students are given the opportunity to explore each of the top five hazards to crew during human spaceflight in order to frame an understanding of how each risk is dangerous on its own, and how the effects are compounded when multiple risks are present. Through problem-based learning activities or engineering design challenges, students are asked to assume the role of researchers in NASA's Human Research Program to help mitigate the risks faced by humans in long-duration spaceflights. The following content will give a better understanding of each of the hazards in the RIDGE acronym and what NASA is learning from research.

## Hazards to Deep Space Astronauts


Space is not empty. In fact, our solar system is full of high-energy particles that burst from the Sun and bombard us from the cosmos. On Earth, humans are relatively safe from this dangerous energy due to the magnetosphere, a protective "magnetic bubble" around the Earth that deflects most solar particles. This dangerous energy is called radiation, and it can have disastrous effects on electronics and the human body. The International Space Station travels through low-Earth orbit, within Earth's protection, and the station's metal hull helps to shield the crew from harmful cosmic rays. Once an astronaut crew journeys beyond Earth's protection, they face harsh radiation and must mitigate the harmful effects such exposure can cause. Two types of radiation are concerning to NASA in deep space: solar energetic particles (SEPs) and galactic cosmic radiation (GCR).



This animated image shows the solar system and the Sun's magnetic bubble, called the heliosphere, that extends far beyond it. Bright streaks represent cosmic rays. During solar maximum, as the heliosphere strengthens, it blocks more cosmic rays. (NASA)

### Solar Energetic Particles (SEPs)

SEPs burst from the Sun in the wake of giant solar flares and coronal mass ejections. These particles are swept across the solar system and carried by the solar wind. Some of these SEPs can reach Earth, almost 93 million miles away, in less than an hour. SEPs are a type of energy that is either packaged in electromagnetic waves or carried by particles, like protons or ions. They are handed off when the wave or particle collides with something else, like an astronaut or spacecraft. SEPs are extremely dangerous because they can pass right through skin, shedding energy and fragmenting cells or deoxyribonucleic acid (DNA) along their way. This damage can increase risk for cancer later in life or—in extreme cases—can cause acute radiation sickness. Monitoring space weather is one way to help protect astronauts. Scientists alert mission control of potential solar events and may recommend that astronauts delay spacewalks or shelter in a heavily shielded area inside the space station until the event passes. During future Artemis missions, astronauts that are beyond Earth's protective magnetosphere may be instructed to build a temporary shelter, making use of whatever mass is available, such as water bags or regolith (lunar soil). The more mass there is between the crew and the radiation, the more likely it is that the dangerous particles will deposit their energy before reaching the astronauts. The Orion spacecraft, which will carry crew members to the Moon during Artemis missions, uses a similar approach to protect astronauts. In addition to the built-in shielding provided by the capsule, radiation-sensing instruments will alert the crew when they need to take shelter using available materials in case of a radiation event. NASA and its partners are also testing wearable vests and devices that add a protective layer of mass to

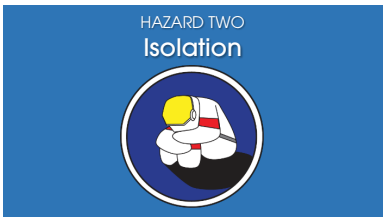
protect the crew. Despite advances in space weather forecasting, the chaotic nature of SEPs makes it difficult to predict where they will go. We still have a lot to learn when it comes to protecting astronauts from space radiation.

Jessica Vos (foreground), deputy health and medical technical authority for Orion, and astronaut Anne McClain (background) demonstrate the radiation protection plan in a representative Orion spacecraft. During a solar energetic particle event, the crew will use stowage bags aboard Orion to create a dense shelter from radiation. (NASA)

### Galactic Cosmic Rays (GCRs)

The second kind of space radiation travels even farther than SEPs. GCRs are the remains of long-gone stars from elsewhere in the Milky Way, and they continuously bombard the solar system. Imagine that SEPs are like a sudden rain shower; GCRs, by contrast, are more like a steady drizzle. Cosmic rays tend to be much more powerful than SEPs. The same spacecraft that has been shielded to protect astronauts from SEPs cannot protect against the damage from GCRs, so they become a more serious concern, especially for long-duration missions like the journey to Mars. GCRs are composed of heavy elements like helium, oxygen, or iron. When these heavy particles collide with something, like an astronaut or the metal walls of a spacecraft, they knock atoms apart. This type of impact creates another problem: secondary radiation, in which a shower of more particles develops during the atomic collisions. This adds to the health concerns of cosmic rays. Cosmic ray exposure is also related to the solar cycle. During a solar minimum, when there is little solar activity, rays can infiltrate the Sun's magnetic field. During a solar maximum, the Sun's magnetic field strengthens, keeping some of the GCRs away.

Going to the Moon will help NASA collect crucial data for developing the necessary tools and strategies to safely send astronauts to Mars. The trip to Mars will take much longer than a trip to the Moon, and the crew will face much more radiation exposure. In Activity One of this module, students will have the opportunity to discover how much radiation astronauts will encounter and how that compares to a trip to the Moon or the International Space Station.




NASA astronauts have been flying to space for more than 50 years. For more than 20 of those years, crew members have been staying in space several months at a time on missions aboard the International Space Station, where they live with only a few other people in about as much space as a six-bedroom house. Astronauts experience various aspects of social isolation and confinement during their missions.

## Hazards to Deep Space Astronauts

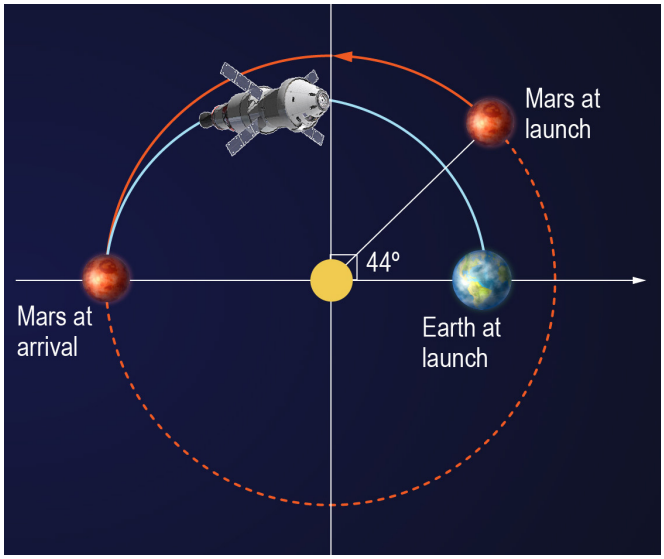
NASA carefully selects crew members and trains and supports them to ensure they can work effectively as a team for as long as 1 year. NASA studies how isolation and confinement can alter astronauts' individual and team health and performance and also tests strategies to mitigate any negative impacts. These isolation studies are conducted with astronauts in space as well as in analog facilities such as the Human Exploration Research Analog (HERA), a Moscow facility called Nezemnyy Eksperimental'nyy Kompleks (NEK), and field locations in Antarctica.

The space station orbits about 400 km (250 miles) above Earth. NASA is preparing for longer, more ambitious missions that will take astronauts farther away to the Moon and Mars. Communication during human exploration missions to Mars will have to be innovative to account for the long delays caused by the much greater distance from the surface of the Earth. One of the lessons we have learned from life aboard the International Space Station is that it is important for crews and family members to manage expectations.

NASA has been studying people in isolated and confined environments for years and has developed methods and technologies to counteract possible problems. During space exploration, sleep restrictions and extended work hours can lead to fatigue. A 5-minute self-test helps astronauts objectively assess the effects of fatigue on performance. Journals give astronauts a safe place to write about their frustrations and give researchers a tool to study behavioral issues and thought processes of crew members who are living and working in isolation and confinement. All of these methods will help us prepare for longer, farther exploration missions.

In Activity Two of this module, students will design a proposal to submit to NASA to mitigate the effects of isolation and confinement. Through research, including podcasts, students will become part of a company trying to sell its proposal to NASA.


One of the most apparent hazards to astronauts embarking on a deep space mission is the vast distance they will be from Earth. While a lunar voyage requires 3 days to travel about 384,000 km (239,000 miles) each way to the Moon, astronauts traveling to Mars will be away for as long as 3 years. The time it takes to travel from Earth to Mars varies depending on the positions of the two planets. Earth is approximately 150,000,000 km (93,205,678 miles) from the Sun and orbits every 365 days. Mars, however, is approximately 214,000,000 km (1,329,734,435 miles) from the Sun, and its orbital period is 687 days. Since Earth has a shorter orbital period, it is always "catching up" to Mars in their orbits around the Sun. Every 26 months, there is a window of time when a rocket can be launched from Earth on a trajectory that will have the spacecraft meet up with Mars in its orbit in the least amount of time. Even when taking advantage of these launch windows, a round-trip mission to Mars will take about 2 years.




NASA will send supplies ahead of crewed missions to the Martian surface in preparation for astronauts' stays on the Red Planet. In addition, supplies will be stationed in orbit to resupply their spacecraft for the voyage home. However, during the journey to Mars and back, the astronauts and their spacecraft must be completely self-sufficient. Once the spacecraft burns its engines, setting a course toward Mars, there is no way to turn back and no way to receive additional supplies until it reaches its destination. Also, due to the mass and volume of consumables such as water and air, there will not be space for supplies that are not absolutely essential.

To make the journey possible, the spacecraft will incorporate regenerative life support systems. These systems are responsible for recovering consumed air and water aboard a spacecraft and recycling them into breathable air and clean, drinkable water. Three of the critical systems, developed at NASA's Marshall Space Flight Center in Huntsville, Alabama, are the water recovery system, the air revitalization system, and the oxygen generation system. The water recovery system is continually being improved for increased efficiency and reliability. The current version of the system, which is in use aboard the International Space Station, can recover and recycle more than 90 percent of the wastewater aboard the space station and turn it back into clean water for the astronauts' use. With limited supplies and no support from their team back on

Earth, astronauts on a journey to Mars will need even more efficient and reliable systems in order to be self-sufficient, including a water resupply system that can recover 98 percent of the water.

In Activity Three of this module, students will calculate the water needs of astronauts on a deep space mission. Using research and their calculated water consumption rates, they will make determinations concerning a water efficiency problem on a deep space mission.


As astronauts travel to deep space, they will encounter three different gravity fields. The gravity they will experience on the Moon's surface is one-sixth of Earth's gravity. In transit from the Moon to Mars, they will be living in an environment that has zero gravity. During a Mars surface mission, they will be living and working in gravity that is three-eighths that of the Earth. Each time the gravity changes, there will be an effect on hand-eye coordination, locomotion, spatial orientation, balance, bones, muscle, and heart function. The way our bodies perform is related to how we react to gravity.

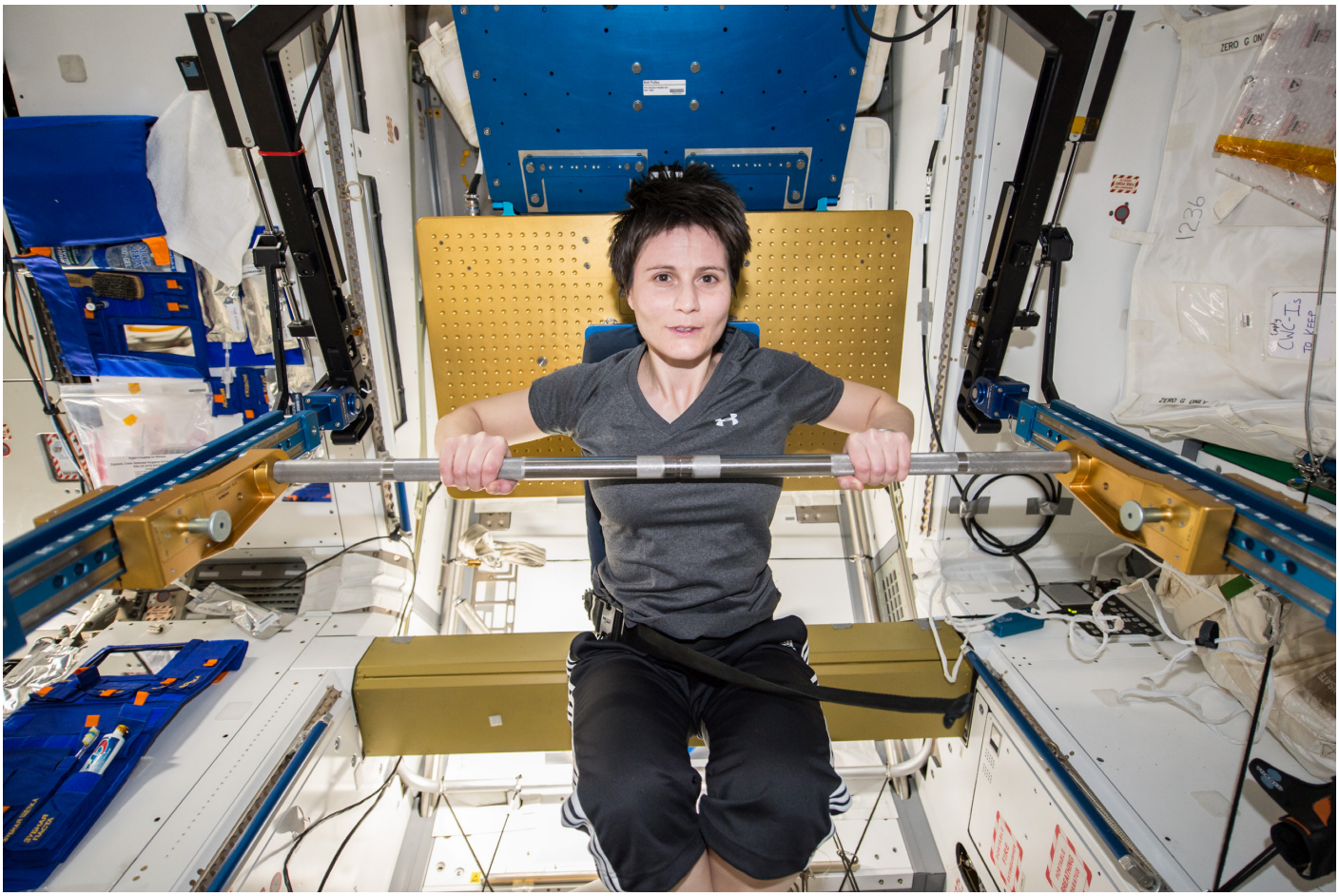
One main reason our bones and muscles are strong is that they must constantly work to fight the effects of Earth's gravity. In the absence of gravity, an astronaut's bone density decreases, which is why it is critical for astronauts to exercise during transit flight. If they do not, there can be serious atrophy of the bone and muscle. Bones weaken because astronauts are not applying stress, or weight load, on the back and leg muscles. This is similar to what happens with bedridden patients on Earth, whose muscles and bones weaken due to lack of movement. Bones are constantly being broken down and rebuilt as a person grows. However, people with osteoporosis have more bone loss than rebuilding. This loss may not hinder astronauts while they are in orbit, but upon returning to Earth, their weakened bones will be fragile and at increased risk for fractures. Additionally, the minerals that are lost from the bones may be displaced elsewhere in the body, causing astronauts to develop kidney stones. The rate of bone density loss in space is 1 percent per month. This is comparable to bone density loss in elderly men and women, whose rate of loss is 1 to 1.5 percent per year. This bone loss can cause astronauts to have osteoporosis-related fractures later in life. Bone loss is just one of the effects of decreased gravity on an astronaut.

Fortunately, NASA scientists know that there are three countermeasures, or activities that can decrease the risks, for preventing bone loss: nutrition, exercise, and medicine. Meals are nutritionally balanced with calcium-rich foods and vitamin D. Physical exercise is important to increase bone load and muscle strength. Astronauts are also given bisphosphates, a therapeutic agent that has been used to treat osteoporosis patients, to increase bone mass and decrease the occurrence of bone fractures. Although the Moon and Mars do exert more gravitational force on the body than is experienced during spaceflight, they exert less force than Earth does. Therefore, even after landing on a celestial body, astronauts will still need lots of exercise to maintain muscle and bone mass that they would maintain just by being on Earth.

Another effect that scientists are closely monitoring is the fluid shift that takes place in the human body during spaceflight. On Earth, an astronaut's circulatory system is accustomed to working against gravity. During spaceflight, the circulatory system receives a different set of signals and stimuli. The heart does not need to work as hard to send blood to the upper body, which leads to an increase in the volume of blood shifting upward toward the head. This shift can put pressure on the eyes and cause vision loss. NASA scientists provide astronauts with compression cuffs to wear on their thighs, which helps keep blood in the lower extremities to counteract the fluid shift.

NASA scientists are still performing research to develop protocols for replacing the positive health effects of Earth's gravity on astronauts. This research will benefit not only astronauts in deep space but also people on Earth who experience loss of bone density and muscle mass.

In Activity Four of this module, students will design an exercise device that can operate in different gravity fields. Using their knowledge of the skeletal system, fracture threshold, and osteoporosis, the students' designs will mitigate the effects of bone loss and muscle atrophy.



European Space Agency astronaut Samantha Cristoforetti exercises on the Advanced Resistive Exercise Device aboard the International Space Station. (NASA)


NASA has learned that the ecosystem inside the spacecraft plays a big role in everyday astronaut life in space. Microbes can change characteristics in space, and micro-organisms that naturally live on the human body are transferred more easily from person to person in closed habitats such as the space station. Stress hormone levels are elevated, and the immune system is altered, which could lead to increased susceptibility to allergies or other illnesses.

Earth-based analogs do not perfectly simulate the spaceflight environment, making them insufficient for studying on the ground how human immune systems react in space. However, NASA-funded Antarctic analog studies could provide insight into how certain spaceflight stressors may affect the human immune system. What is known is that spaceflight changes the immune system, although crews do not tend to get sick upon returning to Earth. Even though astronauts' acquired immunity is intact, more research is needed into whether spaceflight-induced altered immunity may lead to autoimmune issues, in which the immune system mistakenly attacks the healthy cells, organs, and tissues present in the body.

Astronauts are advised to get a flu shot to boost their immunity and are quarantined before their missions to avoid catching any sort of illness before launch. During his 1-year mission aboard the space station as part of the NASA Twins Study, Scott Kelly administered a flu vaccine to himself while his brother received a vaccination on Earth. The immunization proved to work as well in space as it does on Earth, which is a good finding for longer missions to the Moon and Mars.

NASA is using technology to monitor the air quality of the space station to ensure the atmosphere is safe to breathe and not contaminated with gases such as formaldehyde, ammonia, and carbon monoxide. Thermal control systems function to maintain temperatures of the space station and keep astronauts comfortable. Blood and saliva samples are analyzed to identify changes in the immune system and the reactivation of latent viruses during spaceflight. NASA uses advanced molecular techniques to evaluate the risk of microbes that may cause illness for crew members. Various parts of the body and the space station are swabbed regularly

for analysis of the microbial population that inhabits the environment. Crews change out air filters, clean surfaces, and treat the water to prevent illnesses that may result from the accumulation of contaminants.

Beyond the effects of the environment on the immune system, every inch and detail of living and working quarters must be carefully thought out and designed. No one wants their house to be too hot, too cold, cramped, crowded, loud, or not well lit, and no one would enjoy working and living in such a habitat in space either. Living quarters and work environments are carefully planned and evaluated to ensure that designs balance comfort and efficiency. Lighting onboard the space station is similar to what would be experienced naturally on Earth, thanks to the light-emitting diode (LED) lighting system.

NASA is acting on all risks and working to solve the challenges of human spaceflight with some of the most brilliant minds in related fields. The results garnered from laboratories, ground analogs, and space station missions will continue to provide insight into these adaptations and present stepping-stones for longer missions. On upcoming missions to lunar orbit and the surface of the Moon, even more data will be collected as this work continues. On future longer-duration missions to the Moon and Mars, astronauts will benefit from years of research that will ensure they are able not just to survive, but to thrive.

In Activity Five of this module, students will compare and contrast the environment of the Earth, the Moon, and Mars. Students will then use this knowledge to design a habitat on one of the celestial bodies that will be able to renew or recycle elements to sustain life.