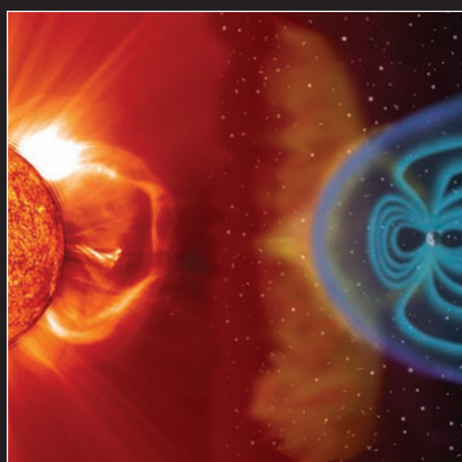
National Aeronautics and Space Administration

Space Faring
The Radiation Challenge

An Interdisciplinary Guide on Radiation Biology for grades 9 through 12



Module 3:

Radiation Countermeasures

Educational Product	
Educators and Students	Grades 9–12

EP-2008-08-118-MSFC

Radiation Educator Guide

Module 3:

Radiation Countermeasures

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Module 3: Radiation Countermeasures

Space radiation can penetrate habitats, spacecraft, equipment, spacesuits, and can harm astronauts. Minimizing the physiological changes caused by space radiation exposure is one of the biggest challenges in keeping astronauts fit and healthy as they travel through the solar system. As mentioned previously, ionizing radiation is a serious problem that can cause damage to all parts of the body including the central nervous system, skin, gastrointestinal tract, skeletal system, and the blood forming organs. However, biological damage due to radiation can be mitigated through implementation of countermeasures that are designed to reduce radiation exposure and its effects. In this section, we will discuss the use of radiation dosimetry and operational, engineering, and dietary countermeasures.

Why is NASA Studying Radiation Countermeasures?

Radiation protection is essential for humans to live and work safely in space. To accomplish this challenging task, NASA has developed the Radiation Health Program. The goal of the program is to carry out the human exploration and development of space without exceeding acceptable risk from exposure to ionizing radiation. Legal, moral, and practical considerations require that NASA limit risks incurred by humans living and working in space to acceptable levels.[1] To determine acceptable levels of risk for astronauts, NASA follows the standard radiation protection practices recommended by the U.S. National Academy of Sciences Space Science Board and the U.S. National Council on Radiation Protection and Measurements.[2]

What is Radiation Dosimetry?

In low Earth orbit, astronauts lose the natural shielding from solar and cosmic radiation provided by the Earth's atmosphere. In deep space astronauts also lose the shielding provided by the Earth's strong magnetic field. So, to achieve the goal of the NASA Radiation Health Program, it is necessary to monitor the radiation environment inside and outside a manned spacecraft.

An important part of every manned mission is radiation dosimetry, which is the process of monitoring, characterizing, and quantifying the radiation environment where astronauts live and work. Radiation biology support during missions also includes: calculated estimates of crew exposure during extra-vehicular activity; evaluation of any radiation-producing equipment carried on the spacecraft; and comprehensive computer modeling of crew exposure. Space station crewmembers routinely wear physical dosimeters to measure their accumulated exposure and, post flight, provide a blood sample to measure radiation damage to chromosomes in blood cells.[3] In addition, experiments on the Space Station have been carried out using a synthetic human torso, which has over 300 strategically placed dosimeters to determine the levels of cosmic radiation absorbed by specific organs in the human body during space flight.[4] Active monitoring of space radiation levels within the Space Station is achieved with dosimeters both to identify the best-shielded locations within the Space Station and to give early warning should radiation levels increase during a mission due to solar storms.

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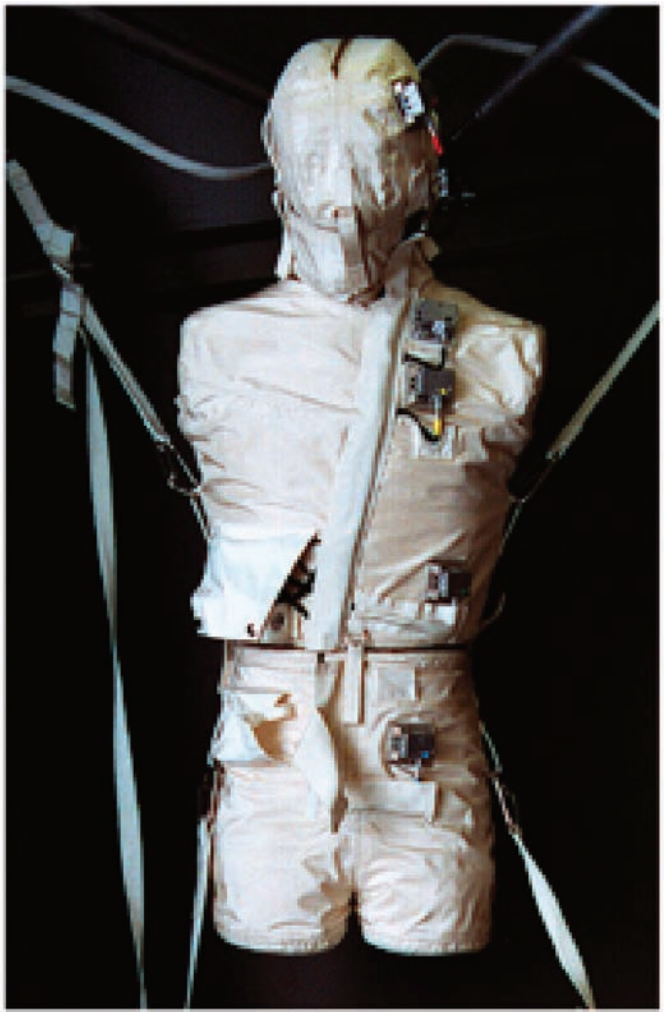
1 http://srag.jsc.nasa.gov/Index.cfm#
2 http://www.nasa.gov/audience/foreducators/postsecondary/features/F_Understanding_Space_Radiation_prt.htm
3 http://exploration.nasa.gov/programs/station/Chromosome-2.html
4 http://exploration.nasa.gov/programs/station/Torso.html



NASA uses an anatomical model of a human torso and head that contains more than 300 radiation sensors.

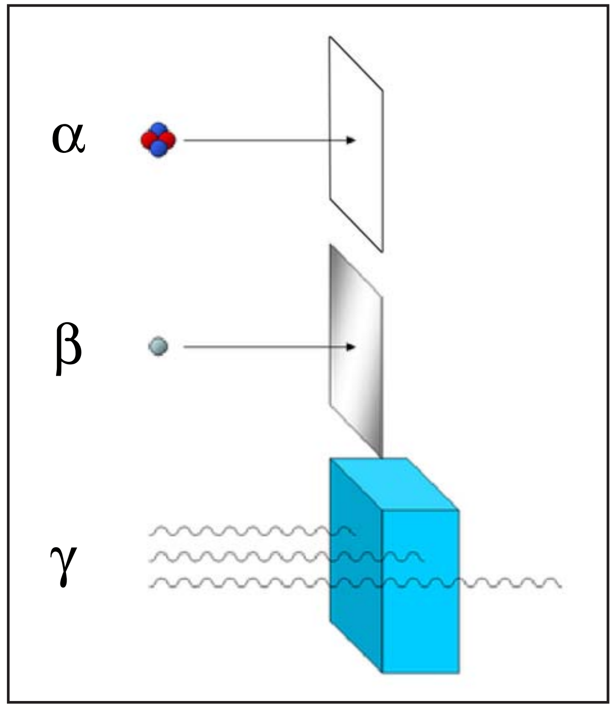
All these sources of information are carefully analyzed before, during, and after to help mission planners mitigate the four significant radiation-related health risks that are described in the NASA Bioastronautics Critical Path Roadmap:[5] cancer, radiation damage to the central nervous system, chronic and degenerative tissue diseases, and acute radiation sickness. See the previous section for information on the biological effects of radiation.

What are Operational Countermeasures?

Currently, the main operational countermeasure against the adverse affects of radiation is simply limiting astronaut exposure, which means limiting the amount of time astronauts are allowed to be in space. This is accomplished primarily by shortening overall mission duration on the Space Station to 3-6 months, reducing the time astronauts spend outside of the spacecraft during spacewalks, and planning space missions during times of reduced solar storm activity. However, since future long-term missions of exploration to the Moon and beyond will both take longer (a round-trip to Mars will last at least 2 years) and expose astronauts to a more damaging types of radiation, other strategies such as better shielding and mitigation strategies are necessary before astronauts can spend extended periods in deep space.

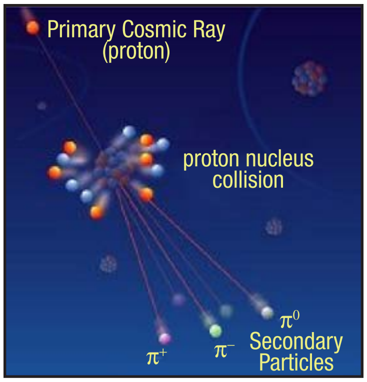
5 http://bioastroroadmap.nasa.gov/User/risk.jsp

The composition and thickness of a material affects its ability to shield radiation.



What are Engineering Countermeasures?

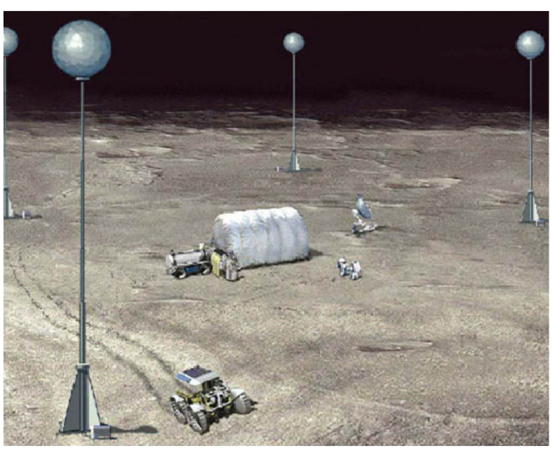
Engineering countermeasures are structures or tools that are designed to shield astronauts from radiation. Depending on where astronauts are living and working, the radiation shielding requirements will vary because of exposure to different types and levels of radiation. The most penetrating ionizing radiation (gamma rays and galactic cosmic rays) can pass through aluminum but is stopped by thick and dense material such as cement. In general, the best shields will be able to block a spectrum of radiation. Aboard the space station, the use of hydrogen-rich shielding such as polyethylene in the most frequently occupied locations, such as the sleeping quarters and the galley, has reduced the crew's exposure to space radiation. Since the Space Shuttle and the International Space Station are in low Earth orbit, where the quantity and energy of the radiation is lower and the Earth's atmosphere provides protection, these spacecraft require less shielding than a base on the surface of the Moon. On the Moon, radiation shields would need to be very thick to prevent the primary cosmic rays (high-energy protons and heavy ions) from penetrating into habitation modules where astronauts will live. Such shielding could include the metal shell of a spacecraft or habitation module, an insulating layer of lunar water, or both.



Collisions between high-energy radiation and shielding can produce damaging secondary particles.

Problems with shields arise when space radiation particles interact with the atoms of the shield itself. These interactions lead to production of nuclear byproducts called secondaries (neutrons and other particles). If the shield isn't thick enough to contain them, the secondaries that enter the spacecraft can be worse for astronauts' health than the primary space radiation. Surprisingly, heavier elements such as lead produce more secondary radiation than lighter elements such as carbon and hydrogen. Consequently, a great deal of research has been performed on a lightweight polyethylene plastic, called RFX1, which is composed entirely of lightweight carbon and hydrogen atoms.[6] Research shows that polyethylene is 50% better at shielding solar flares and is 15% better at shielding galactic cosmic radiation as compared to aluminum. Water is another hydrogen-rich molecule that can absorb radiation. However, the oxygen content in water makes it a lot heavier than polyethylene, and therefore is much more expensive to launch. Generally, lighter shields can greatly reduce the harmful effects of incoming space radiation particles, but they cannot completely stop them.

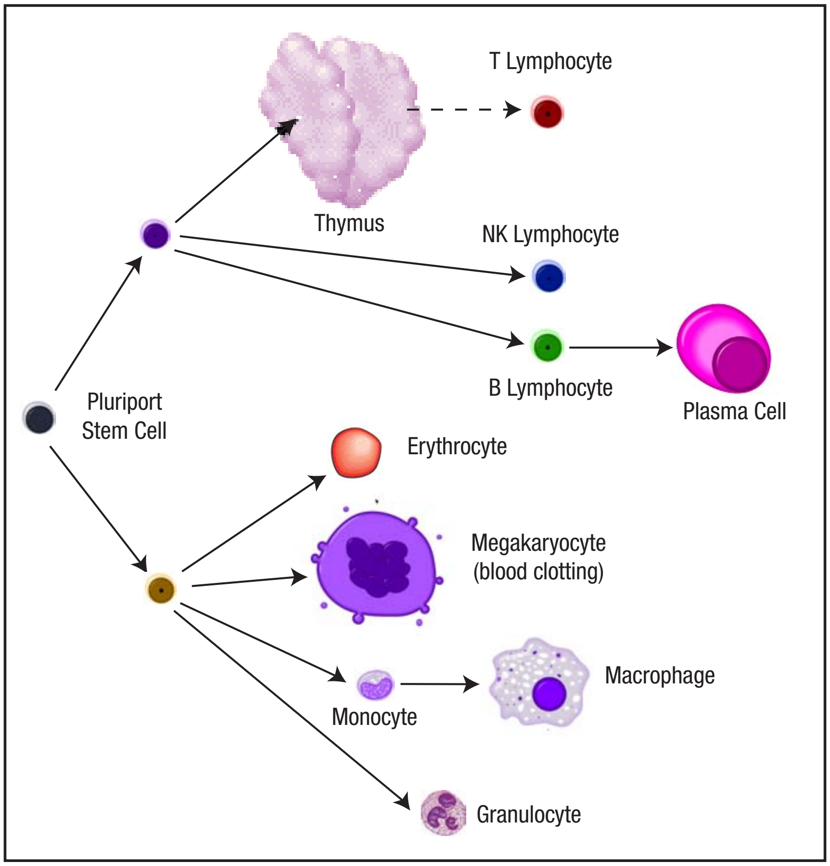
NASA scientists have also investigated the development of electrostatic radiation shields,[7] which generate positive and negative electric charges that deflect incoming electrically charged space radiation. Another method of radiation protection that has been proposed is to use the lunar regolith (the pulverized dusty material on the Moon's surface) to shield a human colony.
Although existing shielding can solve some radiation concerns, it makes spacecraft heavy and expensive to launch. Moreover, it does not provide complete protection against radiation. Shields five to seven centimeters thick can only block 30 to 35 % of the radiation, which means that astronauts could still be exposed to up to 70% of the radiation that passes through the shields.[8] For this reason, NASA is also investigating the use of medical and dietary supplements to mitigate the effects of ionizing radiation.



NASA has investigated electrostatic and plastic shielding. Combinations of different engineering, operational, and dietary countermeasures help improve radiation protection. Image Credit: NASA Goddard Spaceflight Center.

6 http://science.nasa.gov/headlines/y2005/25aug_plasticspaceships.htm
7 http://www.nasa.gov/centers/goddard/news/topstory/2004/0930niac_phase1.html
8 http://www.nasa.gov/vision/space/travelinginspace/keeping_astronauts_healthy_prt.htm

Stem cells in the bone marrow produce a wide range of blood cell types. Image Credit: Stem Cell World.

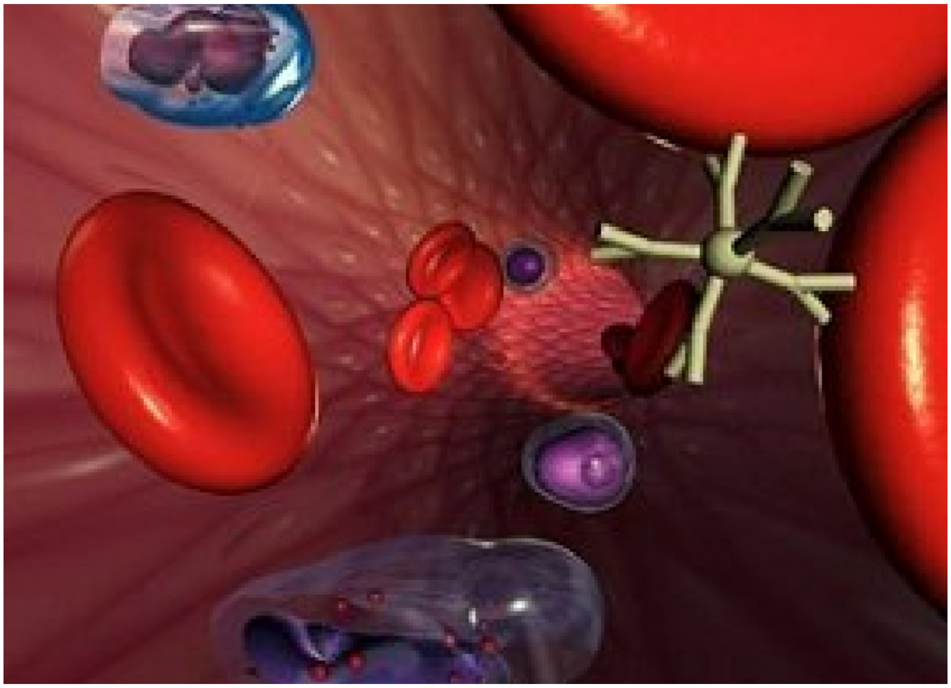


What are Dietary Countermeasures?

Dietary countermeasures are drugs, that when ingested by an astronaut, may have the potential to reduce effects of ionizing radiation. These supplements can be broadly categorized into two groups. The first group includes specific nutrients that prevent the radiation damage. For example, antioxidants like vitamins C and A may help by soaking up radiation-produced free-radicals before they can do any harm. Research has also suggested that pectin fiber from fruits and vegetables, and omega-3-rich fish oils may be beneficial countermeasures to damage from long-term radiation exposure. Other studies have shown that diets rich in strawberries, blueberries, kale, and spinach prevent neurological damage due to radiation. In addition, drugs such as Radiogardase (also known as Prussian blue) that contain Ferric (III) hexacyanoferrate (II) are designed to increase the rate at which radioactive substances like cesium-137 or thallium are eliminated from the body.[9]

The second group of dietary agents currently being considered for protection against ionizing radiation includes drugs that can facilitate faster recovery from radiation damage. These dietary agents offer protection by stimulating the growth of surviving stem and progenitor cells, or by lengthening the duration of the cell cycle segment that checks for and repairs damaged genes.[10] Although these types of drugs (radioprotectants) are now used to treat people exposed to radiation contamination on Earth, they may be good candidates for use on long duration space missions. It is important to note, however, that when administered in effective concentrations, some radioprotectants also have limiting negative side effects such as nausea, hypotension, weakness, and fatigue.

9 http://www.fda.gov/bbs/topics/NEWS/2003/NEW00950.html
10 http://www.nasa.gov/vision/space/travelinginspace/keeping_astronauts_healthy_prt.htm



Collisions between high-energy radiation and shielding can produce damaging secondary particles. Read more about this image at http://www.nasa.gov/vision/space/travelinginspace/keeping_astronauts_healthy_prt.htm

One natural defense system is for an abnormal radiation damaged cell to self-destruct before the cell becomes cancerous; this is achieved by activation of the cell's apoptosis gene (programmed cell death). Apoptosis can also be triggered intentionally by exposing the cell to enzymes or specific ligands (an ion, atom or molecule) that bind to a cell's death receptors. Other approaches that may also be useful aim to enhance the DNA repair system and immunoresponse by facilitating faster recovery of cell populations damaged by radiation. There are several such pharmaceuticals now in clinical trials. Some drugs, for example, stimulate the immune system to "restore and repopulate" bone marrow cells after radiation exposure. Other drugs appear to reduce gene mutations resulting from radiation exposure. Radiation protectants originally developed to protect military personnel in the event of nuclear warfare are now being used to protect cancer patients against the harmful effects of radiation treatment. Although large doses of ionizing radiation are damaging, small amounts are required for some biological processes. For example, vitamin D, necessary for maintenance and growth of bones, is normally produced in a person's skin through exposure to ultraviolet light. Since the Space Station is shielded to keep out harmful amounts of ultraviolet radiation, normal vitamin D production in an astronaut's skin is inhibited. To compensate, the astronauts will require vitamin D supplements.[11]

11 http://www.nasa.gov/vision/space/travelinginspace/keeping_astronauts_healthy_prt.htm

Activity IIIa: Radiation Limits for Astronauts

In this suggested activity that has been adapted from NASAexplores,[12] students will define and calculate the radiation limits for astronauts.

Objectives:

- Describe the radiation limits for astronauts in orbit.
- Discuss engineering, operational, and dietary countermeasures for astronauts.
- Understand radiation unit conversion

Background Information:

To help answer the questions at the end of this activity, use Module 1 and the following background information.

Dose and Dose Rate

When ionizing radiation interacts with the human body, its energy is transferred to tissues, where a range of biological effects can occur. Although radiation energy can be measured in different ways, the concept of "absorbed dose," or "simply dose," is generally used to define the average energy deposited per unit mass inside a small volume. The volume must be large enough to contain many molecules or cells so that a statistical average of energy deposited can be taken. The dose rate is the rate at which this energy is deposited (also described as dose per unit time). For charged particles, the dose rate is equal to the dose per particle times the number of particles traversing the target volume per unit time.

Measuring Radiation Energy

Although there are exceptions, in general when radiation energy is transferred the deposited energy (absorbed dose) is closely related to the energy lost by the incident particles.[13] The energy imparted is expressed in the unit Gray (Gy), which is equivalent to one joule of radiation energy absorbed per kilogram of organ or tissue weight. However, it should be noted that an older unit — the rad — is still frequently used to express absorbed dose; one Gy is equal to 100 rad.

When measuring radiation energy another consideration is that equal doses of all types of ionizing radiation do not produce the same harmful biological effects. In particular, alpha particles (the nuclei of the helium atom) exert more damage than do beta particles, gamma rays, and x rays for a given absorbed dose depositing their energy thousands of times more effectively. While lower energy electrons can pass through the spacing between DNA strands without interacting, some high-energy heavy ions produce an ionization trail so intense that it can kill nearly every cell it traverses (see Module 2 for more detail).

To account for the difference in harmful effects produced by different types of ionizing radiation, radiation dose is expressed as dose equivalent. The unit of dose equivalent is the Sievert (Sv). The dose in Sv is equal to "absorbed dose" multiplied by a "radiation weighting factor" that was previously known as the Quality Factor (Q). Historically, x rays have been used as the standard reference radiation against which all other types of radiation have been compared so the weighting factor for x rays and gamma rays is 1. Since alpha particles cause 20 times the damage of a similar dose of x rays or gamma rays, they have a Q of 20.

Some books use the rem to measure dose equivalent. One Sv, or 100 rem of radiation, is presumed, for the purpose of radiation protection, to have the same biological consequences as 1 Gy of x rays.

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12 http://nasaexplores.com/show_912_student_st.php?id=04032381148

13 For example, high-energy electrons produced by charged particles traversing a cell may escape, to deposit their energy in other locations, outside the cell. At low dose rates, only one or a few particles are likely to traverse a cell. The energy deposited in the cell is less than the energy lost by the particles. However, when a large number of particles are present, then electrons generated outside the cell may compensate for those that are lost. Thus, the concept of absorbed dose incorporates many assumptions and approximations.

The following chart from Module 1 summarizes radiation units:

Parameter	Radioactivity	Absorbed Dose	Dose Equivalent*	Exposure (for x rays and gamma rays only)	Energy
Definition	Rate of radiation emission (transformation or disintegration) from a radioactive substance	Energy imparted by radiation per unit mass onto an absorbing material	Expression of dose in terms of its biological effect	Quantity that expresses the ability of radiation to ionize air and thereby create electric charges that can be collected and measured	The capacity to do work
Common Units Measurement Label	Curie (Ci) 1 Ci = 37 GBq (this is a large amount)	rad 1 rad = 100 ergs/g	rem	Roentgen (R)	Joule (J)
International System of Units (SI) Measurement Label	Becquerel (Bq) 1 Bq = 1 event of radiation emission per second (this is a very small amount)	Gray (Gy) 1 Gy = 100 rad	Sievert (Sv) 1Sv = 100 rem (this is a large dose) 1 Gy air dose equivalent = 0.7 Sv 1 R ≈10 mSv of tissue dose	Coulomb/kilogram (C/kg) $1 \text{ R} = 2.58 \times 10^{-4}$ C/kg air	electronvolts (eV)

*Dose Equivalent = Absorbed Dose x Quality Factor (Q), where Q depends on the type of radiation (Q = 1 for gamma, x ray, or beta radiation; Q = 20 for alpha radiation)

Research Question:

How does the amount of radiation astronauts receive in space compare to radiation exposures on Earth?

Materials:

- Calculators
- Radiation Exposure Chart
- Module 1

Methods:

Ask the students to read the background material and use the following chart[14] to answer the questions listed below.

Radiation Exposure Limits for Astronauts and the General Public (in Sv)				
Type of person	**Time period**	**Organs (Sv)**	**Eye (Sv)**	**Skin (Sv)**
Astronauts	30-day	0.25	1.0	1.5
	Annual	0.5	2.0	3.0
	Career	1.0-4.0	4.0	6.0
Occupational Exposure	Annual	0.05	0.15	0.5
General Public	Annual	0.001	0.015	0.05

Procedure

1. During a hypothetical 10-day mission on the Space Shuttle, astronauts are exposed to an average organ dose of approximately 0.433 rem. Assuming a person of the general public on Earth received a 0.001 Sv organ dose per year every year, how long would it take him or her to receive the same amount of organ radiation exposure on Earth as the shuttle astronaut receives?

2. How many times greater is the annual allowable limit for an astronaut's organ dose than the annual allowable limit for occupational worker's organ dose? How many times greater is the astronaut's annual allowable limit for organ dose than the general public's annual allowable limit for organ dose?

3. Over an entire 10-day shuttle mission, an astronaut's skin was exposed to a total of 7.86 rem. What would be the average skin exposure per day? If this exposure rate was the same for an entire year, what size dose would an astronaut receive? Would this exceed the 30-day skin dose limit? Does it exceed the annual dose limit? Why is the allowable limit for organ exposure for astronauts so much less than the skin exposure (in other words, why is the skin allowed to have more radiation than organs beneath the skin)?

4. How many times greater is the annual allowable limit for an astronaut's eye dose than the annual allowable limit for occupational worker's eye dose? How many times greater is the astronaut's annual allowable limit for eye dose than the general public's annual allowable limit for eye dose?

5. Will astronauts affected by the increased radiation influence the genetic stability of the human population?

6. Each individual astronaut has agreed to be exposed to this extra radiation, knowing that space travel for now cannot avoid it. Why do you think they would be willing to do this?

7. How does NASA keep track of the radiation exposure to each astronaut?

8. Assume that a CT scan of your chest exposes your skin to approximately 5.3 mSv (1 Sv = 1000 mSv) of radiation. How many rem is 5.3 mSv? If we assume that over an entire 8-day shuttle mission, an astronaut's skin is exposed to a total of 5.59 mSv, how many days in orbit would the CT scan equate to for astronauts?

9. NASA limits the amount of radiation exposure per year for astronauts. Why do you suppose there is a need for annual and career limits too?

14 http://srag.jsc.nasa.gov/Publications/TM104782/techmemo.htm

Answers to the questions:

1. Hint: Convert the astronaut exposure to Sv, and divide by the Sv/year. The answer is 4.33 years.

2. 10 times greater. 500 times greater.

3. 0.786 rem skin dose per day is an average of 286.89 rem skin dose per year. It exceeds the 30-day limit but not the annual limit. The skin is the first line of defense. It will begin to absorb radiation to protect the rest of the body. If organs are receiving high doses, it means than the surface of the body is receiving an even higher dose, which would be extremely damaging.

4. 13.333 times greater, and 133.33 times greater.

5. Possibly, but the entire population of people that are directly involved in space activities is of limited size, so the effects will be very small, if any.

6. Student answers will vary. One possibility, the benefit of spaceflight exceeds the risk involved.

7. NASA keeps careful counts of time in orbit, number of missions, and radiation levels before and after each mission.

8. 5.3 mSv = 0.53 rem, approximately 7.58 days.

9. Each mission may fall below the dose limits, but over time the amount may become dangerously high. The effects of radiation are cumulative.

Activity IIIb: Countermeasures for Lunar Explorers

In this suggested literature research activity, students will investigate countermeasures that could be used for astronauts that explore the Moon.

Objectives:

- Describe several countermeasures either currently being used or investigated by NASA.
- Design an experiment to determine what types of shielding are effective against radiation.
- Describe the use of antioxidants to prevent damage from radiation.
- Design a shielding substance that can withstand the effects of radiation while minimizing secondary effects from the collision with matter.
- Explain why understanding solar activity is important to lunar explorers.
- Discuss several drugs that could possibly be used by astronauts as radioprotectants.

Research Question:

Within the context of available countermeasures, how can the astronauts be best protected from over-exposure to radiation while living on the moon for extended periods?

Discussion Questions:

- What time of the day would be best to perform a spacewalk on the surface of the moon?
- What role would space weather play in your determination?
- How long could explorers be on the surface of the Moon without exceeding their lifetime radiation limits?
- What kind of foods should Astronauts take with them to the Moon?
- Should radiation treatment drugs be taken on long duration missions?
- Why must people be shielded from radiation on the Moon?
- How long is the lunar day? How long is the lunar night?
- What is the chemical composition of lunar regolith? How can it be used in radiation shielding?

Activity IIIc: Shielding Yeast From UV Radiation

In this experiment, students will explore how shielding countermeasures can help to lessen the harmful effects of UV radiation. Different sun protection factors, cloth, paper, foil, or sunglasses may be used.

Note: this activity is also suggested in Module 2. It may be adapted to include dietary countermeasures. This can be accomplished by adding vitamin C to the media 1 or 2 days prior to UV exposure. It is suggested to vary the amount of vitamin C concentration used in each yeast culture. Because vitamin C may have toxic effects in high concentrations, test a range of concentrations. For example, try different concentrations from 1 mg vitamin C per 10 ml media up to 1 g vitamin C per 10 ml media. Ensure that you have a control group that has not been exposed to vitamin C for comparison purposes.

Objectives:

- Discuss countermeasures for UV radiation.
- Describe phenotypic changes in yeast as a result of radiation damage.
- Explain why model organisms are important in countermeasures research.

Research Question:

Within the context of available hat is the most effective method of preventing UV damage in yeast?

Discussion Questions:

- Why use yeast to study the effects of UV radiation?
- What are the effects of different types of sunscreen on yeast?
- How can your health be affected by exposure to ultraviolet radiation?
- Do you see any differences between areas of the Petri dish? If so, describe them.
- Did some SPFs of sunscreen protect the yeast cells better than others? Why?
- Does yeast grow less in some areas? Does it grow more than in others? Why?
- Does UV pass through plastic wrap? Plastic Petri dish covers?
- Why is it important to not expose an open yeast extract dextrose agar plate for very long? What is aseptic technique?
- What can you conclude from the results of your experiment?
- Describe another experiment you could carry out to obtain more information about the effects of UV radiation on cells.
- Why would vitamin C be used as a countermeasure?

How Do Sunscreens Work?

Sunscreens act like a very thin shield by stopping the UV radiation before it can enter the skin and cause damage. Some sunscreens contain organic molecules (such as oxybenzone, homosalate, and PABA) that absorb UVB and/or UVA radiation. Others use inorganic pigments (such as titanium dioxide and zinc oxide or both) that absorb, scatter, and reflect both UVA and UVB light. Sunscreens are labeled with a Sun Protection Factor (SPF) rating that could also be thought of as a sunburn protection factor. For example, suppose that your skin begins to redden after 10 minutes in the sun. If you protected it with an SPF 15 sunscreen, it would take 15 times as long, or 2.5 hours, to get a comparable burn. Remember, SPF relates only to UVB protection; there is no standard measurement or rating for UVA protection in the United States.

Why Does NASA Study Yeast in Space?

Like the fruit fly, ordinary baker's yeast (Saccharomyces cerevisiae) also contains genes for DNA repair that are very similar to human genes with the same function. Therefore we can use yeast as a model system to explore the effects of radiation on cells. Like human cells, most yeast cells effectively repair DNA damage caused by UV radiation. However, some yeast strains have mutations that prevent them from performing certain types of DNA repair. Because they cannot repair all the damage to DNA, these cells usually die after exposure to UV radiation. In addition to sensitivity to UV radiation, yeast is also sensitive to space radiation. In a biological assessment of space radiation in low-Earth orbit, yeast inside special experiment hardware has been shown to have a decreased rate of survival following exposure to beta particles (electrons) and low-energy protons.[15] Other findings suggest there are highly coordinated gene expression responses to gamma radiation.[16] This knowledge is especially important when designing countermeasures for astronauts during long-term lunar surface operations or microgravity spacewalks.

Materials:

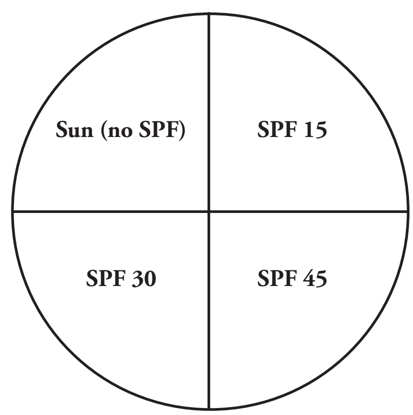
- Yeast-extract dextrose media plates (from kit or recipes for YPD (yeast peptone dextrose media) can be found online. Use the search term "yeast peptone dextrose media".)
- UV-sensitive yeast suspension in liquid media and wild type yeast suspension in liquid media (this needs to be prepared from a stock sample that is purchased from a vendor). Ensure there is enough for the number of plates that will be plated (1 ml of cells per plate is recommended).
- A source of UV radiation such as direct sunlight. For this or future experiments, the radiation source could also be changed. Depending upon the size and design of the experiment, you may want to include black lights, halogen, or fluorescent light bulbs to determine if they also produce damaging radiation).
- Several kinds of sunscreen (each with different SPF), black paper, cloth, metal foil, or other types of materials that can be used to experiment with UV shielding.
- Sterile water, sterile pipets, and sterile toothpicks.
- Plastic wrap (to cover plates).
- UV-sensitive yeast suspension in liquid media with varying concentrations of vitamin C and wild type yeast suspension in liquid media with varying concentrations of vitamin C (optional).

Directions:

1. Ensure that your hands and the work area are clean. Use soap and water and wipe your hands and your work area with alcohol and a paper towel. Good aseptic technique will ensure that the plates do not get contaminated with other organisms.

2. In this step you will plate the yeast suspension. You may want to do this for each group or allow the students to perform the task. Swirl the container of UV-sensitive yeast. Using aseptic technique and a sterile pipet, add 1 ml of the yeast cell suspension uniformly on top of the agar in the Petri dish for every plate that will be used in the experiment. Close the lid. Gently tilt and rotate the dish to spread the liquid. If there are places the liquid does not cover, reopen the dish and use the rounded end of a sterile toothpick to move the liquid over them. Sterile glass beads could also be used to spread the cells across the plate by moving the plate side to side when the beads and sample are on the agar. Let the liquid soak into the agar (remove beads if used by dumping them out). Place the Petri dish in a dark place for 10-20 minutes until the liquid soaks into the media. Note: If only a few colonies are desired on the plate, do several serial dilutions of the cell suspension to reduce the initial concentration of cells plated.

3. Label the dish (see the diagram at the end of this activity) by drawing lines on the top and bottom of the dish to divide it into 4 parts (you could divide it into more parts, depending upon the number of countermeasures you are investigating). Label one area "sun" as a control, and use the other three areas to test sunscreens or other items like cloth, foil, paper, or plastic. Ensure that one area on all plates does not get UV exposure (cover it with black paper during UV exposure) or make certain that at least one entire plate per group is designated as the control, which does not get UV exposure. Label each area on both the top and the bottom of the dish and tape the 2 halves of the Petri dish together along the side so that the lid does not rotate. For one group (or the entire class), have the students remove the lid and replace it with plastic wrap (tape it on tightly). This will test any possible shielding effects of the cover.



15 http://www.spaceflight.esa.int/users/index.cfm?act=default.page&level=11&page=2120
16 http://www.sanger.ac.uk/PostGenomics/S_pombe/docs/851.pdf

4. Spread sunscreen on the lid of the Petri dish (or on the plastic wrap) in the places you marked; use an equal amount in each section and spread the sunscreen evenly. You can also use plastic, foil, etc., instead of sunscreen. If you labeled an area “no sun,” tape a square of dark paper over it. Make sure you know exactly where each sun screening material is used.

5. Expose the Petri dish to the sun or to a UV light. Vary the appropriate exposure times for the students from 20 minutes (in midday summer sun) to as much as 4 hours (in midmorning winter sun) per dish. If you are exposing the Petri dish to the sun, make sure that the surface of the agar is aimed directly at the sun (perpendicular to the incoming radiation). If students are careful, the lids could be removed and replaced with some clear plastic wrap during the exposure (to reduce any possible shielding effects of the lid). Consider allowing one group to remove the lid for a direct exposure.

6. After the exposure, wipe the sunscreen off the lid of the Petri dish. This will reduce the mess. Remove any other materials that were tested. If the students used the plastic wrap, just remove the wrap and replace it with the original lid. Place the Petri dish upside down in an incubator or in a dark place and let it grow for 1-2 days in an incubator at 30°C or 3-4 days at room temperature.

7. If desired, repeat these steps with a wild type strain as a control for comparison.

8. Compare the amount of yeast that has grown in different areas of the Petri dish and draw conclusions.

9. Note: If a wild or UV sensitive yeast suspension with varying concentrations of vitamin C is used, it is suggested to refrain from using additional shielding countermeasures on at least one plate of each yeast strain. This way, if an effect is seen, you will know it is due to the vitamin C in the media, and not due to sunscreen, foil, or other countermeasures.

(Note: Equipment and materials for this activity are commercially available from various educational resources.)

Appendix 1: Additional Websites

Module 3: Radiation Countermeasures

Classroom Resources:
http://www.nasa.gov/audience/foreducators/topnav/subjects/

Appendix 2: National Education Standards[17] by Module

Module 3: Radiation Countermeasures

Content Standards: 9-12

Content Standard C:
Life Science
Matter, energy, and organization in living systems

Content Standard E:
Science and Technology
Understanding about science and technology

Content Standard F:
Science in Personal and Social Perspectives
Science and technology in local, national, and global challenges

17 http://lab.nap.edu/html/nses/6a.html

Space Faring:
The Radiation Challenge
EDUCATOR REPLY CARD

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https://neeis.gsfc.nasa.gov/JDbGenie/vol1/htdocs/edcats/rhsf_edu_reply_card.html

You will then be asked to enter your data at the appropriate prompt.

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   College/University - ______ Undergraduate ______ Graduate

   Number of Students:
   ______ K-4 ______ 5-8 ______ 9-12 ______ Community College
   College/University - ______ Undergraduate ______ Graduate

   Number of Others:
   ______ Administrators/Staff ______ Parents ______ Professional Groups
   ______ General Public ______ Civic Groups ______ Other

2. What is your home 5- or 9-digit zip code? –

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   ❑ Group Discussions
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   ❑ Science and Mathematics Standards Integration
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   ❑ Institution/School System
   ❑ Fellow Educator
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