Bulding a Permanent Human Presence in Space

Grades 9-12

Lesson 1: Radiation Exposure

The United States and its partners around the world are building the International Space Station (ISS), arguably the most sophisticated engineering project ever undertaken. The ISS is an orbiting laboratory where astronauts conduct research in a variety of disciplines including materials science, physiology in microgravity environments, and Earth remote sensing. The ISS provides a permanent human presence in low Earth orbit.

This lesson is one of many grade K-12 lessons developed by Challenger Center to bring the ISS experience to classrooms across the nation. It is part of Building a Permanent Human Presence in Space, one of several Education Modules developed for Challenger Center's Journey through the Universe program. This Education Module addresses the essential question "How can we build a permanent human presence in space?" Start the *Journey* at www.challenger.org/journey.

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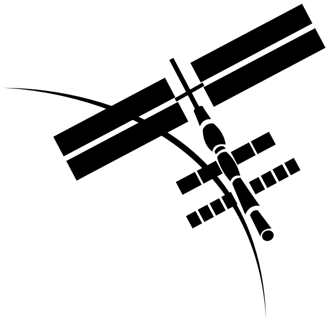

Lesson 1: Radiation Exposure

Lesson at a Glance

Lesson Overview

Astronauts living and working in space are exposed to hazardous radiation more than persons on the surface of the Earth. In this lesson, students will begin by estimating how much radiation each was exposed to in the preceding year. Students will compare their own exposure to the radiation exposure of astronauts living and working aboard the International Space Station (ISS). Students will synthesize this information with knowledge of the solar activity cycle and radiation exposure guidelines for astronauts in order to evaluate the risks and safety measures needed for astronauts in space flight.

Lesson Duration

Two 45-minute class periods

Core Education Standards

National Science Education Standards

Standard B6: Interactions of Energy and Matter

- Waves, including sound and seismic waves, waves on water, and light waves, have energy and can transfer energy when they interact with matter.

Standard F5: Natural and Human-Induced Hazards

- Natural and human-induced hazards present the need for humans to assess potential danger and risk. Many changes in the environment designed by humans bring benefits to society, as well as cause risks. Students should understand the costs and trade-offs of various hazards—ranging from those with minor risk to a few people to major catastrophes with major risk to many people. The scale of events and the accuracy with which scientists and engineers can (and cannot) predict events are important considerations.

Essential Question

- How do we predict the amount of radiation an astronaut will receive while in orbit in order to design ways to minimize radiation exposure?

Concepts

Students will learn the following concepts:

- The Sun's activity affects the amount of radiation received by astronauts and Earth.
- Earth's atmosphere protects us from much of the Sun's radiation.
- Astronauts are exposed to far more radiation than people on Earth, so NASA must take special precautions to protect them.

Objectives

Students will be able to do the following:

- Calculate the amount of high-energy radiation each one received last year.
- Calculate the cumulative radiation dosage for astronauts aboard the ISS at different phases of the Sun's activity.

SCIENCE OVERVIEW

The Earth's atmosphere and magnetic field shield the surface from energetic radiation from the Sun and from Galactic Cosmic Rays (GCRs). Astronauts living and working in space are less protected and are more exposed to hazardous radiation than persons on the Earth's surface. Unlike the other hazards of space exploration, radiation does not cause immediate obvious injuries. Instead, exposure to radiation builds up over time, requiring careful attention to safe practices at all times. The hazards of radiation exposure can be faced intelligently and risks can be reduced to acceptable levels. However, how low a risk is acceptable? How much radiation is tolerable? There is no simple answer to these questions.

It is not possible to reduce radiation exposure to zero, for anybody, anywhere. There is a constant low level of radiation exposure at the Earths' surface, from natural radioactivity in the environment and from the fraction of space radiation that reaches the surface. People live with this "hazard" because they always have and because life on Earth can handle it reasonably well. The risks in space flight must be compared to the risks of living on the surface of the Earth in order to make informed choices about which risks to take and which ones to avoid.

WHAT IS RADIATION?

Radiation, as the word is used by scientists, is a technical term for a broad range of phenomena with certain features in common. Radiation, as the word is used by non-scientists, tends to mean specifically the radiation that is potentially harmful to living things. Unfortunately, the term often is used to mean the radioactive materials that produce potentially hazardous radiation, which is imprecise and can be confusing—even potentially dangerous, when safety information needs to be conveyed accurately. Modern technology often uses radiation and radioactive materials for many purposes. Confusion about the effects of devices and materials can lead to, for example, avoidance of potentially life-saving devices and medical procedures (diagnostic and therapeutic X-rays, MRI, nuclear-powered pacemakers, etc.); or, on the other hand, dangerously casual handling of radioactive materials (as in home smoke detectors) and radiation-producing devices (such as industrial X-ray machines). These sorts of problems are common to using any powerful tool safely—gasoline, for example, is a poisonous explosive that must be handled cautiously—but radiation and radioactive materials are outside most people's direct understanding and awareness.

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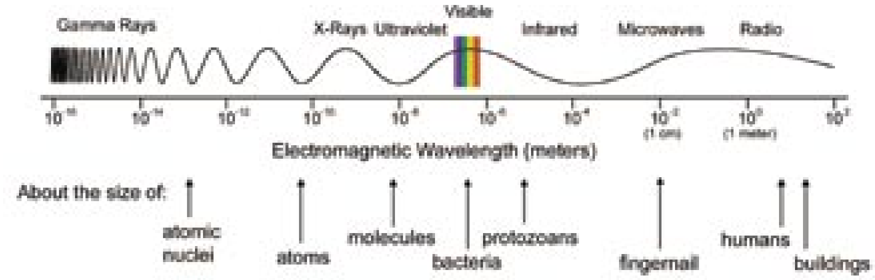

Figure 1. The electromagnetic spectrum. Different parts of the spectrum are shown here as one continuous wave. In reality, a given electromagnetic wave has one particular wavelength. The continuous wave in the picture above is used to illustrate the difference in wavelength from one part of the spectrum to another.

ELECTROMAGNETIC RADIATION

Technically, any process that transports energy over distance is a form of radiation. Sound is a form of radiation detected by the ears. Light also is a form of radiation, electromagnetic radiation. The existence of electromagnetic radiation was deduced from an understanding of electric and magnetic fields, leading to the discovery of what light is—a time-varying combination of electric and magnetic fields that travels through empty space and other media. The frequency of the variation with time is what distinguishes one color of light from another. The speed of light (which has units like meters per second) divided by the frequency (which has units like cycles per second) is the property of wavelength (which has units like meters per cycle), which also is used often to describe the difference between colors of light (Fig. 1).

Electromagnetic radiation is similar to what commonly is called light, in every respect but one: human eyes cannot see most electromagnetic radiation. There is only a narrow band of frequency values that is visible. The full range of electromagnetic radiation is the electromagnetic spectrum, shown in Figure 1. In order of increasing frequency, or decreasing wavelength, the spectrum runs from radio to microwave to infrared radiation to visible light to ultraviolet radiation to X-rays, and finally gamma rays. These days, the definition of light has been expanded to include the whole electromagnetic spectrum.

Perhaps the most perplexing scientific result of the 19th century was the answer to the question of whether light is a stream of particles (which would have properties like kinetic energy, momentum, and position) or is a wave traveling through space (which would have properties like wavelength, frequency, and a characteristic velocity). Important experiments showed that light is composed of waves just as in Figure 1. Later experiments showed, however, that light is composed of particles. Both kinds of experiments can be performed today, and they continue to obtain the same apparently contradictory answers. The modern view is that light is a bundle of waves, called a photon, that acts like a particle when the appropriate type of experiment is performed, and that acts like a wave when the appropriate type of experiment is performed to show that. No experiment ever has been devised that would require light to be both a wave and a particle at the same time.

The photon model of light is a major accomplishment, because it explains many otherwise bewildering phenomena. The most important feature is that each photon carries a certain fixed amount of energy with it that depends on its frequency (wavelength). Low-frequency light (radio and infrared) has low-energy photons. High-frequency light (X-rays and gamma rays) has high-energy photons. An individual high-energy photon carries enough energy to break apart a molecule or to ionize an atom; low-energy photons do not. Microwave ovens heat objects by applying a large total amount of energy (many low-energy photons), but the microwave (radio) photons are of such low energy individually that they do not break down molecules directly. High-energy X-ray and gamma ray photons have a good chance of going right through a thick slab of material without being absorbed at all. High-energy photons can cause chemical changes deep inside a target, even with very few photons, by penetrating deep into the target before being absorbed and damaging the molecule that does the absorbing. Low-frequency photons cannot do this even with many photons.

PARTICLE RADIATION

Energy can be transported over distance by the motion of subatomic particles as well as by light. The casual use of the word radiation usually applies to large numbers of fast-moving electrons, protons, neutrons, and even ions and atomic nuclei. Although there are technologies that can produce energetic particle radiation, most of it comes from naturally-occurring processes: the radioactive decay of elements in the Earth, Galactic Cosmic Rays, and nuclear fusion in the Sun.

Particle radiation has important differences from electromagnetic radiation. Almost all subatomic particles and ions have an electric charge. As a result, their path can be bent by magnetic fields. A magnetic field strong enough to protect a person at short range (i.e., a portable force field) is far beyond current technology. Earth's magnetic field is effective in deflecting charged-particle radiation because it extends over long distances, so that even a tiny deflection can cause particles to miss the Earth. Space exploration poses significant increased exposure to charged-particle radiation as astronauts move farther from Earth's core, which generates the magnetic field. Astronauts in interplanetary space would be exposed to substantially more charged-particle radiation. Some energetic particles from interplanetary space have become trapped by the Earth's magnetic field. These trapped particles form a region of nearby space called the Van Allen belts, centered on the Earth, that is filled with energetic particles. Astronauts leaving Earth orbit experience increased radiation exposure as they pass through.

The only subatomic particles that are not electrically charged are neutrinos and neutrons. These particles are negligible in the space environment, but it is good to understand them in order to distinguish them from other radiation exposure. Neutrinos are uncharged particles with nearly zero mass. Most of the neutrinos reaching the Earth come from nuclear fusion within the Sun. They have such a tiny chance of interacting with any matter that they pass through the Earth almost unimpeded. Neutrons are uncharged particles that are part of atomic nuclei. Energetic neutrons are the only form of radiation that makes a target object become radioactive, by being captured into an atomic nucleus to make a new nucleus. The new nucleus has the same number of protons but one more neutron than before (an isotope of the original nucleus). The newly-formed isotope may be unstable and emit radiation by nuclear decay, releasing its excess energy by releasing a charged particle or gamma ray photon. Some unstable nuclei decay (emit radiation) within minutes or seconds or even faster. Others may last for thousands of years or more before decaying. Each radioactive isotope has a characteristic half-life, which is the time it takes for half the nuclei in a sample to decay at random. It is impossible to predict, however, when any individual isotopic nucleus will decay.

What Is Ionizing Radiation?

Ionizing radiation is a category that combines energetic particle radiation and high-energy electromagnetic radiation. It has the ability to damage living tissues. The term includes the following:

- High-frequency light, including gamma rays, X-rays, and the highest-energy ultraviolet light. Light ionizes atoms when a photon that carries enough energy to eject an electron is absorbed by an atom. The photon nature of light is essential to the ionization of atoms—if light were only a wave and not a particle, an atom could absorb more and more light energy until it ionized, no matter what the frequency of the light. This does not happen: light intensity has no effect on the ability to ionize matter. Only the photon concept accounts for the fact that high-frequency light ionizes, low-frequency light does not.

- High-energy charged particles. Charged particles ionize atoms by impacting the atom's electron cloud. Because charged particles and the electrons in atoms have strong electric fields that extend over a distance, direct impact with an atom is not necessary in order to ionize it. The chances of ionization by charged particles are very high.
- Neutrons sometimes may be included, but the mechanism for ionization is quite different. Neutrons do not interact with electrons. Neutron impact on an atomic nucleus either results in radioactive decays that produce ionizing radiation; or the energy transferred to a nucleus on impact, even if the neutron does not "stick" and become part of the nucleus, causes the atomic nucleus to jostle its electron cloud and eject one or more electrons.

The particles or photons of ionizing radiation often carry so much energy that ejected electrons also have a lot of energy and can be viewed as particle radiation. Energetic electrons, in turn, can interact with atoms in the target to produce X-rays or even more ionization. The result is an electron cascade, producing many times more energetic charged particles in a target than the original number entering the target, maybe hundreds to thousands of times more, each one sharing a fraction of the energy from the original impactor. Damage to living tissue is caused by the multitude of electrons striking and damaging molecules throughout the tissues in an organism.

Radiation Damage to Living Tissue

Most of the molecules in an organism that are damaged by radiation are replaced by ordinary processes in individual cells. DNA molecules, however, are large and complex, easily damaged, and important to the entire cell's functioning. Cells can repair and recover from a substantial amount of damage to their own DNA. Sometimes, though, a DNA molecule can be damaged irreparably. Living cells in complex organisms, like humans, contain a lot of "junk" DNA with no influence on cell metabolism or bodily functions. Junk DNA can be damaged with no real harm to the cell. Damage to important DNA segments, however, can result in failure of a gene. A moderate number of failed genes can be tolerated. With increasing total damage to cellular DNA from the absorption of more radiation, the cell is likely to continue functioning, but be unable to reproduce; eventually, the cell dies without replacement. The effects of radiation exposure are felt most severely with some delay after the incident, as damaged cells begin to die with no replacements.

Some cells may carry damaged DNA, but continue to function and reproduce. In these cells, further damage can accumulate through multiple episodes of radiation exposure. Radiation safety rules are based on limiting total radiation exposure over a certain period of time or over a lifetime, since damage to the DNA in cells can build up over time.

The most frightening consequences of radiation exposure are cancer and genetic mutation. In most cells, radiation damage either kills the cell by DNA damage, or misses it entirely. However, genes in some cells may be damaged in such a way that the cell is healthy and able to reproduce, but the cell fails to eliminate itself naturally (die) when it becomes old. The body's immune system usually destroys and removes abnormal cells. In a small number of cases, these damaged cells resist the immune system's efforts to kill them and go on to develop into a cancerous tumor—an uncontrolled growth of cells that are robust and healthy on their own terms and that consume the body's resources to maintain the ever-increasing number of cancerous cells born from the original genetically-damaged cell. The unlikelihood for any particular cell to become cancerous explains why living things on Earth do not all die naturally of cancer caused by ordinary environmental radiation levels. Exposure to abnormal doses of radiation greatly increases the likelihood that a cell somewhere in the body will be damaged in such a way as to become cancerous. Intense targeted radiation exposure is used intentionally to kill cancer cells, hoping to damage the DNA sufficiently that the cells will die. Since cancerous cells already have significant genetic damage, radiation is fairly effective in killing them. The whole population of cancerous cells needs to be killed, however, so that a surviving cancer cell does not escape to reproduce. The relative effectiveness of radiation in killing cancer cells explains why this treatment continues to be used; the relative difficulty of destroying all the cancer cells explains why cancer is such a terrible disease despite modern medicine.

Genetic mutation is a subject for horror movies and nightmares of radiation exposure. It is an unlikely event. In complex creatures like humans, many genes need to interact properly to produce a living organism. Radical change to any one gene, or a randomly selected set of genes, is unlikely to produce a successful creature: the altered gene must occur in a reproductive cell; it must be the rare reproductive cell that gets the chance to reproduce; the gene must not kill the reproductive cell before it has a chance for conception; the gene must not prevent conception; the altered gene must not prevent development of the embryo into a fetus; and the delivered offspring must be functional outside the support of the uterus. That is a long list of victories to be won before a radiation-induced mutation can appear as a viable creature. Genetic mutations appear in nature (rarely) because nature offers very large numbers of parents and very long periods of time, so that even unlikely events occur sometime. The odds of any individual parent producing healthy mutant offspring are very low.

How Is Radiation Measured?

Ionizing radiation is not visible and cannot be felt directly, but radiation levels can be measured using instruments. The unit for radiation exposure in living tissue is the sievert (Sv). It measures the biological effect of absorbed radiation, referred to as an "effective dose." Often, radiation exposure is expressed in millisievert (mSv), one thousandth of a sievert, or in microsievert (μSv), one millionth of a sievert. An older, non-Standard Internationale (SI) unit that still is often used is a rem. One sievert is one hundred times greater than one rem; that is, 1 Sv = 100 rem. A life-threatening one-time radiation dose would be on the order of 3–4 Sv (300–400 rem). If this exposure were spread out over a lifetime it would give the body's cells more opportunity to repair their DNA or to reject damaged cells from the body bit-by-bit. A one-time dose of 7–10 Sv (700–1000 rem) would generally be fatal within a few weeks without intensive medical support; even with medical care, the chances of survival would not be good.

The sievert is derived from another SI unit called the gray (Gy). The gray measures radiation dose as energy absorbed per kg of mass, and applies equally well to a human being and a rock. Gray do not make useful units for radiation exposure of living tissues, because not all forms of radiation are equally damaging. Particle radiation is much more damaging than the same absorbed dose of energy from X-rays. Sievert, therefore, are derived from gray by the application of an imprecise concept called the quality factor, Q. Q=1 for X-rays, gamma rays, and energetic electrons/positrons (beta particles); Q=2–20 for neutrons (depending on the energy); and Q=20 for energetic helium nuclei (alpha particles). Higher values of Q apply to radiation that is more damaging to living tissue. An older, non-SI unit that still is often used is a rad. One gray is 100 times greater than one rad; that is, 1 Gy = 100 rad.

Radiation Shielding

A radiation shield is an object that absorbs a dose of radiation without any concern about radiation damage to the shield. Every radiation shield is "leaky," meaning it cannot stop every bit of radiation. The limiting factor in a radiation shield might even be natural radioactiv-

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ity in the shield itself. Dense metals with high atomic number, like lead, make a good shield against X-rays and gamma rays, but make a poor shield against neutrons and high-energy atomic nuclei. A better radiation shield is a thick mass of steel-reinforced concrete, say 2 or 3 meters thick, which is inexpensive to make thick enough to stop almost any radiation, which contains elements with high atomic number that are good for stopping energetic gamma rays and X-rays, and which contains elements of very low atomic number, like hydrogen, that are good for stopping neutrons and charged particles. The Earth's atmosphere is composed of materials that make a poor shield against ionizing radiation. The atmosphere is effective against space radiation only because there are so many atoms between the Earth's surface and space that even with poor efficiency, the atmosphere stops essentially all the hazardous radiation. The very best radiation shield is one that most people prefer to use—distance. At 10 meters from a radiation source, the received dose is 100 times less than at one meter from it.

Typical man-made radiation shields pose two opposing problems for space travel:

1. Large amounts of shielding are extremely heavy. No one wants to launch a concrete block building into Earth orbit.
2. Small amounts of shielding can be worse than no shielding. Very energetic ionizing radiation passes right through most materials, including human bodies. It has a low probability of interaction, but in the rare instances when an interaction happens, a lot of energy is released. The electron cascade from ionizing radiation produces X-rays. If a shield is made thick enough to stop the energetic primary particles, it must also be made thick enough to stop the secondary X-rays that are created by the cascade partway through the shield. High-energy cosmic rays that probably would pass right through a body may be made into a shower of low-energy X-rays that are readily absorbed in the body, if the shield thickness is not great enough.

Where Does Ionizing Radiation Come From?

There are three main sources of ionizing radiation: the Earth, the Sun, and the Milky Way Galaxy. It is very difficult to avoid any radiation exposure at all.

Radioactivity on/from the Earth

The Earth includes radioactive materials in its crust, mantle, and core. On the surface of Earth, there are several natural sources of ionizing radiation. The most important of these is radon gas, formed by the decay of naturally occurring uranium in the crust. Once formed, some radon gas seeps through the ground into the air, while some dissolves into underground water deposits.

Naturally-occurring background radiation levels typically are between 1.5 and 3.5 mSv per year, though that rate may be higher in some locations due to local materials, such as uranium-rich granite. Radiation exposure due to human activities, such as nuclear power plants, radiation-sterilization of medical and food supplies, or medical procedures is relatively minor, amounting to about an eighth of total background radiation exposure. Most human-caused radiation exposure is in medical procedures. In the United States, the average person is exposed to approximately 3.6 mSv of whole body exposure per year from all sources.

The Earth itself is partly responsible for radiation exposure in the space environment, due to the Van Allen belts. The radiation dose rate to an astronaut in Earth orbit depends on altitude. Manned flight significantly beyond Low Earth Orbit (LEO) requires radiation shielding and is best handled by passing out of the radiation belts as quickly as possible.

Solar Particle Events

The Sun produces a “solar wind” of moderate-energy charged particles flowing from the Sun at all times. Occasionally, the Sun produces outbursts of charged particles in a Solar Particle Event (SPE) with higher energy and higher number density than the usual flow. The particles in SPEs are released with such energy that they travel at a substantial fraction of the speed of light and may reach the Earth within tens of minutes. The Sun's 11-year solar cycle has a powerful influence on the rate at which SPEs occur. During the maximum activity phase of the cycle, SPEs occur much more frequently and energetically than during the minimum activity phase.

SPEs are one of the great hazards of travel beyond the Earth's magnetosphere (the region shielded by the Earth's magnetic field) and into interplanetary space. The Apollo missions left the magnetosphere on their way to the Moon. Between Apollo 16 and Apollo 17, an SPE occurred that would have delivered a lethal dose of radiation within less than a day of exposure. Plans for manned exploration of Mars must deal with the fact that crews will be in flight for so long that they undoubtedly will be exposed to SPEs on the way to or from Mars. Spacecraft must be provided with sufficient shielding to protect the crew from SPEs.

Galactic Cosmic Rays

Galactic Cosmic Rays (GCRs) include the highest-energy particles and gamma rays ever observed. GCRs include large atomic nuclei, such as iron, carrying terrific energy. The charged particle component of GCR may be deflected by the Earth's and the Sun's magnetic fields, protecting astronauts in Earth orbit. As the Sun goes through its activity cycle, its magnetic field waxes and wanes in strength. With strong solar magnetic field at solar activity maximum, significantly less GCR radiation reaches Earth orbit than with weak solar magnetic field at solar activity minimum. Thus, when there are fewer and less-energetic solar particle events, there are increased and more-energetic GCRs.

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CONDUCTING THE LESSON

WARM-UP & PRE-ASSESSMENT

STUDENT MATERIALS (PER STUDENT)

- Student Worksheet 1
- Calculator

PREPARATION & PROCEDURES

1. Ask students what is radiation. (*Answer: something that is harmful to living things*) Ask students what are some common sources of radiation. (*Desired answer: the Sun, gamma rays, X-rays, Radon, etc.*)

2. Discuss radiation problems that we have here on Earth. Ask students what evidence we have here on Earth of solar radiation. (*Desired answer: people who are exposed to sunlight can receive sunburns, there are satellite and telecommunication problems, etc.*) Ask students what protects us from most of the Sun's harmful radiation. (*Desired answer: Earth's atmosphere and magnetic field*) Ask students what is the intensity level of solar radiation in space, outside of the Earth's atmosphere. (*Desired answer: it is higher than on Earth*) Ask students if the amount of radiation from the Sun is always the same. (*Desired answer: no, it changes throughout the solar cycle*)

3. Have students complete Student Worksheet 1 to determine how much radiation each one received last year.

4. Ask students to report their exposure rate to the class and record the values on the board. Ask students why many of the rates may be almost identical. (*Desired answer: we all live in the same location, and the same distances from radiation sources*) Ask students why some of the exposure rates may vary greatly. (*Desired answer: travel, accidents, medical conditions, etc.*)

TEACHING TIP

Find the elevation of your area and the location of the nearest nuclear and coal-fired power plants in order for students to accurately complete Student Worksheet 1. You can find the closest nuclear plant at http://www.nei.org/doc.asp?catnum=2&catid=93

5. Ask students, based on these sources of radiation, if there are any professions that may have an increased exposure to ionizing radiation. (*Desired answer: pilots, flight attendants, power plant employees, astronauts, medical personnel, etc.*)

TEACHING TIP

If class time is limited, students can calculate their radiation exposure as a homework assignment.

Activity: Determining Radiation Doses on ISS

In this activity, students use data from NASA to determine how much radiation astronauts can expect to receive aboard the ISS. In addition, they will use NASA restrictions on career radiation exposure to determine how long a person can safely work in the space environment.

Student Materials

- Student Worksheet 2
- Calculator

Preparation & Procedures

1. Discuss the dangers of radiation. Ask students what are some of the dangers associated with radiation exposure. (*Desired answer: too much radiation can cause radiation sickness and possibly lead to cancer. Radiation can also damage DNA in cells and cause problems in cells' normal operations*) Tell students that NASA needs to protect the astronauts. To investigate this, students will use data from previous missions and knowledge of the Sun cycle to predict the amount of radiation astronauts will be exposed to.

2. Have students complete Student Worksheet 2 in which they calculate the amount of radiation ISS crews will receive at different phases of the solar cycle. This can be done individually or in cooperative pairs.

Reflection & Discussion

1. How does the radiation received by astronauts compare to the average amount received by humans on Earth? (*Desired answer: astronauts receive much more radiation, actually 20–70 times more*) Have students compare this figure with the amount of radiation they calculated that each one received last year.

2. What type of precautions should astronauts take? (*Desired answer: the level of radiation received by astronauts should be recorded and the number of flights should be limited*) Tell students that this is exactly what NASA does; they keep track of the amount of radiation astronauts receive and ground them before they reach exposure safety limits.

3. Ask students what factors NASA should use to determine the exposure limit. (*Desired answer: age and gender*) Ask students why age should be a factor. (*Desired answer: young people undergo more-rapid cell division, so the effect of genetically damaged cells is greater than in older persons*) Ask students why gender is a factor. (*Desired answer: male reproductive physiology is more resilient against radiation exposure than female reproductive physiology*)

4. Discuss with students their opinion on what they believe is NASA's responsibility to protect astronauts.

TRANSFER OF KNOWLEDGE

Have students complete Student Worksheet 3 in order to apply what they have learned to the lifetime radiation exposure limits for astronauts that NASA imposes. Answers are located in the *Teacher Answer Key* section.

TEACHING TIP

Student Worksheet 3 can be assigned as a homework assignment if class time is limited.

EXTENSIONS

- Divide students into two teams. Have a debate regarding a possible proposal to build a human spacecraft with a nuclear propulsion system. How will that affect the radiation received by the astronauts? What kind of precautions would be necessary to make the spacecraft safe?

PLACING THE ACTIVITY WITHIN THE LESSON

In the activity, students learn how to calculate the amount of radiation astronauts receive during missions at different times of the solar cycle. Students apply this knowledge to NASA's radiation exposure limits to ensure the safety of astronauts.

Assessment Criteria for Activity

4 Points
- All calculations are complete and correct.
- Student used data to support logical conclusions.
- Student restated results of calculations and included personal analysis and thoughts/comments.

3 Points
- Most calculations are present and correct.
- Acceptable use of data to support conclusions.
- Comments are few, but acceptable.

2 Points
- Some calculations are present and correct.
- Data is used, but conclusions are not well supported by this data.

1 Point
- Few calculations are present and correct.
- Conclusions do not refer to data, or does not include thought process.

0 Points
- No work completed.

NOTES ON ACTIVITY:

LESSON WRAP-UP

LESSON CLOSURE

Discuss the fact that without Earth's atmosphere for protection, astronauts are exposed to higher levels of radiation in space than persons on the ground. Many factors such as age, gender, and the phase of the solar cycle are used to anticipate the level of radiation that astronauts may expect to receive and determine whether it falls within responsible safety limits.

CURRICULUM CONNECTIONS

Biology – Have students research the biological effects of radiation.

NOTES:

RESOURCES

INTERNET RESOURCES & REFERENCES

Student-Friendly Web Sites:

National Institute of Environmental Health Sciences - Kids Page
    http://www.niehs.nih.gov/kids/uranium.htm
Nuclear Energy Institute - Fun and Games
    http://www.nei.org/scienceclub/funandgames.html
Radiation from Household Items
    http://www.philrutherford.com/Radinstr.PDF

Teacher-Oriented Web Sites:

EPA - What is Radiation?
    http://www.epa.gov/radiation/students/what.html
National Safety Council - Understanding Radiation in our World
    http://www.nsc.org/ehc/rad/radbroch.htm
Nuclear Energy Institute - Teacher's Lounge
    http://www.nei.org/scienceclub/teacherslounge.html
Challenger Center
    http://www.challenger.org
Journey through the Universe
    http://www.challenger.org/journey

NOTES:

Teacher Answer Key

The answers provided here include both straightforward and complex versions of answers to the questions. The standard to be used for grading students must depend on the level of the class and must be determined by the teacher.

Student Worksheet 1

1. Answers will vary. Compare to these three examples, one representing an extremely cautious lifestyle, one representing an ordinary lifestyle, and one representing an extreme lifestyle:

Cautious hermit:	2.98 mSv. Lives a low-tech life, makes only cautious choices, avoids medical procedures. Still gets nearly the average.
Office person:	3.62 mSv. Makes only ordinary choices, travels a bit by plane, and gets dental X-rays once per year.
"Danger Guy:"	12.48 mSv. Lives dangerously (brick house in Colorado, at high altitude, near a power plant), travels constantly, gets medical X-rays because of regularly breaking bones in wild and dangerous pursuits.

2. Answers will vary. Compare to the three most significant contributions for each of the example cases:

Cautious hermit:	Two thirds of exposure (2 mSv) is from natural radon gas seeping from the ground. Natural radioactivity in food is an eighth of total exposure. Cosmic radiation is about a twelfth. Not much could be done, except to live in a tree-house to avoid radon, a dense gas which stays near the ground.
Office person:	About half of exposure is from radon. Natural radioactivity in food and exposure in air travel each account for a tenth of exposure. Decreasing travel is the only significant change that could be made (plus living in a tree-house).
"Danger Guy:"	About half of exposure is from X-rays and diagnostic procedures (one each, probably an underestimate for real medical procedures). Natural radon accounts for about a sixth of total exposure. A dramatic decrease in exposure to medical X-rays would come from a less injury-prone lifestyle.

3. Airline pilots and flight attendants may receive significant doses predominantly from many hours at high altitude. Professional athletes in contact sports will break bones relatively often and require exposure to medical X-rays. Medical and dental radiologists are exposed to X-rays if they do not use shielding properly. Users of industrial X-ray machines in construction and security screening may receive a significant dose of radiation from exposure to their equipment.

4. Astronauts are exposed to much more radiation than persons on the ground. The radiation dose rate (from the Sun and from cosmic radiation) increases rapidly with altitude, making it the greatest exposure for astronauts. However, astronauts on board the ISS are not exposed to natural radon and do not receive diagnostic medical X-rays in orbit. Verification of flight readiness probably includes significant medical testing with X-rays, however.

Student Worksheet 2

1. There are several reasonable answers, if students wish to go beyond the bare minimum. The closest mission in the list is STS-51G, with an average dose rate of (0.00015+0.00020)/2 = 0.000175 Sv/day = 0.175 mSv/day.

   A wise choice might be to set an upper limit, which would be STS-37, with an average dose rate of (0.00040+0.00070)/2 = 0.00055 Sv/day = 0.55 mSv/day.

   Students also could interpolate. Most accurate is to interpolate the logarithm of the dose rate (since it increases nonlinearly with altitude), then exponentiate the result. The dose interpolated to 220 NM is 0.00029 Sv/day = 0.29 mSv/day.

2. Assume 365.25 days per year (average). For STS-51G, with an average dose rate of 0.000175 Sv/day, the cumulative radiation exposure from one year in space is equivalent to 0.000175•365.25/0.003 = 21.3 years on Earth.

   For STS-37, with an average dose rate of 0.00055 Sv/day, the cumulative radiation exposure from one year in space is equivalent to 0.00055•365.25/0.003 = 67.0 years on Earth.

   Interpolated to 220 NM, the average exposure rate of 0.00029 Sv/day gives a cumulative radiation exposure from one year in space equivalent to 0.00029•365.25/0.003 = 35.3 years on Earth.

Student Worksheet 2 Calculations

1. The average GCR exposure rate aboard the ISS at solar minimum is 2.5 • 1.75×10^{-4} Sv/day = 4.38×10^{-4} Sv/day.

2. One SPE, with an exposure of approximately 0.004 Sv, is equivalent to 0.004 Sv / 0.003 Sv/year = 1.3 years of background radiation on Earth.

3. In eight months, an astronaut would experience 1 SPE, with 0.004 Sv total exposure, or possibly as much as 2 SPE, with 0.008 Sv total exposure.

4. The exposure due to GCR's would be 8 • (365.25 day/yr / 12 mo/yr) = 243.5 days, times 4.38×10^{-4} Sv/day = 0.107 Sv total. With exposure to 1 SPE, the total exposure would be 0.111 Sv; with exposure to 2 SPE, the total exposure would be 0.115 Sv.

5. Solar maximum: GCR exposure rate is 1.75×10^{-4} Sv/day. One SPE/month, so 12 to 13 SPE's at 0.004 Sv each. Total is 365.25 days • 1.75×10^{-4} Sv/day + (12 to 13) SPE • 0.004 Sv/SPE = 0.112 to 0.116 Sv in one year.

   Solar activity transition: estimate GCR exposure rate at square root of 2.5 = 1.58, times 1.75×10^{-4} Sv/day = 2.77×10^{-4} Sv/day. One SPE/four months = 3–4 SPE/yr, so 3–4 SPE at 0.004 Sv each, equals 0.012–0.016 Sv from SPE. Total is 365.25 days • 2.77×10^{-4} Sv/day + (0.012 to 0.016 Sv) = 0.113 to 0.117 Sv in one year.

   Solar minimum: GCR exposure rate is 2.5 • 1.75×10^{-4} Sv/day = 4.38×10^{-4} Sv/day. One SPE/eight months, so 2 SPE at 0.004 Sv each. Total is 365.25 days • 4.38×10^{-4} Sv/day + 2 SPE • 0.004 Sv/SPE = 0.168 Sv in one year.

   Solar maximum and solar activity transition are just about equal. Solar maximum is marginally better. Solar minimum definitely is the least safe time.

6. Assume that the radiation exposure on a spacecraft is comparable to living on the space station.

   Assume that the mission will include 8 months to travel to Mars, 24 months of research on the surface, and 8 months of travel back to Earth.

Assume that the natural background dose of radiation while on the surface of Mars is 0.0017 Sv/year.

The first 8 months is in solar minimum; the last 8 months is in solar maximum. The middle 24 months is at Mars environmental background radiation rates. The total therefore is (0.111 to 0.115 Sv from GCRs) + 2 yr • 0.0017 Sv/yr + 243.5 day • 1.75×10^{-4} Sv/day + (8 to 9 SPE) • 0.004 Sv/SPE = 0.189 to 0.197 Sv total exposure.

Student Worksheet 3

1. Simply apply the formulae. Note that the age calculation reduces the maximum acceptable exposure below 2 Sv for males less than 30 and for females less than 38. Remember that the absolute maximum is 4 Sv, regardless of age.

   Males: at 25 years, max = 2+0.075•(–5) = 1.625 Sv; at 30, max = 2 Sv; at 40, max = 2.75 Sv; at 50, max = 3.5 Sv; at 60 and greater, max = 4 Sv.

   Females: at 25 years, max = 2+0.075•(–13) = 1.025 Sv; at 30, max = 1.4 Sv; at 40, max = 2.15 Sv; at 50, max = 2.9 Sv; at 60, max = 3.65 Sv; at 70 and greater, max = 4 Sv.

2. The formula starts from 2 Sv, increasing the limit by 0.075 Sv for each year past a threshold age (30 for males; 38 for females). Therefore, the age at which the maximum exposure reaches the absolute maximum exposure limit of 4 Sv is:

   Males: (4 Sv – 2 Sv)/0.075 Sv/yr + 30 years = 56.7 years old.

   Females: (4 Sv – 2 Sv)/0.075 Sv/yr + 38 years = 64.7 years old.

3. For females: The estimated exposure rate at solar min is 0.168 Sv/yr. Dividing the exposure limit for a 30-year old woman (1.4 Sv) by the rate yields an initial time estimate: 1.4 Sv / 0.168 Sv/yr = 8.3 years.

   This is most of a solar cycle, so re-do the calculation with an average of the rate throughout the solar cycle = ((0.112+0.116)/2 + (0.113+0.117)/2 + 0.168)/3 = 0.132 Sv/yr (averaging the range of exposure rates in each time period from question 5). The result then is 1.4 Sv / 0.132 Sv/yr = 10.6 years.

This is a long time, and during this time, the astronaut's exposure limit increases significantly. The total exposure she receives in X years is X•0.132 Sv. Her limiting exposure is 2+0.075•(30+X–38) Sv. Equate these expressions and solve for X, to determine when the exposure rate exceeds the exposure allowance:

$0.132 \bullet X = 2 + 0.075 \bullet (30 + X - 38)$,
$0.132 \bullet X = 1.4 + 0.075 \bullet X$,
$X = 1.4\ \text{Sv} \,/\, (0.132\ \text{Sv/yr} - 0.075\ \text{Sv/yr})$,
$X = 24.6$ years.

For males: The estimated exposure rate at solar min is 0.168 Sv/yr. Dividing the exposure limit for a 30-year old man (2 Sv) by the rate yields an initial time estimate: 2 Sv / 0.168 Sv/yr = 11.9 years, more than one solar cycle. Re-do the calculation with an average of the rate throughout the solar cycle = 0.132 Sv/yr. The result then is 2 Sv / 0.132 Sv/yr = 15.1 years. This is a long time, and during this time, the astronaut's exposure limit increases significantly. The total exposure in X years is X•0.132 Sv. The limiting exposure is 2+0.075•(30+X–30) Sv. Equate these expressions and solve for X, to determine when the exposure rate exceeds the exposure allowance:

$X = 2\ \text{Sv} \,/\, (0.132\ \text{Sv/yr} - 0.075\ \text{Sv/yr})$,
$X = 35.1$ years.

However, this puts the man at an age of 65.1, with a nominal limit of 4.63 Sv. The correct answer must be for reaching the maximum exposure limit of 4 Sv. That limit is reached in X = 4 Sv / 0.132 Sv/yr = 30.3 years.

4. According to this calculation, male astronauts would be a somewhat more likely choice for a mission to Mars, as males have a higher maximum permissible radiation exposure limit at all ages until 64.7 years. After age 64.7, both males and females have the same limit of 4 Sv total. At the expected exposure rate, however, both males and females actually are about equal after age 34.4. They each would reach a lifetime total of 4 Sv exposure at just about the time that the female reaches 64.7 years old and a maximum exposure limit of 4 Sv. With a higher exposure rate, the "age of equality" is older; with good shielding and a lowered exposure rate, the age of equality is younger. In any case, however, a manned mission to Mars would be shorter than the decades-long times calculated here. The maximum lifetime radiation exposure therefore is not very relevant to suitability for the mission, and so the gender of the astronauts also is not relevant.

5. March 2000 was during solar maximum, so assume solar maximum rates of 0.114 Sv/yr to obtain an exposure of about 0.114•5/12 = 0.0475 Sv. Without knowing the astronaut's age, assume 4 Sv. The maximum before the mission then is 4–0.0475 = 3.95 Sv. In practice, NASA limits astronauts' exposure as much as possible, so it is unlikely that any active astronaut would be near this limit.

   Students might research the crew on the web in order to refine the answer. Shepherd was born in 1949 and so had a lifetime limit of 3.6 Sv in 2000, limiting prior exposure to 3.55 Sv. Gidzenko was born in 1962 and so had a lifetime limit of 2.6 Sv in 2000, limiting prior exposure to 2.55 Sv. Krikalev was born in 1958 and so had a lifetime limit of 2.9 Sv in 2000, limiting prior exposure to 2.85 Sv.

6. Answers will vary, depending on the age of the students.

   Age 16, male: exposure limit is 0.95 Sv. At solar minimum exposure rate of 0.168 Sv/yr, the limit would be reached in 5.65 years, 4.7 times Polyakov's record. Since the exposure limit increases with age, older students could beat the record by even more.

   Age 16, female: exposure limit is 0.35 Sv. At solar minimum exposure rate of 0.168 Sv/yr, the limit would be reached in 2.08 years, 1.7 times Polyakov's record. Since the exposure limit increases with age, older students could beat the record by even more.

STUDENT WORKSHEET 1

NAME ____ DATE ___________

CALCULATING YOUR YEARLY EXPOSURE TO RADIATION

Calculate your exposure to ionizing radiation over the past year by using the chart on the following pages. Take your time to think about each of the types of exposure you may have had, and how many times you were exposed. The calculation is done in units called Sieverts (Sv), which approximately describes the biological effect a dose of radiation has on living beings. The exposure rates are given in milliSieverts—one thousandth of a sievert—and per one year.

You may notice that the chart does not include ultraviolet radiation from the Sun, low-energy radiation from cell phones, etc. While their potential health effects are being investigated, they are not thought to be as dangerous as the ionizing radiation listed here.

Answer the following questions after you have determined the amount of radiation you received last year.

1. The average level of radiation is approximately 3 mSv per year. Was the radiation you received above or below the average?

2. Identify three sources of radiation that have a significant effect on your own total exposure. How could you protect yourself against these sources?

3. Which professions may increase your exposure to ionizing radiation?

4. Would astronauts aboard the International Space Station (ISS) have to be more concerned or less concerned about exposure to radiation, compared to persons on the ground? Why?

To read more about radiation, you can visit the U.S. Environmental Protection Agency's Radiation Web Pages at http://www.epa.gov/radiation/students/

YEARLY RADIATION EXPOSURE

Radiation can affect living and mechanical things on Earth as well as in space.
How much radiation do you receive in one year? Complete the data below to find out!

Information on local nuclear power plants is available at
http://nei.org/doc.asp?catnum=&catid=&docid=1094&format=print

TYPE OF IONIZING RADIATION	AMOUNT OF RADIATION IN MSV
From space	
Cosmic radiation at sea level, add 0.26 mSv.	
Cosmic radiation adjusted for the elevation of where you live	
Less than 300 m (1,000 feet), add 0.02 mSv.	
300 - 600 m (1,000-2,000 feet), add 0.05 mSv.	
600 - 900 m (2,000-3,000 feet), add 0.09 mSv.	
900 - 1,200 m (3,000-4,000 feet), add 0.15 mSv.	
1,200 - 1,500 m (4,000-5,000 feet), add 0.21 mSv.	
1,500 - 1,800 m (5,000-6,000 feet), add 0.29 mSv.	
1,800 - 2,100 m (6,000-7,000 feet), add 0.40 mSv.	
2,100 - 2,400 m (7,000-8,000 feet), add 0.53 mSv.	
More than 2,400 m (8,000 feet), add 0.70 mSv.	
From the ground (rocks, soil)	
If you live on the Atlantic Coast, add 0.23 mSv.	
If you live on the Gulf Coast, add 0.23 mSv.	
If you live in the Colorado Plateau, add 0.90 mSv.	
If you live elsewhere in the U.S, add 0.46 mSv.	

From the air	
Radon (natural radioactive gas seeping from underground), add 2 mSv.	
Radiation in the living body	
Food and water (e.g., potassium), add 0.4 mSv.	
From building materials	
If you live in a wooden structure, add 0.05 mSv.	
If you live in a brick structure, add 0.07 mSv.	
If you live in a concrete structure, add 0.07 mSv.	
From jet plane travel	
For each 1,000 miles, add 0.01 mSv.	
If your luggage was X-rayed, add 0.00002 mSv.	
From power plants	
If you live within 50 miles of a nuclear power plant operating normally, add 0.00009 mSv.	
If you live within 50 miles of a coal fire plant operating normally, add 0.0003 mSv.	
From radioactive waste disposal	
Average U.S. dose is 0.01, so add 0.01 mSv.	
From weapons test fallout	
Average U.S. dose is 0.01, so add 0.01 mSv.	
From medical procedures	
If you have had X-rays of the chest, add 0.06 mSv.	
If you have had X-rays of the pelvis and hips, add 0.65 mSv.	
If you have had X-rays of the arms, hands, legs, or feet, add 0.01 mSv.	
If you have had X-rays of the skull, head, or neck (including dental X-rays), add 0.2 mSv.	
If you have had a Barium procedure, add 2 mSv.	
If you have had CT scan (head or body), add 4 mSv.	
If you have had a nuclear medicine procedure (such as 99 mTc bone scan), add 5 mSv.	
If any of your teeth have porcelain crowns or you have false teeth, add 0.0007 mSv.	
If you have a plutonium-powered pacemaker, add 1 mSv.	

Lifestyle	
If you watch TV, add 0.01 mSv.	
If you use a computer, add 0.001 mSv.	
If you wear a luminous (LCD) wristwatch, add 0.0006 mSv.	
If you use gas lantern mantles when camping, add 0.00003 mSv.	
If you have a smoke detector at home, add 0.00008 mSv.	
TOTAL	

How does Radiation Affect the Human Body?

100 mSv – Above this level, the probability of cancer increases with dose; when the dose reaches 1000 mSv, the estimated risk of fatal cancer is 5 of every 100 persons (5%).

1,000 mSv (1 Sv) – In a short-term (less than a few days) dose is roughly the threshold for causing immediate radiation sickness in an average person, but it would be unlikely to cause death. A dose of 3,000 mSv gives a 50% chance of death in 30 days if left untreated. Above this, up to 10,000 mSv in a short-term dose would cause severe radiation sickness and would most likely be fatal.

10,000 mSv (10 Sv) – As a short-term (less than a few days) and whole-body dose would cause immediate illness such as nausea, decreased white blood cell count, and probably subsequent death within a few weeks.

STUDENT WORKSHEET 2

NAME ______________________________________ DATE __________

NASA is concerned about the amount of radiation astronauts will receive aboard the International Space Station (ISS). In this activity, you will determine the approximate radiation dosage astronauts can expect to receive during their missions.

DETERMINING DAILY RADIATION DOSES ON ISS

The table below shows the minimum and maximum dosages (in Sv/day) that astronauts received from actual Space Shuttle flights to and from the ISS at different altitudes given in nautical miles (NM).

Space Shuttle Mission	Altitude (NM)	Dose Rate (Sv/day)	
		Min	Max
STS-38	125	0.00003	0.00004
STS-51G	200	0.00015	0.00020
STS-37	245	0.00040	0.00070
STS-31	330	0.00140	0.00220

1. The International Space Station orbits at an altitude of 220 NM. What is the average daily dose rate for the mission closest to the ISS in Sv/day?

2. The average background radiation dose on Earth is 0.003 Sv/year. How many years on Earth equal one year's radiation on the ISS? Show your work in the space below.

SOLAR ACTIVITY

The Sun goes through an 11-year cycle in which its activity fluctuates. While the solar cycle does vary, it can be predicted with reasonable accuracy after solar minimum has been reached. Solar activity is correlated with the appearance of sunspots, patches of variable magnetic field strength and somewhat lowered temperatures on the Sun's surface. The graph below indicates the predicted intensity, measured by number of sunspots, for the remainder of the current solar cycle (solid line). The jagged line indicates the sunspot numbers observed so far.

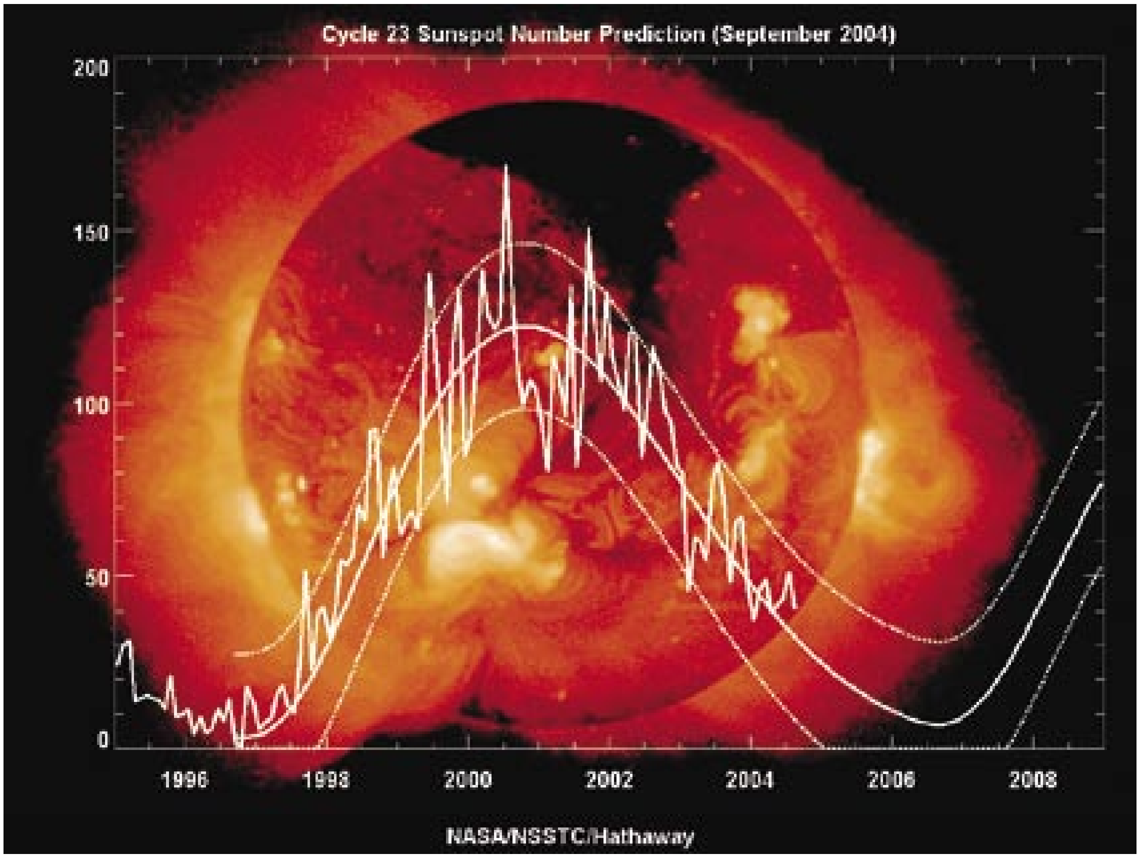

Diagram 1: Solar activity cycle as followed by the number of sunspots on the surface of the Sun. The 11-year cycle has major effects on the radiation environment on Earth as well as for the spacecraft venturing into the inner Solar System, such as the MESSENGER mission to Mercury. (Picture credit: http://science.nasa.gov/ssl/pad/solar/images/ssn_predict_l.gif)

The Sun strongly influences the radiation received by astronauts according to its 11-year activity cycle. During solar maximum, the Sun's magnetic field is strengthened and the Sun produces more Solar Particle Events (SPE). Galactic Cosmic Rays (GCR), on the other hand, are a continuous source of radiation that are lessened during solar maximum because of solar magnetic shielding and greater during solar minimum. GCRs are the most significant routine source of radiation hazard to astronauts.

Show work for ALL calculations.

1. If the average GCR dose rate aboard the ISS is 1.75×10^{-4} Sv/day at solar maximum, and the dose rate is 2.5 times greater at solar minimum, calculate that rate in Sv/day.

2. A typical radiation dose from an SPE is ~0.004 Sv inside a spacecraft or similar shelter. How many years of background radiation on Earth is this equal to?

3. Solar Particle Events occur about once every month for the three years around solar maximum. They occur about once every eight months for the three years of solar minimum. And, they occur about once every four months during the two and a half years between solar maximum and minimum. How much radiation from SPEs would an astronaut receive aboard the ISS for eight months during solar minimum?

4. How much radiation would an astronaut be exposed to from GCRs and SPEs aboard the ISS for eight months during solar minimum?

5. At which stage in the solar cycle is it safest for an astronaut to spend a year aboard the ISS; during solar minimum, solar maximum, or the two and a half years between solar maximum and minimum?

6. Calculate the radiation exposure an astronaut might expect to receive during a four-year mission to Mars, that launches in 2008. Hint: Use the solar activity diagram to help you identify the phase of the solar cycle.
   - Assume that the radiation exposure on a spacecraft is comparable to living on the space station.
   - Assume that the mission will include 8 months to travel to Mars, 24 months of research on the surface, and 8 months of travel back to Earth.
   - Assume that the natural background dose of radiation while on the surface of Mars is 0.0017 Sv/year.

STUDENT WORKSHEET 3

NAME ____ DATE ___________

Some solar radiation is a form of damaging radiation known as "ionizing radiation," which can create electrically-charged ions in the material it strikes. This ionization process can break apart atoms and molecules, causing damage in living organisms, either by affecting living tissue directly (e.g., causing radiation sickness and possibly cancers) or by prompting changes in the DNA (e.g., causing mutations—hereditary mutations are extremely rare, however) which can accumulate with further exposure to radiation. Therefore, there is a maximum cumulative radiation exposure that an astronaut is permitted to receive before being permanently grounded. This level depends on the astronaut's age, with an absolute maximum cumulative exposure of 4 Sv regardless of the astronaut's age. The formulae to compute the exposure limits are:

Males: 2 + 0.075 • (age-30), in Sv
Females: 2 + 0.075 • (age-38), in Sv

LIFETIME RADIATION EXPOSURE LIMITS FOR ASTRONAUTS

Using the information above, and from the two preceding worksheets, answer the following questions. Explain how you obtained the answer using both words and calculations.

1. What is the maximum permitted radiation exposure for a male and for a female at each of these ages: 25, 30, 40, 50, 60, 70, 77 (77 = John Glenn's age during his Space Shuttle flight in 1998).

2. For males, at what age is the maximum permitted exposure 4 Sv? For females?

3. What is the maximum time that a 30-year-old woman could stay on the ISS if she began her trip at solar minimum? A man? Hint: Use your calculated answer from question 5 on Student Worksheet 2.

4. Based on this formula, who would be more likely candidates for a long-term mission to Mars, men or women? Why?

5. The first ISS crew was manned by William Shepherd, Yuri Gidzenko, and Sergei Krikalev. What is the maximum radiation exposure that these astronauts could have received up until they entered the space station in March 2000 for their five-month mission so that they would not have exceeded their maximum exposure during their mission?

6. The record for total consecutive days in orbit is 437.7 held by Russian cosmonaut Valeri Polyakov. Could you beat his record with the cumulative exposure limit, assuming you left for the ISS next week? (Hint: Check the solar activity diagram.)