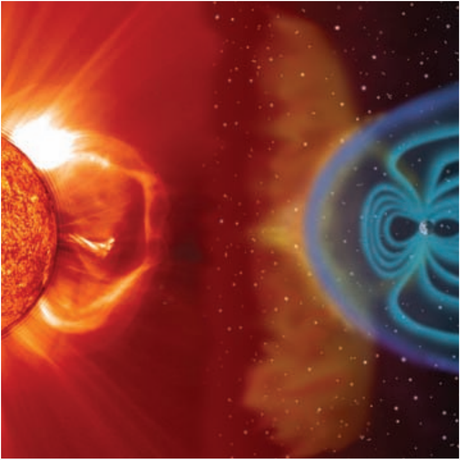
National Aeronautics and Space Administration

Space Faring
The Radiation Challenge

An Interdisciplinary Guide
on Radiation and Human
Space Flight



Introduction and Module 1:

Radiation

Educational Product	
Educators and Students	Grades 9–12

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Radiation Educator Guide

Introduction and Module 1:

Radiation

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Introduction

Radiation biology is an interdisciplinary science that examines the biological effects of radiation on living systems. To fully understand the relationship between radiation and biology, and to solve problems in this field, researchers incorporate fundamentals of biology, physics, astrophysics, planetary science, and engineering. The Space Faring: The Radiation Challenge educator guide helps to link these disciplines by providing background, discussion questions, objectives, research questions, and inquiry-based activities to introduce radiation biology into your high school science classroom. The suggested activities are hands-on investigations that encourage the use of science, mathematics, engineering, technology, problem solving, and inquiry skills. The activities provide a general framework that can be modified based on student needs and classroom resources. This guide is aligned with the National Science Education Standards of Science as Inquiry, Physical Science, and Life Science, and has been organized into the following sections and activities:

1. Radiation
2. Radiation Damage in Living Organisms
3. Protection from Radiation
4. Applications to Life on Earth

The major goal of NASA's Space Radiation Project is to enable human exploration of space without exceeding an acceptable level of risk from exposure to space radiation (for more information, see). Space radiation is distinct from common terrestrial forms of radiation. Our magnetosphere protects us from significant exposure to radiation from the sun and from space. Radiation that is emitted from the sun is comprised of fluctuating levels of high-energy protons. Space radiation consists of low levels of heavy charged particles. High-energy protons and charged particles can damage both shielding materials and biological systems. The amount, or dose, of space radiation is typically low, but the effects are cumulative. Solar activity fluctuates, and so the risk of exposure increases with the amount of time spent in space. Therefore there is significant concern for long-term human space travel. Possible health risks include cancer, damage to the central nervous system, cataracts, risk of acute radiation sickness, and hereditary effects. Because there is limited data on human response to space radiation, scientists have developed methods to estimate the risk. This is based on theoretical calculations and biological experimentation. NASA supports research to analyze biological effects at ground-based research facilities where the space radiation environment can be simulated. Research performed at these facilities is helping us to understand and reduce the risk for astronauts to develop biological effects from space radiation, to ensure proper measurement of the doses received by astronauts on the International Space Station (ISS) and in future spacecraft, and to develop advanced materials that improve radiation shielding for future long-duration space exploration on the Moon and possibly on Mars.

For over 35 years, NASA has been collecting and monitoring the radiation doses received by all NASA astronauts who have traveled into space as part of the Gemini, Apollo, Skylab, Space Shuttle, Mir, and ISS programs (for more information, see http://srag-nt.jsc.nasa.gov/). While uncertainties in predicting the nature and magnitude of space radiation biological risks still remain[1], data on the amount of space radiation and its composition are becoming more readily available, and research is helping to identify the biological effects of that radiation.

The Lunar Outpost Scenario

This guide is designed to provide you with information that will be helpful in understanding why radiation research is a crucial component in the development and planning for long-duration human space exploration. To help inspire students in your classroom, we suggest that you provide your students with a scenario that encompasses the radiation biology problems involved with human space exploration of the Moon, including the development of a permanently human-tended lunar outpost, as seen below[2]. If such an outpost is to be safely constructed and occupied by people from Earth, we must have a complete understanding of how

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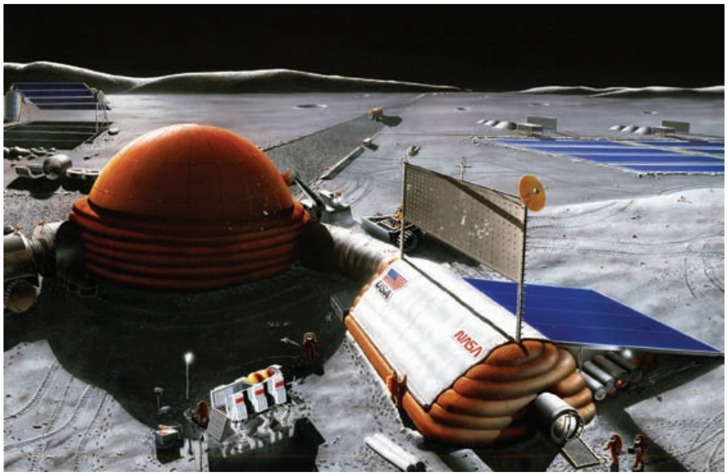
[1] Lancet Oncol 2006; 7:431-35

[2] http://vesuvius.jsc.nasa.gov/er/seh/gotomoon.gif



An artist's conception of a future Moon base. Image Credit: NASA.

the biological limitations of the human body in the space environment will affect its overall design and operation. To successfully grasp the importance of radiation biology, your students will need a solid understanding of why the radiation encountered in long-duration space exploration is such an enormous challenge to the human body.

A Brief History of Humans on the Moon

It is important to note that the NASA Apollo program was designed to land humans on the Moon and bring them safely back to Earth; it was not designed to establish a permanent presence on the Moon. The duration of the lunar surface missions were very short, largely due to the risks of space radiation exposure and the unpredictable nature of the solar weather.

Between 1969 and 1972, six of the seven lunar landing missions (including Apollo 11, 12, 14, 15, 16, and 17) were successful and enabled 12 astronauts to walk on the Moon. While on the surface, the astronauts carried out a variety of lunar surface experiments designed to study lunar soil mechanics, meteoroids, seismic activity, heat flow, lunar ranging, magnetic field distributions, and solar wind activity. The astronauts also gathered samples and returned to Earth with over 600 pounds of Moon rocks and dust. Since 1972, no human has returned to the Moon.

The table below shows the amount of time astronauts spent on the surface of the Moon during each lunar landing, and the average radiation dose they received.

Mission	Total Duration	Lunar Surface Duration	Average Radiation Dose*
Apollo 11	08 days, 03 hrs, 13 mins	21 hrs, 38 mins	0.18 rad
Apollo 12	10 days, 4 hrs, 31 mins	31 hrs, 31 mins	0.58 rad
Apollo 14	09 days, 01 min	33 hrs 31 mins	1.14 rad
Apollo 15	10 days, 01 hr, 11 mins	66 hrs, 54 mins	0.30 rad
Apollo 16	11 days, 01 hr 51 mins	71 hrs, 2 mins	0.51 rad
Apollo 17	12 days, 13 hrs, 51 mins	74 hrs, 59 mins	0.55 rad

* Average radiation dose information can be found on the Life Sciences Data Archive at JSC.[3]

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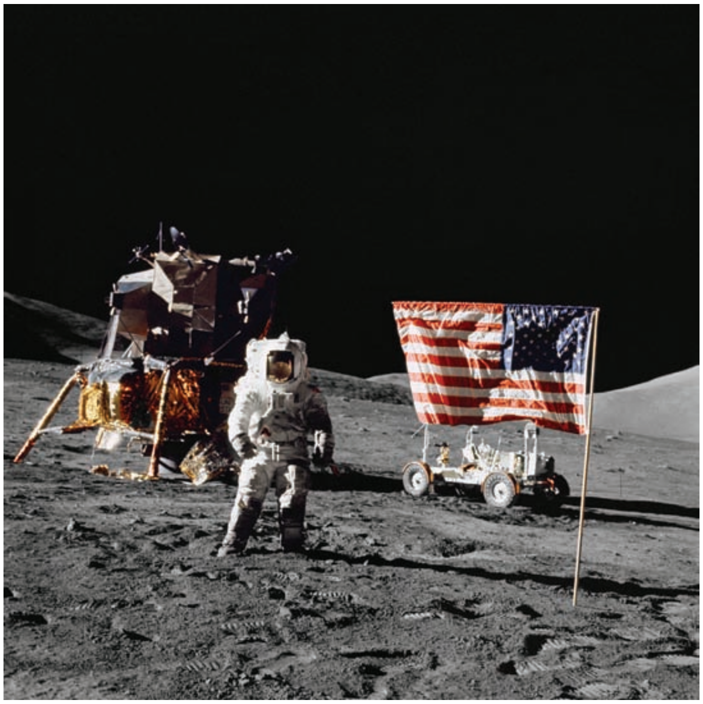
[3] http://lsda.jsc.nasa.gov/books/apollo/Resize-jpg/ts2c3-2.jpg

An Apollo astronaut explores the lunar surface. Image credit: NASA.



Through these and robotic missions (http://nssdc.gsfc.nasa.gov/planetary/lunar/apollo_25th.html) including the three Russian Luna sample return missions, NASA Lunar Prospector (http://lunar.arc.nasa.gov), and the upcoming Lunar Precursor and Robotic Program (http://lunar.gsfc.nasa.gov), scientists have and will continue to learn a great deal about how and when the Moon was formed, how it may have played an important role in the origin of life here on Earth, and the environment, including radiation, on and below the Moon's surface.

Future Lunar Colonization

Ask your students questions intended to prompt them into thinking about what biological requirements must be met for successful long-term human exploration of the Moon[4]. Consider what limitations the human body presents in such an endeavor. Start by asking: "If you had to prepare for future lunar colonization, what would you have to know and need to accomplish this task safely?" To establish a permanently inhabited lunar outpost, your team will need to understand how the space radiation environment affects living systems.

Exploring the surrounding lunar landscape (image above) and traveling to remote locations on the Moon may also be part of the activities lunar explorers will perform. Remind your students that there are unknowns about the proposed long-duration exploration of the Moon. Students will need to understand the hazards of solar and cosmic radiation, their impact on materials and the human body, the radiation environment on the surface of the Moon, and the amount of radiation to which astronauts can be exposed.

Another important concept for students to understand is space weather. Space weather refers to the conditions and processes occurring in space that have the potential to affect spacecraft or people in the space environment. Space weather processes include changes in the interplanetary magnetic field, coronal mass ejections, disturbances in Earth's magnetic field, and changes in the solar wind (energy that flows from the Sun in the form of particles like protons or electromagnetic radiation). Help is needed in deciding the best time to travel in space, and which materials should be used for the spacesuits, spacecraft, and habitation units on the Moons. To provide useful planning and launch date recommendations, students will also need to understand how the Sun's activity affects the radiation environment in the solar system.

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[4] http://quest.nasa.gov/lunar/outpostchallenge/index.html

Module 1: Radiation

What Is Radiation?

Radiation is a form of energy that is emitted or transmitted in the form of rays, electromagnetic waves, and/or particles. In some cases, radiation can be seen (visible light) or felt (infrared radiation), while other forms like x-rays and gamma rays are not visible and can only be observed directly or indirectly with special equipment. Although radiation can have negative effects both on biological and mechanical systems, it can also be carefully used to learn more about each of those systems.

The motion of electrically charged particles produces electromagnetic waves. These waves are also called "electromagnetic radiation" because they radiate from the electrically charged particles. They travel through empty space as well as through air and other substances. Scientists have observed that electromagnetic radiation has a dual "personality." Besides acting like waves, it acts like a stream of particles (called photons) that has no mass. The photons with the highest energy correspond to the shortest wavelengths and vice versa. The full range of wavelengths (and photon energies) is called the electromagnetic spectrum. The shorter the wavelength, the more energetic the radiation and the greater the potential for biological harm.

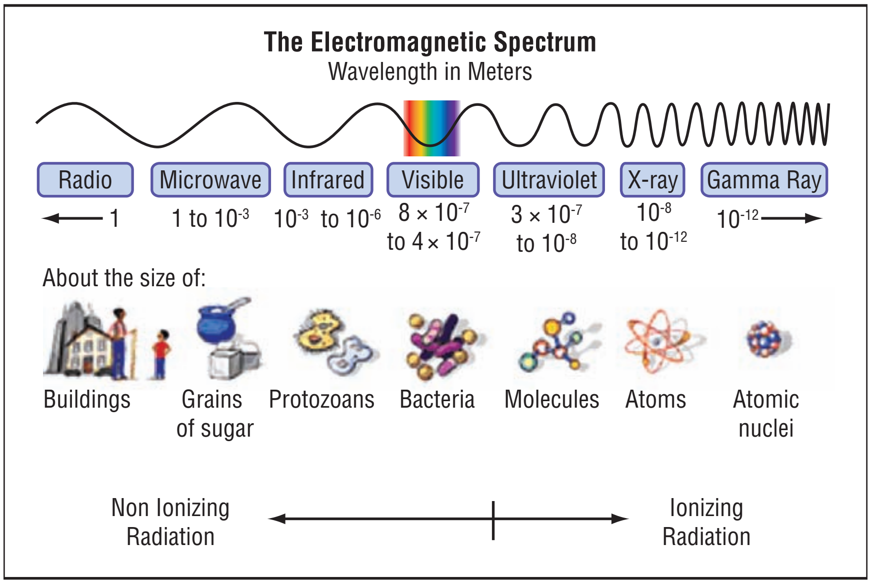


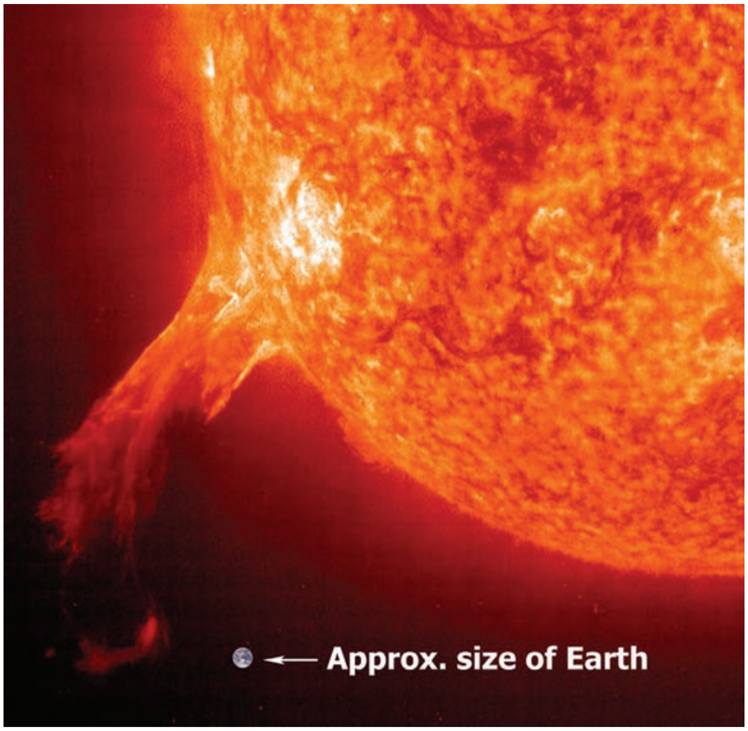
Image Credit: NASA.

On Earth we are protected from much of the electromagnetic radiation that comes from space by Earth's atmosphere and magnetic field. Most radiation does not reach the surface of the Earth except at limited wavelengths, such as the visible spectrum, radio waves, frequencies and some ultraviolet wavelengths, and some high-energy ionizing radiation. As we rise through the atmosphere, climb a high mountain, take a plane flight, or go to the ISS or to the Moon, we rapidly lose the protection of the atmosphere.

Where Does Radiation Come From?

In our daily lives we are exposed to electromagnetic radiation through the use of microwaves, cell phones, and diagnostic medical applications such as X-rays. In addition to human-created technologies that emit electromagnetic radiation such as radio transmitters, light bulbs, heaters, and gamma ray sterilizers (tools that kill microbes in fresh or packaged food), there are many naturally occurring sources of electromagnetic and ionizing radiation. These include radioactive elements in the Earth's crust, radiation trapped in Earth's magnetic field, stars, and other astrophysical objects like quasars or galactic centers.

Earth's biggest source of radiation is the Sun. The Sun emits all wavelengths in the electromagnetic spectrum. The majority is in the form of visible, infrared and ultraviolet radiation (UV). Occasionally, giant explosions called solar flares and Coronal Mass Ejections (CME) occur on the surface of the Sun and release massive amounts of energy out into space in the form of x-rays, Image credit: NASA.



gamma rays, and streams of protons and electrons called solar particle events (SPE).[5] A robotic spacecraft called the Solar and Heliospheric Observatory (SOHO) captured an erupting CME from the surface of the Sun in the image above[6]. Note the Earth inset at the approximate scale of the image. These CMEs can have serious consequences on astronauts and their equipment, even at locations that are far from the Sun.

What Are the Different Kinds of Radiation?

Radiation can be either non-ionizing (low energy) or ionizing (high energy). Ionizing radiation consists of particles or photons that have enough energy to ionize an atom or molecule by completely removing an electron from its orbit, thus creating a more positively charged atom. Less energetic non-ionizing radiation does not have enough energy to remove electrons from the material it traverses. Examples of ionizing radiation include alpha particles (helium atom nuclei moving at very high speeds), beta particles (high-speed electrons or positrons), gamma rays, x-rays, and galactic cosmic radiation (GCR). Examples of non-ionizing radiation include radio frequencies, microwaves, infrared, visible light, and ultraviolet light. While many forms of non-ionizing and ionizing radiation have become essential to our every-day life, each kind of radiation can cause damage to living and non-living objects, and precautions are necessary to prevent unnecessary risks.

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[5] http://solarscience.msfc.nasa.gov/CMEs.shtml

[6] http://www.nasa.gov/vision/universe/solarsystem/perfect_space_storm.html

Why Is Ionizing Radiation More Dangerous than Non-Ionizing Radiation?

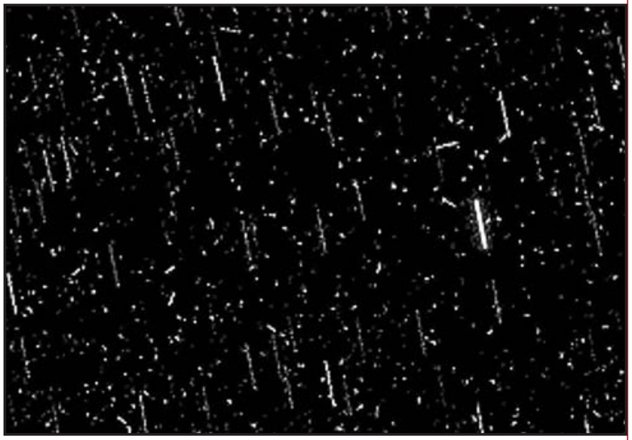
While non-ionizing radiation is damaging, it can easily be shielded out of an environment as is done for UV radiation. Ionizing radiation, however, is much more difficult to avoid. Ionizing radiation has the ability to move through substances and alter them as it passes through. When this happens, it ionizes (changes the charge of) the atoms in the surrounding material with which it interacts. Ionizing radiation is like an atomic-scale cannonball that blasts through material, leaving significant damage behind. More damage can also be created by secondary particles that are propelled into motion by the primary radiation particle. The particles associated with ionizing radiation are categorized into three main groups relating to the source of the radiation: trapped radiation belt particles (Van Allen Belts), cosmic rays, and solar flare particles.[7]

What is Galactic Cosmic Radiation?

Galactic Cosmic Radiation, or GCR, comes from outside the solar system but primarily from within our Milky Way galaxy. In general, GCR is composed of the nuclei of atoms that have had their surrounding electrons stripped away and are traveling at nearly the speed of light. Another way to think of GCR would be to imagine the nucleus of any element on the periodic table from hydrogen to uranium. Now imagine that same nucleus moving at an incredibly high speed. The high-speed nucleus you are imagining is GCR. These particles were probably accelerated within the last few million years by magnetic fields of supernova remnants (but not the supernova explosion itself). The giant expanding clouds of gas and magnetic fields that remain after a supernova can last for thousands of years.[8] During that time, cosmic rays are probably accelerated inside them. The action of the particles bouncing back and forth in the magnetic field of the supernova remnant randomly causes some of the particles to gain energy and become cosmic rays.[9] Eventually they build up enough speed that the remnant can no longer contain them and they escape into the galaxy. As they travel through the very thin gas of interstellar space, some of the GCR interacts with the gas and emits gamma rays. Detection of that reaction is how we know that GCR passes through the Milky Way and other galaxies.

The GCR permeates interplanetary space and is comprised of roughly 85% hydrogen (protons), 14% helium, and about 1% high-energy and highly charged ions called HZE particles. An HZE is a heavy ion having an atomic number greater than that of helium and having high kinetic energy. Examples of HZE particles include carbon, iron, or nickel nuclei (heavy ions). Though the HZE particles are less abundant, they possess significantly higher ionizing power, greater penetration power, and a greater potential for radiation-induced damage.[10] GCR is extremely damaging to materials and biology. In general, we are largely shielded from GCR on Earth because of our planet's atmosphere and magnetic field, whereas the Moon is not shielded from GCR because it lacks a global magnetic field and atmosphere.

In summary, GCR is heavy, high-energy ions of elements that have had all their electrons stripped away as they journeyed through the galaxy at nearly the speed of light. They can cause the ionization of atoms as they pass through matter and can pass practically unimpeded through a typical spacecraft or the skin of an astronaut. The GCR are a dominant source of radiation that must be dealt with aboard current spacecraft and future space missions within our solar system. Because these particles are affected by the Sun's magnetic field, their average intensity is highest during the period of minimum sunspots when the Sun's magnetic field is weakest and less able to deflect them. Also, because GCR is difficult to shield against and occurs on each space mission, it is often more hazardous than occasional solar particle events.[11] The picture at left shows GCR falling onto the surface of Mars. GCR appears as faint white dots, whereas stars appear as white streaks.



GCR appear as dots in this image. Image credit: NASA.

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[7] http://see.msfc.nasa.gov/ire/iretech.htm
[8] http://helios.gsfc.nasa.gov/gcr.html
[9] http://imagine.gsfc.nasa.gov/docs/science/know_l1/cosmic_rays.html
[10] http://hrp.jsc.nasa.gov/?viewFile=program/srp
[11] www.spaceflight.nasa.gov/spacenews/factsheets/pdfs/radiation.pdf

Are We Protected From Space Radiation on Earth?

Yes, but not entirely. Life on Earth is protected from the full impact of solar and cosmic radiation by the magnetic fields that surround the Earth and by the Earth's atmosphere. The Earth also has radiation belts caused by its magnetic field. The inner radiation belt or Van Allen Belt consists of ionizing radiation in the form of very energetic protons—by-products of collisions between GCR and atoms of Earth's atmosphere. The outer radiation belts contain ions and electrons of much lower energy. As we travel farther from Earth's protective shields we are exposed to the full radiation spectrum and its damaging effects.[12]

In addition to a protective atmosphere, we are also lucky that Earth has a magnetic field. It shields us from the full effects of the solar wind and GCR. Without this protection, Earth's biosphere might not exist as it does today, or would be at least limited to the subsurface. The small blue torus near the Earth in the image below[13] is the approximate location of the Van Allen Belts, where high-energy radiation is trapped.

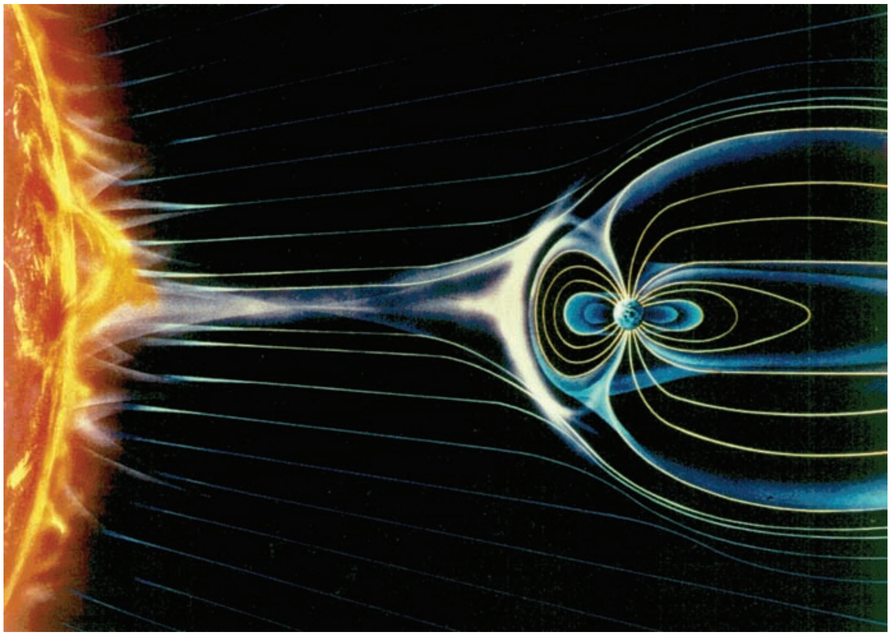

Image Credit: NASA.

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[12] http://www-istp.gsfc.nasa.gov/Education/Iradbelt.html

[13] http://science.msfc.nasa.gov/ssl/pad/solar/images/sunearth_lg.gif

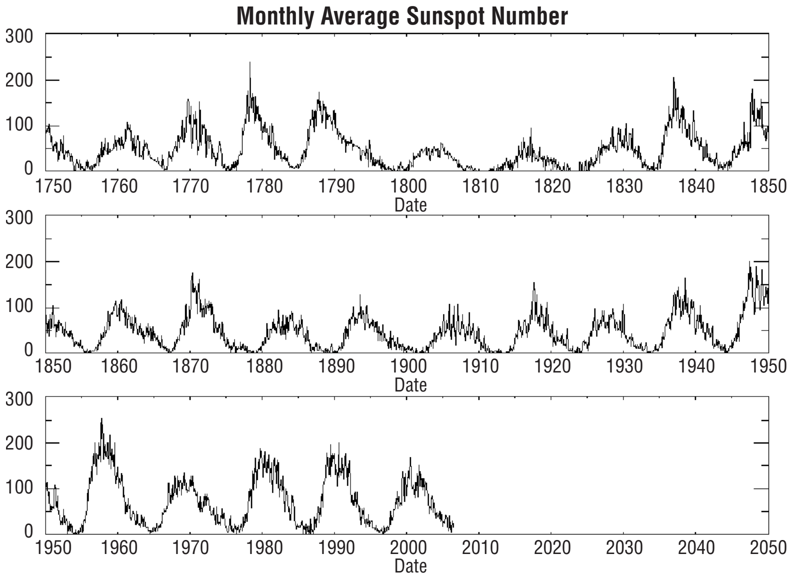
What Factors Determine the Amount of Radiation Astronauts Receive?

There are three main factors that determine the amount of radiation that astronauts receive. They include:[14]

- Altitude above the Earth—at higher altitudes the Earth's magnetic field is weaker, so there is less protection against ionizing particles, and spacecraft pass through the trapped radiation belts more often.
- Solar cycle—the Sun has an 11-year cycle, which culminates in a dramatic increase in the number and intensity of solar flares, especially during periods when there are numerous sunspots.
- Individual's susceptibility—researchers are still working to determine what makes one person more susceptible to the effects of space radiation than another person. This is an area of active investigation.

Does Space Weather Affect Astronauts?

Absolutely. Space weather is closely related to solar activity and this is important for astronauts traveling through space. Scientists have discovered that over an 11-year cycle the number of sunspots increase and decrease as shown below.[15] Interestingly, the Sun is slightly brighter when there are many sunspots. During one of these periods, the Sun is more actively producing SPE and CME so the amount of radiation in the solar system is slightly increased. The number of CMEs varies with the solar cycle, going from about one per day at solar minimum, up to two or three per day at solar maximum. Although scientists can predict that the Sun can produce more SPE and CME during this period, they are unable to determine specifically when SPE and CME will occur.



The sunspot cycle of the Sun. Image credit: NASA.

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[14] www.spaceflight.nasa.gov/spacenews/factsheets/pdfs/radiation.pdf

[15] http://solarscience.msfc.nasa.gov/images/zurich.gif

Because the levels of protection vary, the radiation environments vary between planets and moons, even at different places on the surface of individual planets. The ISS has well-shielded areas. In addition, astronauts and the ISS itself are largely protected by the Earth's magnetic field because it is in low Earth orbit. In contrast, during a deep space journey to the Moon (200,000 miles away) or Mars (35,000,000 miles away at closest approach), astronauts and their vehicles will venture far outside of the 30,000-mile radius of the Earth's protective magnetic shield. For any future long-duration deep-space exploration, radiation levels will be so high that specially designed storm shelters will be needed to protect astronauts from receiving deadly doses of radiation during high SPE/CME periods. For safe operations on the Moon or when traveling to Mars, a coordinated system of satellites will be needed to monitor space weather to help warn astronauts when it is necessary to go into their shelters.[16] This will be necessary because, although increases and decreases in overall solar activity can be fairly well predicted over an 11-year cycle, there are unexpected short-term events like solar flares, SPE, and CME that cannot be predicted, which would put a crew in great danger.

How Is Radiation Measured?

There are several properties of radiation that must be considered when measuring or quantifying radiation. These include the magnitude of radioactivity of the source, the energy of the radiation itself, the amount of radiation in the environment, and the amount of radiation energy that is absorbed. Collectively, these properties determine the nature of the radiation itself. It is very important to understand that equal doses of different kinds of radiation are not equally as damaging. To account for the difference, radiation dose is expressed as "dose equivalent." The following chart summarizes each parameter:

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 GigaBq (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 R = 2.58×10^{-4} C/kg air	electronvolts (eV)

*DE = Absorbed Dose × 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

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 the radiation damage in living organisms section for more detail).

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[16] http://marsprogram.jpl.nasa.gov/spotlight/odyssey-mission-success.html

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 Gray (Gy) of x-rays. 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.[17] The energy imparted is expressed in the unit 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.

Are There Radiation Exposure Limits?

Yes. The specific organ and career exposure limits are determined by one's age and gender. The typical average dose for a person is about 360 mrems per year, or 0.0036 Sv, which is a small dose. However, International Standards allow exposure to as much as 5,000 mrems (0.05 Sv) a year for those who work with and around radioactive material. For spaceflight, the limit is higher. The NASA limit for radiation exposure in low-Earth orbit is 0.50 Sv/year, or 50 rem/year. Note that the values are lower for younger astronauts. Since it is presumed that although they may live longer than older astronauts, exposure to larger amounts radiation early in their careers could present greater health risks during old age.

Career Exposure Limits for NASA Astronauts by Age and Gender*

Age (years)	25	35	45	55
Male	1.50 Sv	2.50 Sv	3.25 Sv	4.00 Sv
Female	1.00 Sv	1.75 Sv	2.50 Sv	3.00 Sv

* Please visit the website for more information on radiation exposure limits. [18]

The career depth equivalent dose limit is based upon a maximum 3% lifetime excess risk of cancer mortality. The total equivalent dose yielding this risk depends on gender and age at the start of radiation exposure. Assume that a younger person can be exposed to less radiation because they have more life to live, and therefore a longer chance to develop subsequent health problems. The following chart compares the specific exposure limits between the general public and astronauts. Astronauts who spend three months in the ISS will be subjected to over three times the maximum recommend dosage of radiation for one year.

Depth of Radiation Penetration and Exposure Limits for Astronauts and the General Public (in Sv)

	Exposure Interval	Blood Forming Organs (5 cm depth)	Eyes (0.3 cm depth)	Skin (0.01 cm depth)
Astronauts	30 Days	0.25	1.0	1.5
	Annual	0.50	2.0	3.0
	Career	1-4	4.0	6.0
General Public	Annual	0.001	0.015	0.05

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[17] 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.

[18] http://srag.jsc.nasa.gov/Publications/TM104782/techmemo.htm

The chart below compares and contrasts various missions and their durations with the observed radiation dose:

Mission Type	Radiation Dose
Space Shuttle Mission 41-C (8-day mission orbiting the Earth at 460 km)	5.59 mSv
Apollo 14 (9-day mission to the Moon)	11.4 mSv
Skylab 4 (87-day mission orbiting the Earth at 473 km)	178 mSv
ISS Mission (up to 6 months orbiting Earth at 353 km)	160 mSv
Estimated Mars mission (3 years)	1,200 mSv

Crews aboard the space station receive an average of 80 mSv for a six-month stay at solar maximum (the time period with the maximum number of sunspots and a maximum solar magnetic field to deflect the particles) and an average of 160 mSv for a six-month stay at solar minimum (the period with the minimum number of sunspots and a minimum solar magnetic field). Although the type of radiation is different, 1 mSv of space radiation is approximately equivalent to receiving three chest x-rays. On Earth, we receive an average of 2 mSv every year from background radiation alone.[19]

How Does the Radiation Environment on Earth Compare to the Radiation Environment on the Moon and Mars?

NASA has collected a variety of radiation and environmental data from the Moon and Mars. During the Lunar Prospector mission, NASA scientists discovered that there are some areas of the Moon that have a weak magnetic field. Magnetic fields have the ability to deflect small amounts of radiation. Locations with these fields are slightly more protected and might be candidate sites for bases on the Moon. Mars also has similar magnetic fields, though greater than those of the Moon. As shown in the right image, the strongest magnetic fields on the Moon are located at ≈20˚S, 170˚E and ≈43˚S, 170˚E. The Lunar Reconnaissance Orbiter will continue to measure magnetic fields on the Moon beginning in 2008.

The Moon and Mars are still extremely vulnerable to the effects of space radiation in spite of localized magnetic fields. They do not have global magnetic fields like those of Earth. As a result, their surfaces are not shielded from SPE that erupt from the surface of the Sun. In addition, the GCR that permeates interstellar space can freely bombard the surface of the Moon and Mars.

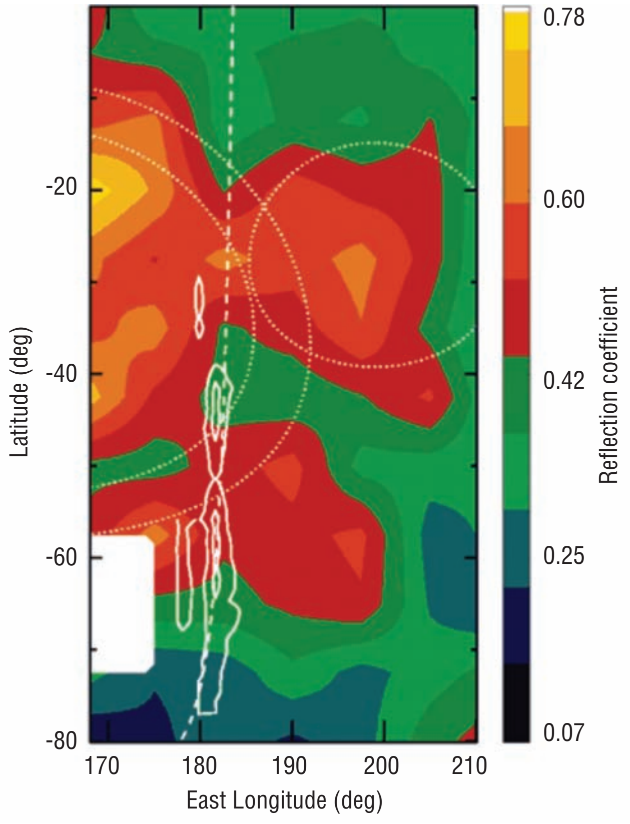

Image credit: NASA.

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[19] www.spaceflight.nasa.gov/spacenews/factsheets/pdfs/radiation.pdf

Finally, the Moon and Mars do not have dense atmospheres. Although Mars has an extremely thin atmosphere composed primarily of carbon dioxide, it is not thick enough to shield it from most cosmic radiation. The Moon essentially lacks an atmosphere altogether.

In order to minimize radiation exposure, people living on the Moon or Mars will need to limit the time they spend outside in their spacesuits and the distance they travel from their protective habitats. The total amount of radiation that astronauts receive will greatly depend upon solar activity, their location with respect to planetary magnetic fields, and the amount and type of radiation shielding used in habitats and spacecraft. Radiation exposure for astronauts aboard the ISS in Earth orbit is typically equivalent to an annualized rate of 20 to 40 rems (200 – 400 mSv).[20] The average dose-equivalent rate observed on a previous Space Shuttle mission was 3.9 µSv/hour, with the highest rate at 96 µSv/hour, which appeared to have occurred while the Shuttle was in the South Atlantic Anomaly region of Earth's magnetic field (1 Sv = 1,000 mSv = 1,000,000 µSv).[21]

For a six-month journey to Mars an astronaut would be exposed to roughly 300 mSv, or a total of 600 mSv for the round-trip. If we assume that the crew would spend 18 months on the surface while they wait for the planets to realign to make the journey back to Earth possible, they will be exposed to an additional 400 mSv, for a grand total exposure of about 1,000 mSv. Note that an astronaut repeating the same journey on multiple occasions could receive less or more radiation each time, depending if they are in the line of a CME or SPE.

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[20] http://hrp.jsc.nasa.gov/?viewFile=program/srp

[21] http://www.nasa.gov/mission_pages/station/science/experiments/BBND.html

Name: ________________________________ **Date:** ____________________

Pretest Activity: Ionizing, Non-Ionizing, or Both?

The following objects and medical procedures produce or use radiation. Your task is to classify items 1-16 as using or producing ionizing radiation, non-ionizing radiation, or both. Place an "✗" in the column that correctly identifies the type of radiation produced or used for each. Finally, circle the picture of those that emit particle radiation.

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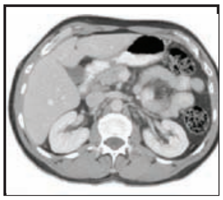

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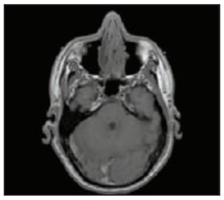

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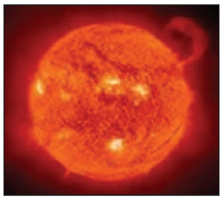

11.


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16.


Object or Medical Procedure	Type of Radiation Produced or Used		
	Ionizing	Non-Ionizing	Both
1. Cell phone			
2. Laptop computer			
3. Chest x-ray			
4. Abdomen CT scan*			
5. Remote Control			
6. Tanning Bed			
7. Skull MRI*			
8. Flat Panel Screen			
9. Television (tube type)			
10. Sun			
11. Microwave			
12. Supernova			
13. Dental x-ray machine			
14. Earth			
15. Ultrasound of a baby			
16. Atomic bomb			

*CT = Computed Tomography
*MRI = Magnetic Resonance Image

Name: ______________________________ **Date:** ____________________

Pretest Activity: Ionizing, Non-Ionizing, or Both? Answers

The following objects and medical procedures produce or use radiation. Your task is to classify items 1-16 as using or producing ionizing radiation, non-ionizing radiation, or both. Place an "✗" in the column that correctly identifies the type of radiation produced or used for each. Finally, circle the picture of those that emit particle radiation.

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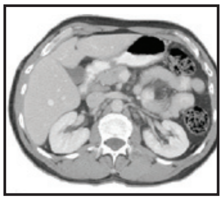

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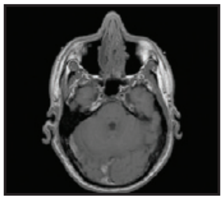

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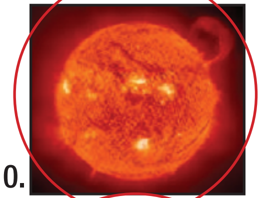

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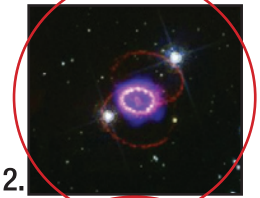

13.


14.


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16.

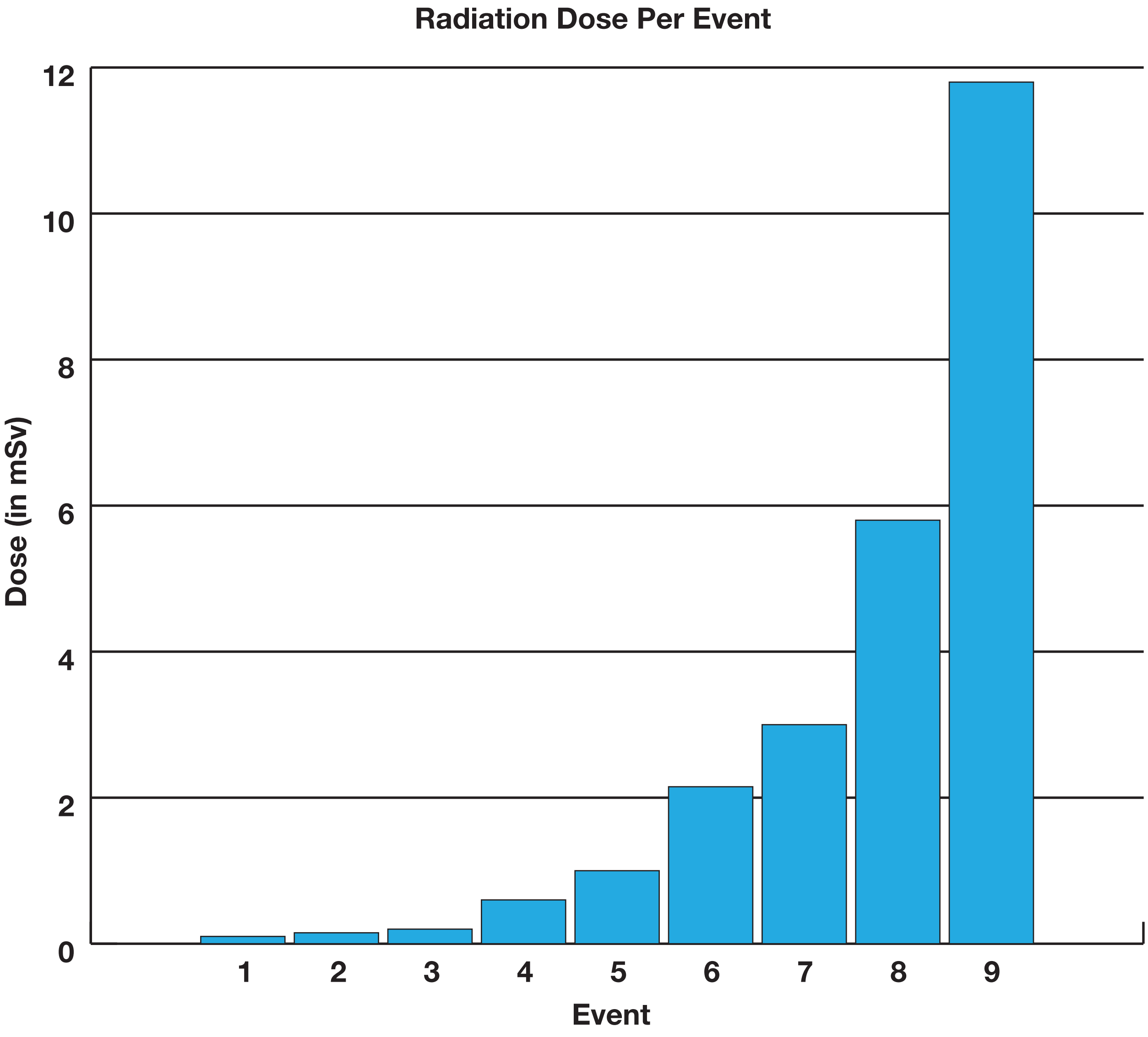

Object or Medical Procedure	Type of Radiation Produced or Used		
	Ionizing	Non-Ionizing	Both
1. Cell phone		✗	
2. Laptop computer		✗	
3. Chest x-ray	✗		
4. Abdomen CT scan*	✗		
5. Remote Control		✗	
6. Tanning Bed		✗	
7. Skull MRI*		✗	
8. Flat Panel Screen		✗	
9. Television (tube type)			✗
10. Sun			✗
11. Microwave		✗	
12. Supernova			✗
13. Dental x-ray machine	✗		
14. Earth			✗
15. Ultrasound of a baby		✗	
16. Atomic bomb			✗

*CT = Computed Tomography
*MRI = Magnetic Resonance Image

Name: ______________________________________ **Date:** _______________________

Pretest Activity: Matching Radiation Doses – Directions: The bars in the graph below compare nine different radiation doses received during events A through I. Your task is to write the correct letter of the event in the line below the bar that represents the radiation dose for that event. The letter choices of the events are:

(A) Nine days on the Moon
(B) One single CAT Scan of body
(C) One single chest x-ray
(D) Eight days on the Space Shuttle
(E) A single dental x-ray exposure to your arm, hand, foot or leg
(F) A single upper GI x-ray
(G) A single skull/neck x-ray
(H) A single pelvis/hip x-ray
(I) One year of normal radiation on Earth



Answers: _____ _____ _____ _____ _____ _____ _____ _____ _____

Name: ______________________________ **Date:** ____________________

Pretest Activity: Matching Radiation Doses–Answers: The bars in the graph below compare nine different radiation doses received during events A through I. Your task is to write the correct letter of the event in the line below the bar that represents the radiation dose for that event. The letter choices of the events are:

(A) Nine days on the Moon
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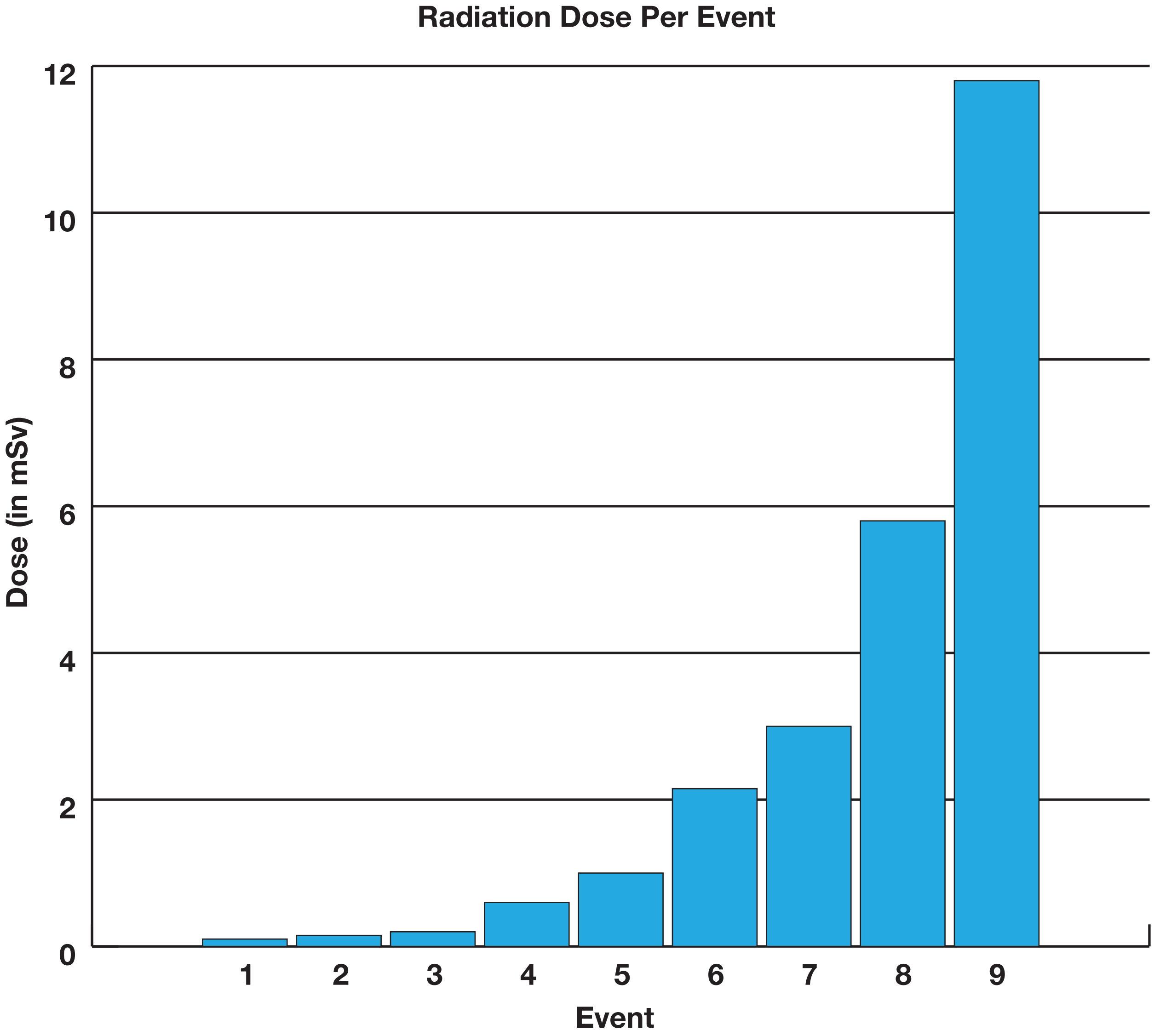
(F) A single upper GI x-ray
(G) A single skull/neck x-ray
(H) A single pelvis/hip x-ray
(I) One year of normal radiation on Earth



Answers: E C G H B F I D A

Activity Ia: Modeling Waves in the Electromagnetic Spectrum

In this activity you will use a spring-coiled toy to model electromagnetic radiation and measure the properties of the wave you create.

Objectives:

- Model waves in the electromagnetic spectrum.
- Classify types of electromagnetic energy by wavelength.
- Demonstrate the relationship between wavelength, frequency, and energy.

Research Question:

What kind of radiation strikes the surface of the Moon? How is it different from what is found on the surface of the Earth?

Discussion Questions:

- What happens to wavelength if you increase the frequency of the waves?
- How does the amount of energy in continuously generated high-frequency waves compare to low-frequency waves?

Materials

- Metal spring-coiled toy
- Meter stick
- Stopwatch

Directions:

1. Stretch a spring-coiled toy out over several meters between two people on a smooth, open floor.

2. Wave one end of the spring-coiled toy side to side to produce transverse waves that ripple toward the other person.

   (Note: if the spring-coiled toy is stretched very tight, the wave will reflect back to the source and will alter the speed of the wave; make sure you are producing waves that are uniform and alike.)

3. Measure and record the amount of time it takes one wave to travel from one person to the next and the distance between the two people. Use this information to calculate frequency in waves per second and the velocity of the wave. Use the diagram and formulas to help in your calculations.

4. Calculate wavelength and energy. After completing this for a wave of one frequency, alter the wavelength or frequency and make more calculations to observe how waves of different wavelengths or frequencies behave. Use the diagram and formulas to help in your calculations.

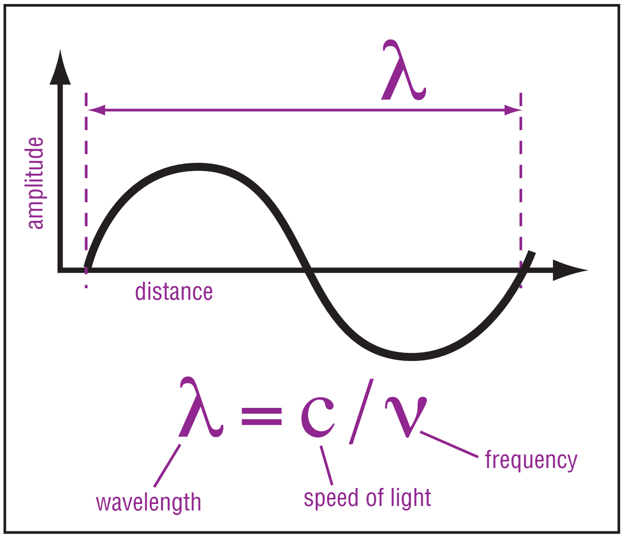


Image Credit: NASA.[22]

For electromagnetic waves, use the image to the left to help understand this equation:

$$\lambda = c / \nu$$

Wavelength (λ) [pronounced lambda] equals the speed of light (c) [300 million m/s in empty space] divided by the frequency (ν) [pronounced nu]

$$E = h \times \nu$$

Energy equals Planck's constant* (h) times the frequency
*Approximately 6.625×10^{-27}

For the waves generated with the spring-coiled toy:

$$V = \lambda \times f$$

Speed of the wave equals wavelength times the frequency of the wave

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[22] http://imagine.gsfc.nasa.gov/docs/science/know_l2/emspectrum.html

Activity Ib: The Cloud Chamber

In this activity[23] you will use a device called a cloud chamber to observe the footprints of radiation in a dense gas.

Objectives:

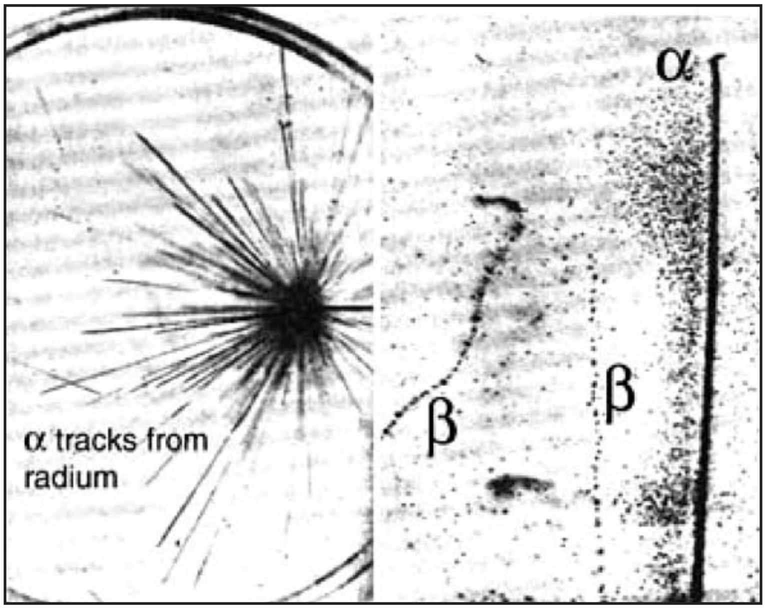
- Define and identify common examples of radiation.
- Distinguish between non-ionizing and ionizing radiation.
- Describe the differences between alpha (α), beta (β), and gamma (γ) particles.
- Determine what methods of protection are necessary for each type of radiation.

Research Question:

It is January 16, 2023; your team continues to develop recommendations for materials to be used for spacesuits and habitation units on the Moon. How much protection do we need from alpha, beta, and gamma radiation on Earth? On the Moon? In space?

Discussion Questions:

- Do you see radiation in the cloud chamber? Why or why not?
- What is happening to the radioactive source?
- How do things become less radioactive as time passes?



An alpha particle left a broad, straight path of definite length while an electron produced a light path with bends due to collisions. Gamma rays did not produce a visible track since they produce very few ions in air.
Image credit: www.nrc.gov.

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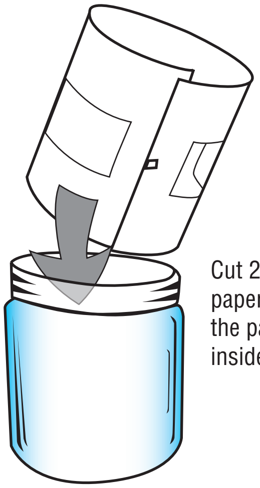
[23] http://www.nrc.gov/reading-rm/basic-ref/teachers/unit1.html#activity_1

Materials:

- small transparent container with transparent lid
- flat black spray paint
- blotter paper
- pure ethyl alcohol
- radioactive source
- masking tape
- dry ice and gloves or tongs for handling
- flashlight

Directions:

1. Paint the bottom of the container with black paint and let it dry. Cut the blotter paper into a strip about as wide as the height of the container. Cut two windows in the strip, as shown, and place it against the inside of the container.
2. Pour enough ethyl alcohol into the cloud chamber to cover the bottom of the container. The blotter paper will absorb most of it.
3. Place the radioactive source in the cloud chamber and seal the lid with tape.



Cut 2 "windows" in the paper strip and wrap the paper around the inside of the container.

Caution: Dry ice should be handled very carefully! It can burn unprotected skin.

4. Place the cloud chamber on the dry ice to super-chill it. Wait about five minutes. Darken the room. Shine the flashlight through the windows of the chamber while looking through the lid. You should see "puffs" and "trails" coming from the source. These are the "footprints" of radiation as it travels through the alcohol vapor. The vapor condenses as the radiation passes through. This is much like the vapor trail left by high-flying jets.

Each kind of particle will have a unique footprint:

- Alpha: sharp tracks about 1 cm long
- Beta: thin tracks 3 cm to 10 cm long
- Gamma: faint, twisting and spiraling tracks

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

References:

http://www.nrc.gov/reading-rm/basic-ref/teachers/unit1.html#activity_1

Activity Ic: Radiation Exposure on Earth

In this activity you will use the following worksheets to determine your average annual radiation dose here on Earth.

Objectives:

- Explain the differences between geomagnetically trapped particles, galactic cosmic rays, and solar particle events.
- Discuss the protection offered by Earth's atmosphere.
- Describe why a space weather forecast is important for people on Earth and in space.
- Determine your average annual radiation dose here on Earth.

Research Question:

It is February 22, 2023 and you are deciding the best launch dates for the voyage to the Moon. Your recommendation is needed for the best timeframe to travel to avoid peak solar activity. Use the space weather forecast data to determine several options.

Discussion Questions:

- What are some good examples of each source of cosmic radiation?
- How could you model the Earth's atmosphere to demonstrate its layers and thin nature?
- How have humans affected the atmosphere's ability to protect us from radiation?
- What spacecraft are important in forecasting space weather?
- How can you reduce the amount of radiation you are exposed to?

Materials:

Measuring Your Annual Radiation Dose worksheet

References:

The primary source for this information is the Environmental Protection Agency and the American Nuclear Society's brochure *Personal Radiation Dose*.

Radiation Exposure on Earth

Name: ________________________________ **Date:** ____________________

Directions: Estimate your annual radiation dose by adding together the amount of radiation you are exposed to from common sources of radiation. Place the value from the "Common Sources of Radiation" column (middle column) that corresponds to your situation in the "Annual Dose" column (right column). All values are in milliSieverts (mSv). Add all of the numbers in the right column to determine your total estimated annual radiation dose.

Factors	Common Sources of Radiation		Annual Dose
Where You Live	**Cosmic Radiation (from outer space)** Exposure depends on your elevation (how much atmosphere is above you to block radiation).		_________mSv
	Elevation (average cities' data from the United States Geological Survey website: http://www.usgs.gov)	**Value (mSv)**	
	Sea level (New York, Philadelphia, Houston, Baltimore, Boston, New Orleans, Jacksonville, Seattle)	0.26	
	1-1,000 feet (Chicago, Detroit, San Diego, Dallas, Minneapolis, St. Louis, Indianapolis, San Francisco, Memphis, Washington, DC, Milwaukee, Cleveland, Columbus, Atlanta)	0.28	
	1,001-2,000 feet (Phoenix, Pittsburgh, San Jose, Oklahoma City)	0.31	
	2,001-3,000 feet (Las Vegas, Los Angeles, Honolulu, Tucson)	0.35	
	3,001-4,000 feet (El Paso)	0.41	
	4,001-5,000 feet (Salt Lake City)	0.47	
	5,001-6,000 feet (Denver, Albuquerque)	0.52	
	6,001-7,000 feet	0.66	
	7,001-8,000 feet	0.79	
	8,001-9,000 feet	0.96	
	Terrestrial Radiation (from the ground) • If you live in a state that borders the Gulf of Mexico or Atlantic Ocean, add 0.16 mSv. • If you live in the Colorado Plateau area (around Denver), add 0.63 mSv. • If you live anywhere else in the continental U.S., add 0.30 mSv.		_________mSv
	House Construction • If you live in a stone, adobe, brick, or concrete building, add 0.07 mSv.		_________mSv
	Power Plants • If you live within 50 miles of a nuclear power plant, add 0.0001 mSv. (For locations of nuclear power plants, visit the United States Nuclear Regulatory Commision website: http://www.nrc.gov/info-finer/reactor) • If you live within 50 miles of a coal-fired power plant, add 0.0003 mSv.		_________mSv
Food **Water** **Air**	**Internal Radiation (average values)** • From food (most food has naturally occurring radioactive carbon-14 and potassium-40) and from water (radon dissolved in water). • From air (radon emanating from the ground).		______0.40/mSv ______2.00/mSv
Total	Add all the values for your annual radiation dose in the third column.		_________mSv

Factors	Common Sources of Radiation		Annual Dose
Total (page 1)	Transfer the total from the previous page onto this line.		__________mSv
How You Live	**Add the following values if they apply to you:**		
	Live near a weapons test fallout site	0.01 mSv	__________mSv
	Jet plane travel	0.005 mSv per hour in the air (total for all flights in one year)	__________mSv
	If you have porcelain crowns or false teeth	0.0007 mSv per tooth/crown (2 crowns = 0.0014 mSv)	__________mSv
	If you wear a luminous wrist-watch	0.0006 mSv	__________mSv
	If you watch TV	0.01 mSv	__________mSv
	If you use a computer screen	0.01 mSv	__________mSv
	If you have a smoke detector	0.00008 mSv	__________mSv
	If you use a gas camping lantern	0.002 mSv	__________mSv
	If you smoke	160.0 mSv	__________mSv
Medical Tests	**Medical diagnostic tests performed on you this year (per procedure)**		
	Extremity x-ray (arm, hand, foot, or leg)	0.01 mSv (if you had two x-rays, then = 0.02 mSv)	__________mSv
	Dental x-ray	0.01 mSv	__________mSv
	Chest x-ray	0.06 mSv	__________mSv
	Pelvis/hip x-ray	0.65 mSv	__________mSv
	Skull/neck x-ray	0.20 mSv	__________mSv
	Upper gastro-intestinal x-ray	2.45 mSv	__________mSv
	CAT scan (head and body)	1.1 mSv	__________mSv
	Nuclear medicine (e.g. thyroid scan)	0.14 mSv	__________mSv
Total Annual Dose	Add up all of the numbers in the third column of this page. This is your annual radiation dose on Earth.		__________mSv

Appendix 1: Additional Websites

Introduction and Module 1: Radiation

Jet Propulsion Laboratory: 2001 Mars Odyssey
http://mars.jpl.nasa.gov/odyssey/

Space Environment Center Space Weather
http://www.sec.noaa.gov/wwire.html

The Center for Science Education
http://cse.ssl.berkeley.edu/

Appendix 2: National Education Standards[24] Module 1

Module 1 Radiation:

Content Standards: K-12

Unifying Concepts and Processes
  Systems, order and organization

Content Standards: 9-12

Content Standard B:

Physical Science
  Conservation of energy and increase in disorder
  Structure of atoms

Content Standard D:

Earth and Space Science
  Energy in the Earth System

Content Standard F:

Science in personal and Social Perspectives
  Natural and human-induced hazards

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[24] http://lab.nap.edu/html/nses/6a.html

Space Faring:
The Radiation Challenge
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Please take a moment to respond to the statements and questions below. You can submit your response through the Internet or by mail. Send your reply to the following Internet address:

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.

Otherwise, please return the reply card by mail. Thank you.

1. With what grades did you use the educator guide?
Number of Teachers/Faculty:
______ K-4 ______ 5-8 ______ 9-12 ______ Community College
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? –

3. This is a valuable educator guide?

☐ Strongly Agree ☐ Agree ☐ Neutral ☐ Disagree ☐ Strongly Disagree

4. The information provided in the product is relevant to my role in education.

☐ Strongly Agree ☐ Agree ☐ Neutral ☐ Disagree ☐ Strongly Disagree

Fold along line and tape closed.

5. How would you rate the effectiveness of the product in teaching the intended standards.

☐ Excellent ☐ Good ☐ Average ☐ Poor ☐ Very Poor

6. How did you use this educator guide?

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☐ Group Discussions
☐ Integration Into Existing Curricula
☐ Lecture
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☐ Demonstration
☐ Hands-On Activities
☐ Interdisciplinary Activity
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☐ Other: Please specify: ☐

7. Where did you learn about this educator guide?

☐ NASA Educator Resource Center
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☐ Workshop/Conference
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☐

9. How can we make this educator guide more effective for you?

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