Dangers of Radiation Exposure

Lesson Overview

Lesson Summary

Radiation can affect living and mechanical things on Earth as well as in space. In the first part of the lesson, students calculate their yearly exposure rate to harmful high-energy radiation and cumulative effects over time, and use the information to evaluate the various sources of radiation that are of greatest concern for them. In the second part of the lesson, students learn that spacecraft and other objects in space must be concerned with the same kinds of radiation that humans are exposed to. The MESSENGER spacecraft will orbit Mercury and be subjected to much more intense solar radiation than it would near Earth. Students discuss the notion that even though some of the radiation is needed to study the properties of the planet, too much of it can be quite damaging.

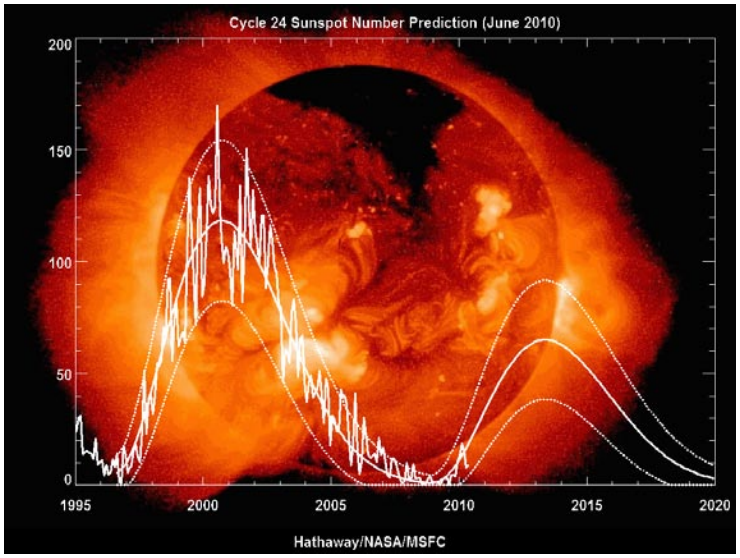


Figure 1. Solar activity cycle as followed by the number of sunspots on the surface of the Sun. The 11-year cycle has major effects on the radiation environment on Earth as well as for spacecraft venturing into the inner Solar System, such as the MESSENGER mission to Mercury.

Picture credit: solarscience.msfc.nasa.gov/images/ssn_predict_l.gif

Grade Level
9 - 12

Duration
About 1 hour

Essential Question
What sources of high-energy radiation do we need to be concerned with in our daily lives?

Lesson 2 of
Grades 9-12 Component
of *Staying Cool*

Objectives

Students will be able to:

- Calculate their annual exposure to high-energy radiation.
- Identify sources of high-energy radiation with which they may come into contact.
- Explain why the high-energy environment near Mercury is a concern for the MESSENGER mission.

This lesson was developed by the National Center for Earth and Space Science Education (http://ncesse.org).

Concepts

- Radiation is a process of emitting energy in the form of particles or waves.
- Ionizing (high-energy) radiation is particularly dangerous because it can cause severe damage to humans. In sufficiently high doses, radiation can cause sickness and death.
- Most of the high-energy radiation to which humans are exposed comes from natural sources.
- Spacecraft need radiation of various kinds to observe objects in space but too much radiation can be a hazard.
- Understanding the causes and seriousness of risks can help engineers and scientists to reduce the likelihood of severe problems.

MESSENGER Mission Connection

MESSENGER will use radiation of various kinds to study the planet Mercury and its space environment. However, since Mercury receives more than 20 times the amount of radiation from the Sun that we receive on the surface of Earth, exposure to too much radiation is a concern for the mission.

Standards & Benchmarks

National Science Education Standards

Standard F5 Natural and human-induced hazards

- Human activities can enhance potential for hazards. Acquisition of resources, urban growth, and waste disposal can accelerate rates of natural change.
- 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.

American Association for the Advancement of Science, Project 2061

Benchmark 10G5 Radioactivity has many uses other than generating energy, including in medicine, industry, and scientific research in many different fields.

Benchmark 1C6 Scientists can bring information, insights, and analytical skills to bear on matters of public concern. Acting in their area of expertise, scientists can help people understand the likely causes of events and estimate their possible effects…

Science Overview

Radiation comes across as something mysterious. We cannot feel it, hear it, smell it, and apart from visible light, even see it, but it can be useful in our lives or cause us harm. On Earth, in our daily routine, radiation is not a great concern (barring exceptional circumstances, such as a nuclear power plant accident). However, once we travel into space, radiation can be a significant problem, because the atmosphere—the air that we breathe—which normally blocks out most of the harmful cosmic radiation arriving on Earth, is no longer present to protect us. Without the shielding atmosphere, cosmic radiation could reach the Earth's surface unimpeded. Some scientists claim that under such conditions, life might never have evolved here.

What Is Electromagnetic Radiation?

Weather forecasters often show temperature maps of the United States based on the temperature measurements in different parts of the country that day. The maps are created by assigning each temperature a color, and then filling the map with colors corresponding to the temperatures measured at each location. A map created this way shows the temperature field of the United States on that particular day. The temperature field covering the United States, in this sense, is a description of the temperatures at every location across the country.

In a similar fashion, the Universe can be thought of as being permeated by an electric field. All electrically charged particles (such as electrons) have a region of space around them where they influence the behavior of other charged particles wandering there. This region can be described as an electric field around the particle. Just as temperatures in different parts of the country create the temperature field of the United States, the electric charges in the Universe can be thought of as creating an electric field permeating the whole Universe. Magnetic objects behave in a similar fashion: every magnetic object creates a magnetic field around it, and their collective magnetic field

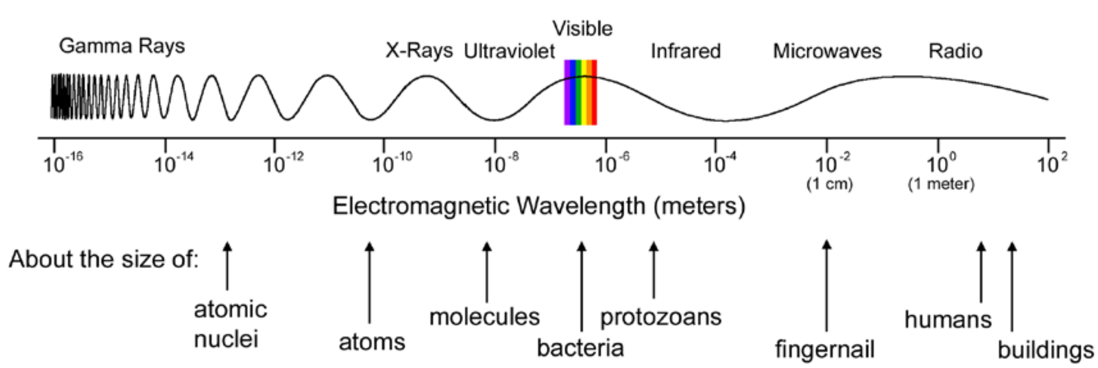


Figure 2. The electromagnetic spectrum. In the picture, different parts of the spectrum are shown as one continuous wave. In reality, a given electromagnetic wave has one particular wavelength. The continuous wave in the picture above is used to better illustrate the difference between wavelengths from one part of the spectrum to another.

permeates the Universe.

Most things in the Universe tend to move around, and electric charges are rarely an exception. If the velocity of an electric charge changes (that is, it accelerates or decelerates), it creates a disturbance in the electric and magnetic fields permeating the Universe. These disturbances move across the Universe as waves in the "fabric" of the electric and magnetic fields. The waves also carry energy from the disturbance with them, in a similar way that the energy of the wind striking a flag is carried across the fabric by the waving of the flag. The waves carrying the energy of the disturbance across the Universe are characterized by their wavelength, which measures the distance between two consecutive wave crests.

A familiar example of this kind of wave is visible light. Different colors of visible light have slightly different wavelengths, and there are waves which have much higher and shorter wavelengths than the light that humans can see. Together, the waves of all different wavelengths are called electromagnetic radiation, and the whole array of different kinds of light, arranged according to their wavelength, is called the electromagnetic spectrum (see Figure 2). Electromagnetic radiation travels at the speed of light (300,000 km/s or 186,000 miles/s in a vacuum such as space).

The complete electromagnetic spectrum includes, from low to high energy:

- Radio: Used for transmitting radio and television (includes microwaves).
- Infrared: Seen by many animals (not humans), also used in night vision goggles.
- Visible light: The portion of the spectrum that humans can see.
- Ultraviolet (UV): Causes sunburns.
- X-rays: Used in hospitals to make internal images of the human body.
- Gamma rays: Used in the radiation treatment of cancer.

The effect of radiation on matter depends on how much energy it carries. For example, radio waves have low energy and are fairly harmless. On the other hand, high-energy radiation, as discussed more fully below, can be harmful to matter, particularly living organisms.

The lower-energy parts of the electromagnetic spectrum (ultraviolet to radio waves) are not as dangerous as high-energy radiation but can still be harmful. For example, sunburn is caused by too much exposure to the Sun's ultraviolet radiation, and it is possible that low-frequency radio and microwave radiation from cell phones could be a health concern, though the current data suggests that it is not a significant concern. Note that there is a popular misconception that cell phones (as well as microwave ovens) can cause cancer; this is wrong. The energy of the microwaves and low-frequency radio waves emitted by the cell phones is not sufficient to create the effects by which radiation can cause cancer.

What Is Radiation?

Electromagnetic radiation is one of many different kinds of radiation that exist in nature. Radiation in general can be defined as the process of emitting energy. There are two basic carriers of this energy:

- Particles: E.g., high-energy protons, neutrons, electrons, atoms, and ions (which are atoms that have lost or gained electrons, resulting in an electric charge).
- Waves: E.g., light and sound.

That is, the energy can be carried from one place to another in the form of particles or waves. A form of radiation with which all of us are familiar is sunlight.

What Is Ionizing Radiation?

An especially damaging form of radiation is "ionizing radiation," which can create electrically-charged ions in the material it strikes. This ionization process can break apart atoms and molecules, causing severe 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 (i.e., causing mutations—hereditary mutations are extremely rare, however). The most significant forms of ionizing radiation are:

- X-rays and gamma rays: High-energy parts of electromagnetic spectrum.
- Alpha particles: Atomic nuclei consisting of two protons and two neutrons.
- Beta particles: Fast-moving electrons ejected from the nuclei of atoms.
- Cosmic radiation: Energetic particles arriving at Earth from outer space.
- Neutrons: Produced mainly in nuclear power plants.

As the list indicates, ionizing radiation can be either waves (X-rays, gamma rays) or particles (alpha and beta particles, neutrons and cosmic radiation).

In newspapers and public discussions, ionizing radiation often is just called "radiation." This may cause us to forget that both low-energy and high-energy forms of radiation are processes of transmitting energy, and that they have a very different impact on the materials they encounter. In addition, sometimes even radioactive elements are called "radiation" in the media, further confusing the situation. When seeing or hearing the term "radiation," it is always good to determine exactly what is being discussed.

Atomic Sources of Radiation

Radiation is created by changes in the state of an atom. For example, the disturbances in the electric and magnetic fields permeating the Universe arise from the vibration of atoms (at high temperatures) or excitation of electrons (at lower temperatures). Gamma rays are produced when the nucleus of the atom changes state.

Much ionizing radiation comes from radioactive elements, when "unstable" or "radioactive" atoms change to a completely new atom. During this spontaneous change to a more stable form (radioactive decay), some of the excess energy of the atom is released as radiation. One way to describe the radioactivity of an element is its half-life, which is the time it takes for half of the atoms of a radioactive substance to decay. Half-lives can range from less than a millionth of a second to millions of years.

Cosmic radiation comes from many sources, both inside and outside the Solar System, and even from outside the Milky Way galaxy. Many, but not all, of the processes that create cosmic rays are at least roughly understood.

How Do We Measure Radiation?

While we cannot see ionizing radiation or directly feel whether an item is radioactive, we can use a variety of instruments that detect and measure radiation levels accurately. The basic unit used to measure exposure to ionizing radiation is a sievert (Sv). It measures the biological effect of absorbed radiation (referred to as an "effective dose"). Most often, radiation exposure is expressed in millisieverts (mSv), one thousandth of a sievert, or in microsieverts (μSv), one millionth of a sievert. An older, non-Standard-Internationale (SI) but still often-used unit of exposure is a rem. One sievert is one hundred times larger than one rem; that is, 1 Sv = 100 rem.

Where Does Ionizing Radiation Come From?

On the surface of Earth, there are several natural sources of ionizing radiation. The most important of these is radon, a gas formed by the radioactive decay of naturally occurring uranium in rock, soil, and water. Once formed, some radon gas seeps through the ground into the air we breathe, while some remains below the surface and dissolves in underground deposits of water. These kinds of radiation from natural sources are commonly referred to as "background radiation." Naturally-occurring background radiation levels are typically between 1.5 and 3.5 mSv per year, though levels more than ten times higher have been measured in parts of Brazil, China, Europe, India, Iran and Sudan.

Ionizing radiation is also produced in a variety of human activities. A familiar example is a nuclear power plant, where radiation is created as a by-product of electricity generation. In other facilities, large doses of radiation are used to kill cancerous cells in our bodies or harmful bacteria in food, and to sterilize medical equipment.

It is a common misconception that most harmful radiation to humans comes from human activities. Typically, about 88% of the ionizing radiation exposure to humans comes from natural sources; most of the remaining 12% comes from 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.

Once we go up into space and leave the protection of the Earth's atmosphere behind, radiation becomes a significant problem. Of most concern to both humans and equipment are different types of particle radiation from sources such as:

- Trapped particle radiation regions near the Earth (the Van Allen belts).
- Solar energetic particles, which are high-energy particles emitted by the Sun.
- Galactic cosmic rays, which are high-energy particles created outside the Solar System by stellar flares, nova and supernova explosions, and quasars.

How Does Radiation Cause Damage to Humans?

We are exposed to different forms of radiation every day. Radiation only becomes a problem if we are exposed to too much of it. A familiar example is ultraviolet radiation from the Sun here on Earth; over-exposure to it may cause eye and skin damage, and in the worst case, lead to cataracts, glaucoma, or skin cancer.

Ionizing radiation can be very harmful, which is why it is useful in killing cancer cells as long as it is carefully directed so that its effect on healthy tissue is minimal. Large doses of ionizing radiation on healthy tissue can result in cancer after a delay of a few years. At very high levels, high-energy radiation can cause sickness and death within weeks of exposure. By creating changes in the DNA, ionizing radiation can also cause genetic mutations that could affect future generations, but in fact a person exposed to levels of radiation sufficiently high to cause mutations is more likely to die from the radiation exposure than pass the mutations to his/her offspring.

The level of damage caused by radiation depends on many factors such as the dose, the type of radiation, the part of the body exposed, and the age of the exposed person. Embryos are particularly sensitive to radiation damage. For the health concerns raised by different doses of ionizing radiation, see the table on Student Worksheet 2.

There is a common misconception that people exposed to high-energy radiation (especially radioactive material) become radioactive themselves. However, in reality, ionizing radiation usually does not cause the exposed body to become radioactive beyond its natural level; it just causes damage to the living tissue. The exception to this is a very high dose of high-energy neutron radiation, which can cause the material it strikes to become radioactive. However, this is a very rare occurrence for living things, and only tends to happen to nuclear power plant generators and other related equipment over long periods of time.

The level of exposure to radiation during nuclear bomb blasts and nuclear power plant accidents also depends on the distance. For example, most people killed in Hiroshima died from the immediate blast and not from radiation, and people farther away experienced a short-term dose of about 200 mSv. During the 1986 Chernobyl nuclear power plant accident in the former Soviet Union (present Ukraine), most fatalities came from the fire fighters and workers inside the power plant (their doses were well over the 10,000 mSv level), while people downwind were exposed to smaller doses that are expected eventually to cause a total of about 24,000 deaths from cancer.

The most effective ways to protect against radiation are to limit exposure time, increase the distance from the source, or use shielding. The effectiveness of shielding material depends largely on the density of the material—dense materials generally are more capable of blocking all kinds of radiation than low-density materials.

Much ionizing space radiation is stopped by Earth's atmosphere, as well as by Earth's magnetic fields. Once above the thick atmosphere, though, astronauts are exposed to much higher radiation levels. The research into understanding the effect of space radiation on people is still in its early stages. For example, an experiment aboard the International Space Station (ISS) Expedition Two in 2001 used a test dummy called Fred, which was designed to mimic some of the characteristics of a real human even though it was built of artificial materials. Fred was placed on the station for four months to measure the radiation dose rate on human tissue. The results from these kind of experiments will help us achieve a much better understanding of the effects of space radiation on humans.

MESSENGER and High-Energy Radiation

Much of the radiation that spacecraft encounter in space is actually beneficial for the mission. For example, the instruments aboard the MESSENGER mission to Mercury will be making observations in various parts of the electromagnetic spectrum, from gamma rays to radio waves; they will also make observations of the high-energy particle radiation near Mercury. This will help us get a better understanding of the space environment near the planet. High-energy radiation is also used to help determine whether water ice exists in permanently shadowed craters near the planet's poles.

Just as for people on Earth, radiation becomes a concern only if the spacecraft is exposed to too much of it. Fortunately, spacecraft can be specially built to survive much higher doses of radiation than humans can handle. It is not possible to specially build humans this way!

Based on the properties of high-energy radiation in different parts of the Solar System, ionizing radiation levels encountered by the MESSENGER spacecraft are expected to be 3-10 times higher than what a spacecraft near Earth or in interplanetary missions away from the Sun usually experience. Therefore, high-energy radiation is a concern for the mission. On the other hand, the levels are thought to be about 30 times less than what a spacecraft encounters near Jupiter, which has a particularly harsh radiation environment.

Of greatest concern for the MESSENGER mission are solar energetic particles, which are created in solar flares; big explosions in the Sun's atmosphere. Their amount is controlled by an 11-year solar activity cycle, which goes from about four years of solar activity minimum to roughly seven years of solar activity maximum. The current cycle (number 23), began in early 1997, and reached maximum in late 2000. The cycle's progression can be followed by observing changes in the number of sunspots visible on the Sun's surface (see Figure 1).

MESSENGER's journey to Mercury will take place during solar activity minimum years, when the typical dose is only 1% of that during the maximum years. However, during the time that the spacecraft will orbit the planet (2011-2012), Sun's activity will be near maximum. Therefore, MESSENGER will experience large changes in the radiation environment during its operation.

Possible radiation effects on the MESSENGER spacecraft are: Damage to the electronics including computer memory, decreased power production by the solar cells, and interference with the onboard instruments. These dangers can be reduced by effective shielding. The overall spacecraft structure offers some protection, and critical electronic components are radiation-hardened. Redundancy and the use of radiation-resistant materials also reduce the probability of major problems.

Lesson Plan: Calculating yearly exposure to ionization radiation

Students calculate their exposure to ionizing radiation during the previous year. They are given a list (in Student Worksheet 1) of various types and the amount of ionizing radiation they may experience throughout the year. They are asked to estimate their exposure and discuss their results. This will help them determine whether high-energy radiation is something they should be concerned with in their daily lives.

Materials

Per student:

- Optional: Calculator

Per class:

- A chart of the entire electromagnetic spectrum
- Optional: 1 tube of glitter; about a handful is needed (only if Additional Warm-up is used)
- Optional: a Geiger Counter or dosimeters

Preparation

- Find out the elevation of your area, and where the nearest nuclear and coal fire power plants are located (to help fill out Student Worksheet 1). You can find the elevation of the 50 largest cities in the United States at http://mac.usgs.gov/mac/isb/pubs/booklets/elvadist/elvadist.html. You can also find the nearest nuclear plant at http://www.nei.org/doc.asp?catnum=2&catid=93.

  For the nearest coal fire power plants, consult your state listings.
- Make one copy of each student worksheet per student.
- (If using the Additional (optional) Warm-up) Before students enter the room, sprinkle glitter on the students' desks.

Additional Warm-up & Pre-assessment (optional)

Using Glitter: (Don't spend too much time on this part of an hour-long lesson; it's just a warm-up! You can also skip this warm-up altogether.)

1. Tell the students that you have poured some glitter on their desks. Ask them to imagine that the glitter is some kind of radioactive material (and assure them it is not). See how students react, and ask whether they would mind having radioactive material on their desks. Why or why not?
2. Ask students to pick up a little bit of glitter on their hand. Have them take some more, and again. Ask them if they think that they are exposed to any more radiation when they hold more of the "radioactive" glitter material in their hand.

3. Ask students what they think would happen to their exposure if they held the "radioactive" glitter in their hands for five minutes? Ten? Would their exposure rate and total exposure to the radioactive material increase or stay the same? Why? What if they were exposed 10 times or 100 times as long? What if they were exposed to the substance for a while and then washed it off? (Exposure rate is defined as the amount of radiation energy that reaches an object's surface in a given time period.)

4. Tell the students to imagine that the vial holding the glitter is actually a container for more of the radioactive substance. Ask, "If the container were closed, would the classroom be protected from the radiation from the substance, even if no more of it were spread by touching?" and, if not, "What kind of a container would we need?" This discussion should be used for stressing the point that radiation can spread invisibly through the air from a radioactive substance even if we do not touch it.

Teaching Tip

Some students may also wonder how you could get hold of a radioactive substance in the first place, and this can later serve as a launching point for the follow-up discussion regarding the storage of radioactive material. While there are very few known incidents at this time, there is much concern about the black market illegal sale of radioactive material, especially from the former Soviet republics. Of more immediate concern may be the sometimes poorly supervised and unsafe handling of legally-acquired radioactive materials.

5. Compare your touching of the objects once, twice, or three times to an "exposure rate." Have students hypothesize as to the ramifications of a higher exposure rate on people and objects over a short or long time.

Warm-up & Pre-assessment

1. Tell the students that the topic of today's lesson is radiation. Explain that they probably are familiar with at least some forms of electromagnetic radiation, and review the electromagnetic spectrum with them using a chart. Point out familiar uses based on different parts of the spectrum (such as radio and TV signals, microwave and cell phones, infrared remote controls, visible light, X-rays, etc.).

2. Ask the students to place their hand on top of their desk or table. Ask them "Does the table feel cool?" Explain that the table feels cool because the atoms and molecules in their hand are vibrating faster than the atoms and molecules in the table. Ask them whether the table is getting warmer when they hold their hand against it. Explain that this is because the heat from their hand is being transferred to the table.

3. Ask them why the air above a lit stovetop feels hot. (Answer: Because the atoms and molecules of the air vibrate faster than the ones in their hand.)

4. Explain that the more energy something has, the more it vibrates. If you make the atoms vibrate extremely fast, they may "break." In this case, electrons may break from the atoms and ionize them. This kind of damage is very harmful, if a large number of molecules within the body become ionized all at once. Radiation with very high energy is called ionizing radiation for this reason. Of all the forms of radiation, the ionizing kind is of the greatest health concern, because it can cause immediate damage and also long-term effects such as cancers and changes in DNA. Ionizing radiation will be the topic for the rest of the lesson.

Procedures

1. Make a 4-column-chart on the board as below. Ask students to identify different types of radiation. List answers in the left column. As students call out answers, place them in order from longer to shorter wavelengths on the chart (i.e. radio waves, microwaves, infrared radiation, visible light, ultraviolet, X-rays, gamma rays). See if they can identify the radiation sources and possible uses (there may be more than one for each type). Finally, discuss whether or not each particular kind of radiation is harmful to humans.

Types of Radiation	Sources of Radiation	Use of Radiation	Is it harmful to humans?

Explain that radiation is a way of transmitting energy from one place to another. Visible light is one form of radiation and just part of the electromagnetic spectrum. The amount of energy carried by radiation determines whether it is harmful or not—high-energy forms (called ionizing radiation) are especially damaging. Explain how ionizing radiation differs from other kinds of radiation, and how ionizing radiation can be both harmful and beneficial to humans. There are sources of low-energy radiation that we use daily (such as microwave ovens and cell phones), but their health risks seem not that great a concern based on current research. [Note that some of this discussion may have been covered during the warm-up.]

SAMPLE TABLE

Types of Radiation	Sources of Radiation	Use of Radiation	Is it harmful to humans?
Radio Waves	Radio and TV transmitters	Send radio & TV signals to receivers	No
	Cell phones	Telecommunications	Not certain
	Sun & astronomical objects	Detect properties of the Sun and other astronomical objects	No
Microwaves	Microwave appliances	Cook and heat food	Not in typical amounts if operating normally
Infrared Light	Sun & astronomical objects	Detect properties of the Sun and other astronomical objects	No
	All warm objects	Use heat to detect objects	No
Visible Light	Remote controls	Operate machines from a distance	No
	Light bulbs	See objects	Usually not, but severe eye damage if too intense
Ultraviolet	Sun & astronomical objects	Detect properties of the Sun and other astronomical objects	Usually not, but severe eye damage if too intense
	Black lights	Entertainment lighting, detect chemical "markers" on money and manufactured products	Not in typical amounts
X-Rays	Sun & astronomical objects	Detect properties of the Sun and other astronomical objects	In large amounts from the Sun (skin cancer)
	Medical and industrial X-ray equipment	X-ray imaging and cancer treatments	Yes; radiation must be carefully controlled and directed to avoid damaging healthy tissue
		Food irradiation to eliminate bacteria	No (food does not become radioactive)
	Sun & astronomical objects	Detect properties of the Sun and other astronomical objects	Yes (but blocked by Earth's atmosphere)
	TV & computer screens	By-product of the screen, no practical use	Not in typical amounts

Types of Radiation	Sources of Radiation	Use of Radiation	Is it harmful to humans?
Gamma Rays	Decay of radioactive elements	Food irradiation to eliminate bacteria	No (food does not become radioactive)
		By-product of nuclear power plants, no practical use	In typical amounts, no; in large amounts, yes
	Sun & astronomical objects	Detect properties of the Sun and other astronomical objects	Yes (but blocked by Earth's atmosphere)
Particle radiation (alpha & beta particles, protons, ions)	Decay of radioactive elements	Cancer treatments	Yes; radiation must be carefully controlled and directed to avoid damaging healthy tissue
	Radon gas	Naturally-occurring, no practical use	In typical amounts, no; in large amounts, yes
	Sun & astronomical objects	Detect properties of the Sun and other astronomical objects	Yes (but mostly blocked by Earth's atmosphere)
	Smoke detectors	Detect fine particles in the air	Not under normal circumstances

Note that there are entries in the sample table above that can be sources of misconceptions. For example, people sometimes think that irradiating food to kill bacteria can cause the food to become radioactive. However, the kind of radiation used in the process cannot cause the food to become radioactive, so in that sense the process is perfectly safe. There are other possible concerns in using the process (such as giving a false sense of security that the food is bacteria-free even though new bacteria could have been introduced after irradiation through unsafe handling methods); students will consider these aspects in Student Worksheet 3.

2. Discuss ways we can detect radiation. As a lead-in, ask students if they know what miners used to keep in the mines to detect toxic gases until quite recently. (Answer: Canaries, which, if they fell asleep, indicated that gas levels were becoming dangerous for life, and the miners had to immediately leave.) You can also discuss the use of pigeons to monitor the possible use of chemical weapons in the Iraqi War of 2003 (a sudden death of the pigeons could have signaled a chemical attack and advised the soldiers to put on their gas mask). Ask what other detectors are now used to identify and quantify our exposure to potential health hazards, such as ionizing radiation. (Possible answers: Dosimeter badges, Geiger counters, carbon monoxide detectors, etc.)

3. Hand out Student Worksheet 1 to each student. Place the students in pairs. Explain that they are going to estimate their yearly exposure to ionizing radiation. Make sure that if they have been exposed more than once to X-rays, for example, that their estimates reflect multiple exposures. Have students help each other understand the meaning of each item, and check each other's math. If they have trouble with the chart, go through it with them.

4. Ask students, "What are your exposure rates?" Write them on the board. Ask "Why are many rates almost identical; why do some vary greatly?" Use leading questions to have students consider common family experiences, geography, age, travel, accidents, health issues, etc.

Teaching Tip

Stress again that the students have calculated their exposure to high-energy (ionizing) radiation. There are sources of low-energy radiation they may encounter every day (cell phones, UV radiation from the Sun, etc.), but they are not thought to be a significant hazard.

5. Hand out Student Worksheet 2. Introduce the scale and terms used to measure radiation. Ensure that students understand the amounts in relative terms. Have students check their exposure rates against the chart on Student Worksheet 2 to determine if they need to be concerned with their exposure to ionizing radiation. Point out that their exposure in most cases would have to increase by a factor of 10 or more, before it becomes much of a health risk. Remind students that radiation is natural and that the levels of it we encounter in our daily lives are extremely low. If you have access to a Geiger counter, you can prove this. Reassure students that radiation only becomes a problem if we are exposed to too much of it.

6. Distribute Student Worksheet 3 and have students individually answer the questions, based on their understanding of classroom discussions and Student Worksheet 1.

Discussion & Reflection

The following section may be discussed in a follow-up class session or assigned as homework:

On Ionizing Radiation

1. What is ionizing radiation? Name the sources that release it.
2. How can you limit your exposure to radiation?

On Solar and Cosmic Radiation

3. How can we see the effect of solar radiation on Earth? (Possible answers: Sunburn, satellite and telecommunication problems. Note also that sunlight is solar radiation—the damaging high-energy parts are stopped by the Earth's atmosphere and most of the radiation reaching the surface is less harmful, low-energy forms of it.)
4. Hand out Student Worksheet 4. Ask how we can monitor solar activity. Briefly describe sunspots and the 11-year solar activity cycle, using the current cycle (number 23) as an example.
5. What happens to solar radiation if we move closer to or further from the Sun? (Answer: Closer to the Sun it gets stronger; further away, weaker.)
6. Describe the MESSENGER mission to Mercury with the help of the attached MESSENGER Information Sheet as a transparency or as a student handout. Explain that since MESSENGER will go much closer to the Sun (to one-third the Earth-Sun distance), solar radiation and its damaging effect on the spacecraft is a major concern. What can be done to protect the exposure of spacecraft, recording instruments, communications hardware and software, etc? What other kind of radiation can be found in space? (Cosmic radiation–since it arrives from outside the Solar System, it is stronger in the outer parts of the Solar System than in the inner regions.)
7. Have students complete Student Worksheet 4 answering questions about the MESSENGER mission in the context of the solar activity cycle.
8. Discuss what astronauts have had to do to reduce their exposure to cosmic radiation in Earth orbit or on the Moon. What would they have to do if they got as close to the Sun as Mercury?

Teaching Tip

Remind students to never look directly at the Sun—this can cause severe eye damage and even blindness.

Extensions

- Divide students into two debate teams. Have a debate regarding a possible proposal to build a nuclear power plant in their neighborhood. Have the students discuss the social and political implications of the N.I.M.B.Y. philosophy (Not In My Back Yard).

- If you have a Geiger counter and it is sensitive enough, measure and chart the radiation levels of different objects, different parts of the building, the room, indoors and outdoors. Typically, Geiger counters are sensitive on the range of 0.01-1000 μSv/hr (that is, up to 1 mSv/hr). Natural radiation sources result in typically 10-20 clicks/minute. (Note that if you are exposed to an effective dose of 3.6 mSv per year, this is equivalent to an exposure rate of 0.41 μSv per hour.)

- If you have access to dosimeters, you may hand some out to students and ask them to wear them for a few weeks and check for changes. (The students' dosimeters would not be expected to change much.) If any of the students' friends or relatives work with X-rays in hospitals, for example, have students ask them to wear a dosimeter and then bring it to school for follow-up discussions once a week or once a month.

- Have the students create an informational poster or brochure about one particular topic. For example, cell phone radiation (and misconceptions about it; as mentioned in the Science Overview, cell phones are not a source of ionizing radiation), medical equipment, etc.

- You can have students research and answer the essay questions listed below. Remind students that radiation is a hotly-debated topic, and if you do not choose your sources carefully, you may get biased information. The best sources of information are usually government agencies, universities and affiliated research institutions. Have the students write down their sources on the finished essays.

  1. Describe the difference between ionizing radiation and other forms of radiation. What are the effects of ionizing radiation on both equipment and living organisms and under what conditions do we need to be concerned about it?
  2. Why is natural radiation not a significant problem on Earth?
  3. Which materials would you need to protect a living organism against all known forms of radiation? Discuss the consequences of living inside such a protective place.
  4. Storing radioactive waste. Is inexpensive electricity worth the potential risk?
  5. Discuss food irradiation and public health.

Curriculum Connections

- *Biology:* Have students research the biological effects of radiation.

- *Political science and current events:* Have students research how radioactive substances are stored. How could radioactive material get into the hands of people who are not qualified to handle it? Research the concerns about how radioactive substances from the former Soviet Union might end up in the hands of criminals. Discuss concerns about the use of radiological "dirty bombs." Follow the discussion of the storage of nuclear waste in Yucca Mountain in Nevada, and examine how much of the discussion is based on science, and how much is politics (such as NIMBY).

- *History:* Have students investigate the history of research on radioactivity. For example, profile Marie Curie, one of the pioneers of the field. Discuss ways in which exploring unknown phenomena can be dangerous; early scientists at first did not know of the dangers of radioactivity and did not protect themselves against it.

- *Chemistry:* Have students research the idea of radiometric dating and its use in archaeology. [For example, carbon dating is based on the fact that living things maintain a balance of the regular form (isotope) of carbon called carbon-12, and a radioactive version of carbon called carbon-14. When they die, the intake of carbon-14 stops. By calculating how much carbon-14 has decayed away in a sample of a dead organism, the time since its death can be estimated. This applies to humans, animals and plants alike, making it possible to date clothes, for example, in addition to actual bodies.]

- *Health:* Have students research the use of radiation in cancer treatments.

- *Health:* Have students research nuclear power plant accidents (especially Chernobyl, Ukraine; in 1986 still part of the Soviet Union), and their effect on health in surrounding areas.

Closing Discussion

Discuss ways in which we use science to examine unknown phenomena, such as radioactivity. By using scientific methods to examine how high-energy radiation is produced, how it affects materials and varies from one environment to another, we can identify effective ways to shield living beings and equipment, on Earth as well as in space. Refer back to any questions not answered in the "Discussion & Reflection" section.

Conclude with the connection to MESSENGER: Decades of research into radiation and its effects has enabled us to send a spacecraft close to the Sun, to a hostile radiation environment and to be confident it will continue to function properly over a long period of time.

Assessment

5 points

- Student's answers to the questions on Student Worksheet 3 showed a clear understanding of the concept of man-made versus natural radiation.

- Student's answers to the questions on Student Worksheet 3 showed a clear understanding of the concept of the pros and cons of radiation.

- Student's answers to the questions on Student Worksheet 4 showed a clear understanding of the concept of the effect that radiation will have on the MESSENGER mission.

4 points

- Student's answers showed a clear understanding of two of the concepts above, and a moderate understanding of one of the concepts above.

3 points

- Student's answers showed a clear understanding of one of the concepts above, and a moderate understanding of two of the concepts above.

2 points

- Student's answers showed a moderate understanding of the concepts above.

1 point

- Student's answers showed little understanding of the concepts above.

0 points

- No work completed.

Internet Resources & References

MESSENGER Website

messenger.jhuapl.edu

American Association for the Advancement of Science, Project 2061 Benchmarks for Science Literacy

www.project2061.org/tools/benchol/bolintro.htm

NASA Explores Article "Radioactive Fred"

www.nasaexplores.com/search_nav_9_12.php?id=02-016&gl=912

National Science Education Standards

www.nap.edu/html/nses/html/

Nuclear Energy Institute: U.S. Nuclear Plants State-by-State Interactive Map

www.nei.org/doc.asp?catnum=2&catid=93

Space Environments & Effects (SEE) Program

see.msfc.nasa.gov

Space Radiation Environmental Effects (Arizona State University)

www.eas.asu.edu/~holbert/eee460/spacerad.html

United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR)

www.unscear.org

University of Michigan: Radiation and health physics

www.umich.edu/~radinfo/

Uranium Information Centre Ltd (Australia): Radiation and Life

www.uic.com.au/ral.htm

U.S. Environmental Protection Agency Radiation Pages

www.epa.gov/radiation/students/

U.S. Geological Survey: Elevations and distances in the United States:

erg.usgs.gov/isb/pubs/booklets/elvadist/elvadist.html

Acknowledgments

The student activity in this lesson has been adapted from NASA Explores lesson "Radioactive Fred" (http://www.nasaexplores.com/search_nav_9_12.php?id=02-016&gl=912) and EPA's Student and Teacher Pages (www.epa.gov/radiation/students/calculate.html).

CALCULATING YOUR YEARLY EXPOSURE TO IONIZING RADIATION

An especially damaging form of radiation is "ionizing radiation," which can create electrically-charged ions in the material it strikes. This ionization process can break apart atoms and molecules, causing severe 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 (i.e., causing mutations—hereditary mutations are extremely rare, however). There are several forms of ionizing radiation:

- X-rays and gamma rays: High-energy parts of the electromagnetic spectrum.
- Alpha particles: Atomic nuclei consisting of two protons and two neutrons.
- Beta particles: Fast-moving electrons ejected from the nuclei of atoms.
- Cosmic radiation: Energetic particles arriving at Earth from outer space.
- Neutrons: Produced mainly in nuclear power plants.

Calculate your exposure to ionizing radiation over the past year. 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, 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.

Note 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—and ultraviolet radiation from the Sun is known to be able to cause skin cancer with repeated exposure over time—they are not thought to be as dangerous as the ionizing radiation listed here.

Have someone check your math before you turn in your work.

Name ______________________________

For your information:

(1) Sample one-way distances (as the crow flies) in the United States:

New York City – Los Angeles	2462 miles (3961 km)
Oklahoma City – Washington, DC	1153 miles (1855 km)
Oklahoma City – San Francisco	1387 miles (2248 km)
Seattle – San Diego	1058 miles (1702 km)
Chicago – Houston	937 miles (1508 km)
Boston – Miami	1255 miles (2020 km)

Sample distances from the United States:

New York City – Paris, France	3635 miles (5850 km)
New York City – New Delhi, India	7301 miles (11750 km)
New York City – Cairo, Egypt	5621 miles (9046 km)
Los Angeles – Sydney, Australia	7487 miles (12049 km)
Los Angeles – Tokyo, Japan	5478 miles (8815 km)
Houston – Mexico City, Mexico	747 miles (1203 km)
Miami – Buenos Aires, Argentina	4372 miles (7037 km)

Remember to double your one-way distance for round-trip travel. If you want to know the exact distance for your city and target, search for distance calculators on the Internet.

(2) Remember to multiply the numbers given by how many times during the last year you had the procedure (e.g., if you had dental X-rays done twice, multiply 0.2 by 2).

BE PREPARED TO DISCUSS THE FOLLOWING QUESTIONS:

1) Identify three sources of radiation that have virtually no effect on your own total yearly exposure. How could you protect yourself against these sources? Would it be worthwhile?

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

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

CHART OF YEARLY RADIATION EXPOSURE FOR ______________________

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. (see page 2)	
If your luggage was X-rayed, add 0.00002 mSv.	
SUBTOTAL THIS PAGE	

Type of ionizing radiation	Amount of radiation in 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 (see page 2)	
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	
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 ^{99m}Tc 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.	
SUBTOTAL THIS PAGE	
ADD SUBTOTAL FROM LAST PAGE	
TOTAL	

Likely effects of ionizing radiation for whole body radiation doses to individuals

0.3-0.6 mSv/yr is a typical range of dose rates from artificial sources of radiation, mostly from medical procedures.

2 mSv/yr (approximately) is the typical minimum amount of background radiation from natural sources. About 0.7 mSv/yr of this amount comes from radon gas in the air. This is close to the minimum dose received by humans anywhere on Earth.

3 mSv/yr (approximately) is the typical background radiation from natural sources in North America. This includes an average of almost 2 mSv/yr from radon gas in the air.

5-8 mSv/yr is the typical dose rate received by uranium miners.

20 mSv/yr (averaged over 5 years) is the recommended limit for exposure from the workplace. This includes employees in the nuclear industry, uranium or mineral sands miners, and hospital workers (who are all closely monitored).

50 mSv is the lowest dose at which there is any concrete evidence of cancer being caused by radiation for adults. It is also the highest dose which is allowed by regulation in any one year of workplace exposure for radiation-workers. There are several parts of the world where the dose rate is greater than 50 mSv/yr from natural background sources, but it does not appear to cause any harm to the local population.

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) 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 whole-body dose would cause immediate illness such as nausea, decreased white blood cell count, and probably subsequent death within a few weeks. Aggressive treatment may be able

Name ____________________________________

Questions About Radiation Exposure

1. Based on the entries in Student Worksheet 1, what are some natural sources of radiation to which people are commonly exposed?

2. Are you exposed to larger amounts of naturally occurring radiation or to man-made sources of radiation? Explain your answer.

3. What are some benefits of man-made radiation?

4. In food irradiation, food products are exposed to very large doses of high-energy radiation to kill bacteria in the food. What pros and cons do you see in this process?

5. Review your total score in Students Worksheet 1. How could you reduce your amount of exposure to ionizing radiation? Would the reductions be significant?

Name ____________________

Questions about MESSENGER and the Solar Activity Cycle

In 2004, NASA launched a spacecraft called MESSENGER (messenger.jhuapl.edu/) to study the planet Mercury. After one flyby of Earth, two flybys of Venus, and three flybys of Mercury, it will go into orbit around Mercury in March 2011. It will remain in orbit for one Earth year.

One of the concerns for the mission designers is the high levels of ionizing radiation from the Sun to which the spacecraft will be exposed. The amount of solar radiation depends on the phase of the Sun's activity cycle (see Figure S1).

During what part of the solar cycle does the MESSENGER mission take place?
What effects will this have on the radiation environment the spacecraft is likely to encounter?

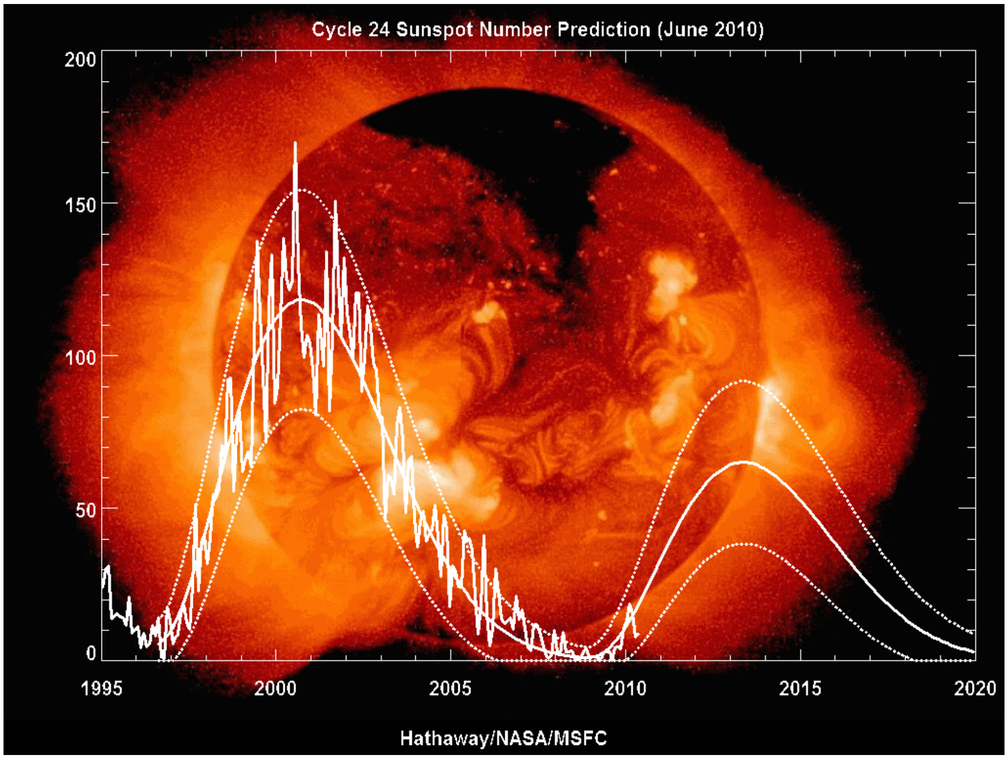


Figure S1. Solar activity cycle as followed by the number of sunspots on the surface of the Sun. The 11-year cycle has major effects on the radiation environment on Earth as well as for the spacecraft venturing into the inner Solar System, such as the MESSENGER mission to Mercury. (Picture credit: solarscience.msfc.nasa.gov/images/ssn_predict_1.gif)

Answer Key

Student Worksheet 1

1. Most people will have very low doses. Possible exceptions include people who have experienced unusually high number of medical procedures, but even then the levels would be expected to be well below serious health concerns.

Student Worksheet 3

1. Radon in the air and water, food, cosmic radiation from space, some medical procedures.

2. Most people are exposed to much more natural radiation than man-made. An exception could be students that have had exceptionally intensive medical treatments.

3. Sample answers: Electricity produced by power plants (radiation is a side effect). Safer food and medical equipment, ability to diagnose medical problems inside our bodies, radiation treatments slowing down (or eliminating) diseases.

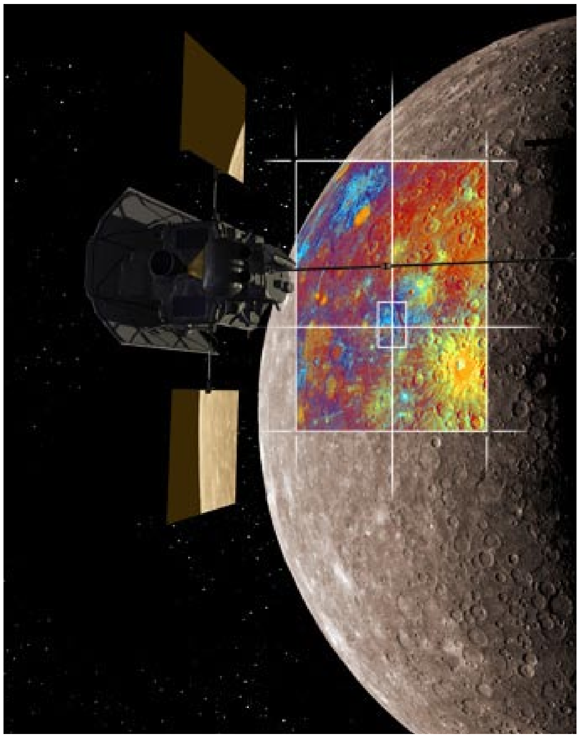
4. Sample answers: Pros – safer food, longer shelf life of food products. Cons – may give false sense of security that there is no bacteria in the food, even though unsafe handling after irradiation may introduce new bacteria; irradiation kills bacteria but leaves their remnants in the food; may enable food packagers to use less fresh meat which is then irradiated to make it safe for consuming even if it wouldn't have been so otherwise. (Note that irradiation does not make food radioactive! That would be a wrong answer.)

5. Sample answers: Find ways to be exposed to less radon (e.g., adequate ventilation); move closer to the sea level; travel less; have no need for medical treatments; watch less TV. Most reasonable reductions would have little effect on the total effective dose.

Student Worksheet 4

The current 11-year solar activity cycle (Cycle 24) began in late 2008 and is expected to reach its maximum in 2013. Note that since the prediction of the Sun's activity cycle is just that—prediction based on past experience—the actual times of the various phases will be known only once they have occurred. During MESSENGER's travel to Mercury, from the launch of the spacecraft in 2004 to orbit insertion in 2011, solar activity has been low. However, MESSENGER will begin its orbital operations during rising solar activity. During the one-year orbital phase, the solar activity, and therefore solar radiation in the form of solar energetic particles, will be increasing rapidly toward the anticipated maximum in 2013. Therefore, MESSENGER will experience large changes in the radiation environment during its operation, and this had to be taken into account while designing the mission.

MESSENGER INFORMATION SHEET



The MESSENGER Mission to Mercury

MESSENGER is an unmanned U.S. spacecraft that was launched in 2004 and will arrive at the planet Mercury in 2011, though it will not land. Instead, it will make its observations of the planet from orbit. MESSENGER will never return to Earth, but will stay in orbit around Mercury to gather data until the end of its mission.

MESSENGER is an acronym that stands for "**ME**rcury **S**urface **S**pace **EN**vironment, **GE**ochemistry and **R**anging," but it is also a reference to the name of the ancient Roman messenger of the gods: Mercury, after whom the planet is named.

MESSENGER will be only the second spacecraft ever to study Mercury: In 1974 and 1975 Mariner 10 flew by the planet three times and took pictures of about half the planet's surface. MESSENGER will stay in orbit around Mercury for one Earth-year; its close-up observations will allow us to see the whole planet for the first time.

Sending a spacecraft to Mercury is extremely complicated. The planet is very close to the Sun; it moves very fast in its orbit, and intense radiation and heat can cause catastrophic consequences. Therefore, engineers and scientists have planned the mission carefully. They have found ways to protect the spacecraft against radiation, and they have built safeguards to make sure it can operate reliably in the difficult Mercurian environment.

During its mission, MESSENGER will attempt to answer many questions about the mysterious planet. How was the planet formed and how has it changed? Mercury is the only rocky planet besides Earth to have a global magnetic field; what are its properties and origin? Does ice really exist near the planet's poles? Answers to these scientific questions are expected to hold keys to many other puzzles, such as the origin and evolution of all rocky planets. As we discover more, we expect that new questions will arise. You could be the one answering these new questions!