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	Uses 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
	Remote controls	Operate machines from a distance	No
Visible Light	Light bulbs	See objects	Usually not, but severe eye damage if too intense
	Sun & astronomical objects	Detect properties of the Sun and other astronomical objects	Usually not, but severe eye damage if too intense
Ultraviolet	Black lights	Entertainment lighting, detect chemical "markers" on money and manufactured products	Not in typical amounts
	Sun & astronomical objects	Detect properties of the Sun and other astronomical objects	In large amounts from the Sun (skin cancer)
X-Rays	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

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.
    6. Discuss high-energy radiation and the human exploration of space.

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

http://messenger.jhuapl.edu

NASA Explores Article "Radioactive Fred"

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

NASA's Extravehicular Activity Radiation Monitoring (EVARM)

http://www1.msfc.nasa.gov/NEWSROOM/background/facts/evarm.html

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

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

Space Environments & Effects (SEE) Program

http://see.msfc.nasa.gov/

Space Radiation Environmental Effects (Arizona State Universuty)

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

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

http://www.unscear.org/

University of Michigan: Radiation and health physics

http://www.umich.edu/~radinfo/

Uranium Information Centre Ltd (Australia): Radiation and Life

http://www.uic.com.au/ral.htm

U.S. Environmental Protection Agency Radiation Pages

http://www.epa.gov/radiation/students/

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

http://mac.usgs.gov/mac/isb/pubs/booklets/elvadist/elvadist.html

National Science Education Standards

http://www.nap.edu/html/nses/html/

American Association for the Advancement of Science, Project 2061

http://www.project2061.org/tools/benchol/bolframe.htm

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 (http://www.epa.gov/radiation/students/calculate.html).