Activity One: Radiation

Educator Notes

Learning Objectives

Students will

- Identify everyday radiation exposures on Earth.
- Contrast Earth radiation exposures with those experienced by astronauts in deep space.
- Explain the effects of radiation exposure on the human body.
- Investigate the importance of radiation shielding for deep space travel.

Challenge Overview

Students will compare and contrast radiation exposure on Earth with radiation exposure in space. This activity culminates with a challenge in which students will need to protect a potato "astronaut" from the harmful effects of the radiation in their ovens.

Suggested Pacing

90 to 120 minutes

National STEM Standards

Science and Engineering (NGSS)	
Disciplinary Core Ideas • MS-PS3-3: Energy: Apply scientific principles to design, construct, and test a device that either minimizes or maximizes thermal energy transfer. • MS-LS3-1: Heredity: Inheritance and Variation of Traits: Develop and use a model to describe why structural changes to genes (mutations) located on chromosomes may affect proteins and may result in harmful, beneficial, or neutral effects to the structure and function of the organism. • MS-ETS1-2: Engineering Design: Evaluate competing design solutions using a systematic process to determine how well they meet the criteria and constraints of the problem. *Crosscutting Concepts* • Energy and Matter: The transfer of energy can be tracked as energy flows through a designed or natural system.	*Crosscutting Concepts* • Structure and Function: Complex and microscopic structures and systems can be visualized, modeled, and used to describe how their function depends on the shapes, composition, and relationships among its parts, therefore complex natural structures/systems can be analyzed to determine how they function. *Science and Engineering Practices* • Constructing Explanations and Designing Solutions: Apply scientific ideas or principles to design, construct, and test a design of an object, tool, process, or system. • Developing and Using Models: Modeling in 6–8 builds on K–5 experiences and progresses to developing, using, and revising models to describe, test, and predict more abstract phenomena and design systems. • Engaging in Argument From Evidence: Evaluate competing design solutions based on jointly developed and agreed-upon design criteria.
Technology (ISTE)	
Standards for Students • Knowledge Constructor: Students critically curate a variety of resources using digital tools to construct knowledge, produce creative artifacts, and make meaningful learning experiences for themselves and others. • Innovative Designer: Students use a variety of technologies within a design process to identify and solve problems by creating new useful, or imaginative solutions.	*Standards for Students (continued)* • Creative Communicator: Students communicate clearly and express themselves creatively for a variety of purposes using the platforms, tools, styles, formats, and digital media appropriate to their goals. • Global Collaborator: Students use digital tools to broaden their perspectives and enrich their learning by collaborating with others and working effectively in teams locally and globally.
Mathematics (CCSS)	
Mathematical Practices • MP.27.EE.3: Solve multistep real-life and mathematical problems posed with positive and negative rational numbers in any form (whole numbers, fractions, and decimals), using tools strategically. Apply properties of operations to calculate with numbers in any form, convert between forms as appropriate, and assess the reasonableness of answers using mental computation and estimation strategies.	

Challenge Preparation

The educator should

- Read the introduction and background information, Educator Notes, Student Handout, and Radiation Exposure on Earth Worksheet to become familiar with the activity.
- Print copies of the Student Handout and the Radiation Exposure on Earth Worksheet for each student.
- Preheat oven or toaster oven.

Materials

- ☐ Wooden block tower
- ☐ Potato (at least 2 per team)
  Note: Ensure potatoes are similar in mass. Educator may also use several different varieties of potatoes as an extension activity.
- ☐ Cookie sheet or another oven-safe pan
- ☐ Oven or toaster oven set to 350 °F
- ☐ Food thermometer or probe thermometer to test internal temperature of the potato
- ☐ Various oven-safe materials to protect potato (tin foil, parchment paper, clay, oven bags, salt, etc.)

Safety

- Use potholders or oven mitts and wear protective eyewear when moving items in and out of the oven and when checking the temperature of the potato.
- Be sure to use oven-safe materials, including the oven mitt, sheet or pan, and materials wrapped around the potato.
- Do not place potato directly on oven rack, but instead use a cookie sheet or other type of oven-safe pan.
- Have a flat and heat-resistant surface ready to place the cookie sheet or pan on after removal from oven. Remove any clutter, other equipment, and all combustible materials from area.

Introduce the Challenge

- Inform students that they will be learning about radiation and the effects of radiation exposure on astronauts in space.
- Explain to students that they will be working in teams to protect a potato "astronaut" from the harmful effects of radiation exposure in an oven. It is important to note and explain to students that the infrared radiation from an oven is different in wavelength and intensity than the radiation from solar energetic particles (SEPs) or galactic cosmic radiation (GCR) and that this activity is just an illustration of the effects of radiation.
- Ask students what they think astronauts and potatoes have in common.
- Review the following criteria and constraints of the activity with students:

Criteria	Constraints
After baking, the experimental potato must have a lower internal temperature than the control potato (the lower, the better).	You may not use more than three layers of protection on your "astronaut."
All protective materials for the potato must be oven safe.	You may not use water or other liquids as protection for this activity.
The experimental and control potatoes must be cooked for the same amount of time at the same temperature.	

Facilitate the Challenge

? Ask

- Begin this activity with a demonstration using a stacked tower of wooden blocks (e.g., a tumble tower). Explain to students that the game represents a strand of their DNA. Remove a block from anywhere on the structure and explain to students that when

Share With Students

Brain Booster

Bananas are a natural source of radioactive isotopes. A "banana equivalent dose (BED)" is a unit that compares radiation exposure to the amount you naturally get from eating a banana. 1 BED is equal to 0.001 millisievert (mSv).

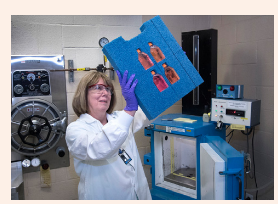
A lethal dose of radiation would be comparable to the radiation you would get from eating 80 million bananas!

See more comparisons on the Student Handout.

Learn more:
www.nasa.gov/sites/default/files/files/Radiation_Math.pdf

On Location

The research performed at the NASA Space Radiation Laboratory (NSRL) at the Brookhaven National Laboratory in New York increases our understanding of ionizing radiation and cell damage. Researchers are working to limit the damage to healthy tissue by cosmic radiation, which will lead to safer exploration for astronauts and possible improvements in cancer-fighting treatments for everyone.



Learn more:
www.bnl.gov/nsrl/

someone is exposed to radiation, it destroys or changes a small part of that strand. Continue to pull out random blocks and ask for student observations. Explain that sometimes the tower tumbles with the removal of one block, but that other times several blocks need to be removed before the tower tumbles.

- Ask students what would happen if a marble was thrown at the stack of blocks instead of single blocks being carefully removed. Explain that a marble would represent what being exposed to galactic cosmic radiation (GCR) is like. GCR is much more damaging than exposure from solar energetic particles (SEPs) because GCR is high in atomic mass and has extremely high energy. For more information on DNA damage, read "Space Radiation is Risky Business for the Human Body" at www.nasa.gov/feature/space-radiation-is-risky-business-for-the-human-body. This website page also includes a video that can be shared with students.
- Explain to students that in this activity they will be learning how much radiation they are exposed to on a yearly basis on Earth and will be comparing this exposure rate to that of astronauts on the International Space Station, on a trip to the Moon, and even on a deep space exploration trip to Mars. Before students complete the Radiation Exposure on Earth Worksheet, hold a whole-group discussion about radiation exposure on Earth. How commonly do students think it occurs? What causes it?

  Note: It may be helpful to complete the worksheet while the potato "astronauts" are baking in the oven.
- In the last part of this activity, students will work in small teams to create protective shielding for "potato" astronauts before baking them in an oven. Discuss with students the importance of shielding to protect astronauts from SEPs while they are in space, away from the protection of Earth's magnetosphere. Putting as much mass as possible between the astronauts and SEPs will help shield the astronauts from harmful radiation.

Imagine

- Hand out to each student a copy of the Radiation Exposure on Earth Worksheet.
- Students will work individually on the handout to determine the amount of their own personal exposure rates.
- As a large group, determine the exposure rates in Banana Equivalent Doses (BEDs) of astronauts on (1) the International Space Station, (2) a trip to the Moon, and (3) a trip to Mars.

Discussion Questions and Answer Key

1. The average exposure for 1 year on Earth is about 3.0 mSv. How does your annual radiation dose compare to the average? How does your annual radiation dose compare to other students?
2. The average exposure rate for astronauts on the International Space Station for a 6-month stay is 160 mSv. What is the banana equivalent dose, or BED, for those astronauts? **Answer: 160,000**
3. The average radiation exposure for astronauts living on the Moon for 9 days is 11.4 mSv. What is the BED for those astronauts? **Answer: 11,400.** Why is this number less than the BED for a stay on the International Space Station? **Answer: Astronauts are on the International Space Station for 6 months, not 9 days.**
4. The estimated radiation exposure for astronauts on a 3-year round-trip mission to Mars is 1,200 mSv. What is the BED for a trip to Mars? **Answer: 1,200,000.** If a lethal dose of radiation is the equivalent of eating 80 million bananas, about how many trips to Mars could you make? **Answer: 8**

Plan

- Place students in small teams of no more than four.
- Explain that students will need to brainstorm how they will protect a potato "astronaut" from the radiation of an oven.
- Make sure students understand what materials they have available to them and how much they are permitted to use.
- Teams should be given at least two potatoes. One will serve as a control, where no protection is given, and the other will be the experimental potato.

  Note: At the discretion of the educator, teams can be given only one potato and the final temperature of a control potato can be given to the students beforehand. Students can also use more than one potato, or potatoes of different varieties, and protect them in various ways. For example, they can compare the effectiveness of one layer of aluminum foil versus the effectiveness of three layers of aluminum foil.

Create

- After students have brainstormed a solution to best protect their potato, they will wrap the potato "astronaut" using no more than three layers of material and ensuring the entire potato is covered, with no gaps or holes. Discuss how this protective "spacesuit" is similar to the lead apron that is worn during x-rays.
- If students are using more than one potato, each protective spacesuit should be made differently.

Test

- Teams will bake their "astronaut" potatoes in an oven. To save time, preheat the oven. The control potato will have no protection and must be baked at 350 degrees for 30 minutes.

  Note: Educator can vary time or temperature but must keep variables consistent for all potatoes. If an oven is not available, consider using the school cafeteria, or send potatoes home to be baked and tested.
- Teams will then bake their protected astronauts for 30 minutes at 350 degrees.

  Note: It may be helpful to have students work on the Radiation Exposure handout while the potatoes are baking.
- Teams will take the internal temperature of their control potato and their protected potato "astronauts."
- Have students graph or create a table of their results to share with the rest of the teams.

Improve

- Ask students if their spacesuit protected their astronauts. Did the internal temperature improve over the control potato's temperature?
- If no improvement was made, allow teams to brainstorm and discuss what they would do to improve their designs. If time permits, allow teams to test their new designs and include any new data in their original graph or table.

Share

Engage students with the following discussion questions:

- Compare your team's results with the other teams' results. How did your spacesuit compare to the others? What improvements could be made if you had the time?
- How is this activity similar to the development of protective spacesuits for astronauts?
- Compare and contrast between the radiation that real astronauts are exposed to in space and the radiation that your potato "astronauts" experienced.

Optional: Share students' results on social media using #NextGenSTEM. Be sure to include the module and activity name.

Extensions

- Create a price list for materials and give student teams a budget they must work within. For example, make aluminum foil more expensive than parchment paper to help students realize that engineering involves tradeoffs between price and performance.
- In your journal, write a reflection on what you have learned from this activity. Describe the importance of spacesuit and spacecraft materials in the mitigation of radiation exposure on a deep space journey.

Reference

Space Faring: The Radiation Challenge (Middle School Educator Guide)
www.nasa.gov/pdf/284277main_Radiation_MS.pdf

Activity One: Radiation

Student Handout

Your Challenge

You will be comparing and contrasting radiation exposure on Earth with radiation exposure in space. This activity culminates with a challenge in which you will need to protect a potato "astronaut" from the harmful effects of the radiation of an oven.

Criteria	Constraints
After baking, the experimental potato must have a lower internal temperature than the control potato (the lower, the better).	You may not use more than three layers of protection on your "astronaut."
All protective materials for the potato must be oven safe.	You may not use water or other liquids as protection for this activity.
The experimental and control potatoes must be cooked for the same amount of time at the same temperature.	

Ask

- Your instructor will demonstrate the effects of radiation by using a stack of blocks to represent your DNA. DNA is located inside each of your cells and carries all the information about how you look and function. Removing a block from the stack demonstrates the effect that a small dose of radiation has on your DNA. What do you anticipate will happen as your instructor continues to remove blocks? What would happen if you threw a marble at the tower of blocks? That would be an illustration of another type of radiation that astronauts are exposed to in space: galactic cosmic radiation (GCR).

Imagine

- In the next part of this activity, you will learn how much radiation you are exposed to on a yearly basis on Earth. Reflect and discuss with the whole group how you think radiation exposure occurs here on Earth. After this group discussion, you will receive a handout to complete and compare your data with other students.
- Next, you will compare your yearly exposure rate to that of astronauts who are (1) living on the International Space Station, (2) on a trip to the Moon, and (3) on a deep space exploration trip to Mars.

Plan

- In the last part of this activity, you will work in a small team to create protective shielding for a potato "astronaut" before baking it in an oven. This is to illustrate the radiation exposure astronauts would face in space. Understand that radiation from the oven is very different than the types of radiation encountered in space, but this is a good way to illustrate the importance of protection and shielding for astronauts.
- Use a sheet of paper to brainstorm how your team will use the materials provided to protect a potato "astronaut" from the radiation of an oven. Be descriptive, and be sure to label your drawings.

Fun Fact

Did you know that there is a type of fungus that feeds on radiation to create chemical energy for growth? It's true! Scientists have discovered a type of fungus at Chernobyl, the site of the world's worst nuclear disaster. The fungus survives using a unique process called radiosynthesis that works like photosynthesis but uses the energy from radioactivity instead of sunlight. Scientists have recently discovered that the properties of this fungus could help protect people from radiation, like the astronauts on the International Space Station. The fungus could eventually be used to create a space-approved sunscreen!

Learn more:
hub.jhu.edu/2019/11/01/melanin-space-study/

Career Corner

Scientists working with the Johnson Space Center's Space Radiation Group (SRG) monitor the space weather forecast from the National Oceanic and Atmospheric Administration's Space Weather Prediction Center. They alert mission control of potential solar activity and can recommend postponing activities that would require astronauts to perform spacewalks. Anywhere astronauts may go, SRG scientists will keep watch over the space environment. Interested in becoming a space meteorologist?

Learn more:
ccmc.gsfc.nasa.gov/

Create

- After your team has brainstormed a solution to best protect your potato, use the materials you have chosen to carefully wrap your potato "astronaut." Make sure the entire potato is covered, with no gaps or holes. This is your experimental potato.
- The second potato will be your control potato. It should be left completely unprotected. Ideally, your experimental potato will "survive" what the control potato could not. Whenever possible, good experiments have a control to make sure that the experiment did not just work, but worked better than doing nothing, because sometimes you can make things worse by accident.

Test

- It is time to test your protective spacesuits! Place both of your potatoes—your experimental potato and your control potato—on a cookie sheet or other oven-safe pan.
- Put on your protective eyewear and oven mitts.
- Place both the experimental potato and the control potato in a preheated 350-degree oven and bake them for 30 minutes.
- After 30 minutes, put your protective eyewear and oven mitts back on. Clear the area where you will place the cookie sheet or pan.
- Carefully remove the cookie sheet from the oven using oven mitts or potholders.
- Using your oven mitt, hold your potato "astronaut." Carefully insert the thermometer and take the internal temperature of your protected potato "astronaut," then take the temperature of your control potato.
- Create a table or graph to illustrate the results, comparing your potato "astronaut" with the control potato.

Improve

- Did the internal temperature of the protected potato "astronaut" improve over the control potato's temperature? Why or why not?
- If no improvement was made, brainstorm and discuss with your team what you could do to improve your design. If time permits, test your new design and record your new data on your table or graph.

Share

- Compare your team's results with the other teams. How did your spacesuit compare to the others? What improvements could be made if you had the time?
- How is this activity similar to the development of protective spacesuits for astronauts?
- Compare and contrast between the radiation that real astronauts are exposed to in space and the radiation that your potato "astronauts" experienced.

Radiation Exposure on Earth Worksheet

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), which is the standard unit of measurement for a dose of radiation. Add up all 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)		
	Elevation (Average cities' data from U.S. Geological Survey: http://usgs.gov)	**Value, mSv**	
	• **Sea level** (New York, Philadelphia, Houston, Baltimore, Boston, New Orleans, Jacksonville, Seattle)	0.26	
	• **1 to 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 to 2,000 feet** (Phoenix, Pittsburgh, San Jose, Oklahoma City)	0.31	
	• **2,001 to 3,000 feet** (Las Vegas, Los Angeles, Honolulu, Tucson)	0.35	
	• **3,001 to 4,000 feet** (El Paso)	0.41	
	• **4,001 to 5,000 feet** (Salt Lake City)	0.47	
	• **5,001 to 6,000 feet** (Denver, Albuquerque)	0.52	
	• **6,001 to 7,000 feet**	0.66	
	• **7,001 to 8,000 feet**	0.79	
	• **8,001 to 9,000 feet**	0.96	__________ mSv
	Terrestrial Radiation (from the ground) • If you live in a state that borders the Gulf of Mexico or the 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 0.07 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 Commission website: www.nrc.gov/info-finder.html.) • 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
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 air (total for all flights in 1 year)	________ mSv

How you live	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 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 gastrointestinal x-ray	2.45 mSv	________ mSv
	Computed axial tomography (CAT) scan (head and body)	1.1 mSv	________ mSv
	Nuclear medicine (e.g., thyroid scan)	0.014 mSv	________ mSv
Total annual dose	Add up all the numbers in the last column. This is your annual radiation dose on Earth.		______ mSv annually

Banana Equivalent Dose (BED):

Bananas are a natural source of radioactive isotopes. A “Banana Equivalent Dose” (BED) is a unit that compares radiation exposure to the amount you naturally get from eating a banana. A lethal dose of radiation would be comparable to the radiation you would get from eating 80 million bananas! Using the following conversion, what is your BED each year? _______________

1 BED = 0.001 mSv

Example:

Your annual radiation dose is 2.8514 mSv.

You will need to convert millisieverts to BEDs by multiplying your answer by 1,000.

$2.8514 \times 1000 = 2851.4$ bananas for the year

Discussion:

1. The average exposure for 1 year on Earth is about 3.0 mSv. How does your annual radiation dose compare to the average? How does your annual radiation dose compare to other students?
2. The average exposure rate for astronauts on the International Space Station for a 6-month stay is 160 mSv. What is the BED for those astronauts?
3. The average radiation exposure for astronauts living on the Moon for 9 days is 11.4 mSv. What is the BED for those astronauts? Why is this number less than the BED for a stay on the International Space Station?
4. The estimated radiation exposure for astronauts on a 3-year round-trip mission to Mars is 1,200 mSv. What is the BED for a trip to Mars? If a lethal dose of radiation is the equivalent of eating 80 million bananas, about how many trips to Mars could you make?