NAVIGATING™ NUCLEAR
Energizing Our World

Project Starters

Topic

Exploring the Present and Future of Radioactive Decay

OBJECTIVES

Students will:

- Explore advantages of using radioactive decay for a micro energy source.
- Explore how radioactive isotopes and other materials are used in nuclear batteries technology.
- Design a prototype for a small-scale battery using the engineering design cycle.

Overview

Nuclear scientists research different ways of using natural radioactive decay. In this activity, students will compare and contrast different types of nuclear processes and their applications for humanity. Students will then use the engineering design process to design a future prototype for a small-scale nuclear battery that will address one of three design problems.

Grade level

9–12

Real World Science Topics

- Radioisotopes & Nuclear Decay
- Battery Technologies
- Engineering Design Cycle

Next Generation Science Standards (NGSS)

HS-PS2-6, HS-PS3-3 *Integrates traditional science content with engineering through a Practice or Disciplinary Core Idea

HS-PS2-6. Communicate scientific and technical information about why the molecular-level structure is important in the functioning of designed material*

HS-PS3-3. Design, build, and refine a device that works within given constraints to convert one form of energy into another form of energy.*

Science and Engineering Practices

Constructing Explanations and Designing Solutions

- Constructing explanations and designing solutions in 9–12 builds on K–8 experiences and progresses to explanations and designs that are supported by multiple and independent student-generated sources of evidence consistent with scientific ideas, principles, and theories.
- Design, evaluate, and/or refine a solution to a complex real-world problem, based on scientific knowledge, student-generated sources of evidence, prioritized criteria, and tradeoff considerations. (HSPS3-3)

Disciplinary Core Ideas

PS1.C: Nuclear Processes

- Nuclear processes, including fusion, fission, and radioactive decays of unstable nuclei, involve release or absorption of energy. The total number of neutrons plus protons does not change in any nuclear process. (HSPS1-8)

Crosscutting Concepts

Structure and Function

- Investigating or designing new systems or structures requires a detailed examination of the properties of different materials, the structures of different components, and connections of components to reveal its function and/or solve a problem. (HS-PS26)

Time Needed

60–90 minutes

Key Vocabulary

- **Half-life**—amount of time required for half of a quantity of a radioactive isotope to decay
- **Radioactive decay**—a spontaneous process an element undergoes in which nuclear transformations result in the emission of ionizing radiation. Decay transforms an unstable isotope to a stable one.
- **Radioisotope**—an atom that has excess nuclear energy, making it unstable.
- **Decay**—when unstable nuclei of radioisotopes become stable by emitting charged particles and energy
- **Isotopes**—atoms of the same element (same number of protons) that differ in their numbers of neutrons

Materials & Equipment

- Computers connected to the Internet
- Warm-up Vocabulary Strips (optional)
- Energy from Radioactive Decay Statements Student Handout
- Energy from Radioactive Decay Graphic Organizer Student Handout
- Copies of the “8 Step Engineering Design Process” 3-page packet: Diagram (pg. 1), Engineering Design Journal questions and sketch grid (pgs. 2 & 3)
- Engineering journals for each student, such as a marble notebook or a scientific notebook

Additional Resources (Optional)

- Cooperative Group Roll Cards
- Digital Graphic Organizer
- Teacher Guidance for Engineering Design
- CAD application for prototype construction, such as these.

Procedure

Warm-Up Activity

- Introduce students to Radioisotope Power Systems that power spacecraft to remote locations using an academic vocabulary strategy.
- Guide individual students to use a scrap piece of paper and rip it into eight pieces. Ask them to write a vocabulary word on each piece: plutonium-238, decay, radioactivity, radioisotopes, isotopes, radioactive decay, half-life, and Radioisotope Power System.
- Students should then be directed to mix them up.
- In small groups of 3–4, have students discuss which words are familiar and share their understanding of the meanings.
- As a whole group, briefly have students share and review the words and their meanings.Explain to students that they will work with a partner to place the vocabulary words in order as they are heard in the segment.
- Play https://rps.nasa.gov/resources/20/harnessing-half-life/
- After the video segment concludes, have students discuss the sequence of topics from the segment, using the order identified for the vocabulary words. Invite students to predict what they might be learning about today.

Radioactive Decay

- Explain to students that there are many different approaches to convert energy and they all have advantages and disadvantages. Nuclear scientists and engineers explore different ways to use radioactive decay for energy.
  Tell students that they will first compare Radioisotope Thermoelectric Generator (RTG), a type of radioisotope power system, and nuclear reactors which generate energy using fission, the splitting of an element into lighter elements.

- Distribute the Energy from Radioactive Decay Statements and Radioactive Decay Graphic Organizer. Invite students to sort the statements into categories defined on the graphic organizer. They may cut the statements into strips and place them on the graphic organizer or write them on the graphic organizer. Review the answers together. Alternatively, a digital graphic organizer can be created for students to sort and type in the statements: https://graphicorganizer.net/
- Summarize with students that RTGs have been used by NASA and are sometimes referred to as "nuclear batteries." RTGs are not fission reactors. They are used in missions where other options cannot provide the power that a mission may need to accomplish its scientific goals. It may be in darkness and where things like gas stations and outlets aren't available. Dozens of U.S. space missions have used RTGs since the first one was launched in 1961. Nuclear fission may be used to power larger spacecrafts in the future but for now is used in power plants to produce large amounts of energy to power communities.
- Additional information and visuals of Radioisotope Thermoelectric Generators can be found at https://solarsystem.nasa.gov/missions/cassini/radioisotope-thermoelectric-generator/.

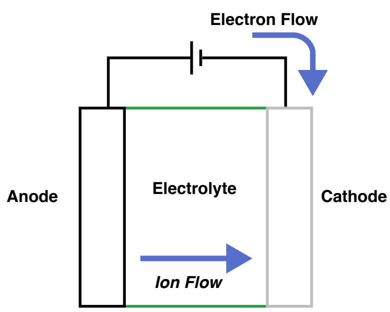
Nuclear Battery Engineering

- Explain to students that as a society, we are increasingly dependent upon batteries to power devices we use every day. Therefore, finding ways to engineer batteries at a smaller scale with enhanced lifetimes is of practical significance. Research into battery technology ranges from trying new materials to changing the configuration of key components.
- Nuclear batteries are devices that are engineered to utilize energy from the decay of a radioactive isotope to generate electricity. Similar to nuclear reactors, they generate electricity from nuclear energy. They are another way scientists are exploring how we can use radioactive decay for energy!
- Next, have students take out their Engineering Design Journal. Brainstorm with students the basic components of batteries as you draw a schematic of how an ion battery works.
- Exemplary response includes:

  A battery converts chemical energy to electrical energy and is composed of three general parts: anode (positive electrode), cathode (negative electrode), and electrolyte. The anode and cathode have two different chemical potentials, which depend on the reactions that occur at either terminus. The electrolyte can be a solid or a liquid, referring to a dry cell or wet cell respectively, and is ionically conductive.

  Sample Schematic of Ion Battery:

- The arrows indicate discharging. If both arrows reversed direction, the battery would be charging, and this battery would then be considered a secondary (rechargeable) battery.



https://tinyurl.com/yygcnud6

- Instruct student to copy your sketch and accompanying notes into their Engineering Design Journal.
- Next, explain that you will be exploring how engineers are working to refine and enhance this basic design, changing a battery's structure and composition to improve energy storage. Ask students to think about how many times they have to plug in their cell phones to charge. Then, prompt students to determine an average time for charging a phone to full capacity. Ask them to imagine a world in which they would be able to charge electronic devices in a matter of a couple of minutes or even seconds!

- Then, ask students to read the following articles independently (online or print a class set):
  https://wonderfulengineering.com/a-new-nanobattery-could-charge-your-phone-in-5-seconds/
  https://www.zdnet.com/article/3d-nano-structure-gives-batteries-a-quicker-charge/
- Lead a class discussion using the following questions:

  What are some characteristics of an ideal battery?

  How have engineers manipulated the structure of a battery to reduce its size and increase its power density?
- Next, pass out the handout, "8 Step Engineering Design Process." Tell students that they will be working in small engineering teams to identify a nuclear battery solution to improve energy storage and to investigate the underlying concepts through more in-depth research.
- Place students into teams, review the handout, and let them know that their Engineering Journal will be collected at the end of the activity.
  - First, they will select one of the problems/needs below to guide their research:
    - A cell phone battery that can last a week or longer and charge in less than 10 minutes.
    - An implantable medical device that includes a glucose sensor to help diabetics control their sugar levels.
    - A battery that uses beta decay to create electricity and can be used in portable devices in the military.
- Then, students should work in their engineering groups to begin their research using devices connected to the Internet. Here are some useful web sites to get students started on their research:

  https://www.understandingnano.com/batteries.html

  https://newatlas.com/city-labs-nanotritium-betavoltaic-battery/23720/

  https://www.energy.gov/sites/prod/files/2015/08/f26/Cabauy%20Tritium%20Focus%20Group%20Presentation.pdf

  https://citylabs.net/wp-content/uploads/2017/08/MicropowerBetavoltaicHybridSources.pdf

  https://www.electronicproducts.com/Power_Products/Batteries_and_Fuel_Cells/Powering_miniaturized_medical_devices.aspx

  https://www.medgadget.com/2019/05/crumpled-carbon-nanotube-forests-to-power-medical-devices.html
- They will document their chosen problem/need and the results of their investigation in an engineering journal. At this point, they will have completed the first two steps of the engineering design process:
  - Step 1: What is the need or problem?
  - Step 2: How will your team research the need or problem?
- Engineering teams will now complete the remaining steps of the engineering design process which are shown below.
  - Step 3: How will your team develop possible solution(s)?
  - Step 4: How will your team select the best possible solution(s)?
  - Step 5: How will your team design a prototype?
  - Step 6: How will your team test/evaluate the solution(s)?
  - Step 7: How will your team communicate the solution(s)?
  - Step 8: How will your team redesign the prototype?
- Remind students that they will need to document their explanations/diagrams for steps 3–8 of the engineering design process in their engineering journals.

- Allow each team to report out the results of their work. Give each engineering team two minutes to communicate their identified need/problem and the solution they came up with to address that need/problem. Using nuclear batteries has some obvious advantages but still have a way to go for use in consumer products. Share with students this is an exciting and evolving field with many pathways to careers. Check out.

Extension Activities

- As an extension, students can explore an engineering process that uses materials more efficiently to make very small batteries: 3D printed batteries.

  Resources:

  - https://www.nanowerk.com/spotlight/spotid=37541.php
  - https://3dprint.com/65973/3d-printed-microbatteries/
  - After reviewing these resources, invite students to participate in a discussion forum in which they address the following questions:
    - What is unique about this breakthrough engineering process for making batteries?
    - What are some practical applications of this breakthrough technology?
- Or, did you know the 2019 Nobel Prize in Chemistry was awarded for work with the Li+ battery? Read about the three awardees (Stanley Whittingham, Director of the Northeastern Center for Chemical Energy Storage (NECCES), a U.S. Department of Energy, Energy Frontier Research (EFRC) Center at Binghamton University) and check out their Nobel-approved diagram!
  https://www.nobelprize.org/uploads/2019/10/StudentWorksheet_ChemistryPrize_2019_NobelPrizeLessons.pdf

  How does it compare to your innovation?
  https://www.nobelprize.org/uploads/2019/10/Slideshow_ChemistryPrize_2019_NobelPrizeLessons.pdf

plutonium-238

decay

radioactivity

radioisotopes

isotopes

radioactive decay

half-life

Radioisotope Power System

Energy from Radioactive Decay Statements

STUDENT HANDOUT

Read the following statements and organize them into the graphic organizer. Two statements define Radioisotope Thermoelectric Generator and Nuclear Fission. The others should be sorted as alike or different.

Usually located near water to remove the heat the reactor makes

Uses uranium as fuel

A nuclear power plant is a type of power station that generates electricity using heat from nuclear reactions.

Uses plutonium as fuel

Portable

Desirable power source for unmaintained situations and long durations.

Power source for satellites, space probes, and remote unmanned lighthouses.

Power homes and businesses

An electrical generator that uses thermocouples to convert the heat released by the decay of radioactive material into electricity.

When an atom splits apart into smaller atoms it releases a lot of energy that can generate electricity.

Nuclear process

Generates electricity

Converts radioactive material into electricity

Uses fission

Energy from Radioactive Decay Graphic Organizer

STUDENT HANDOUT

Radioisotope Thermoelectric Generator	Nuclear Fission

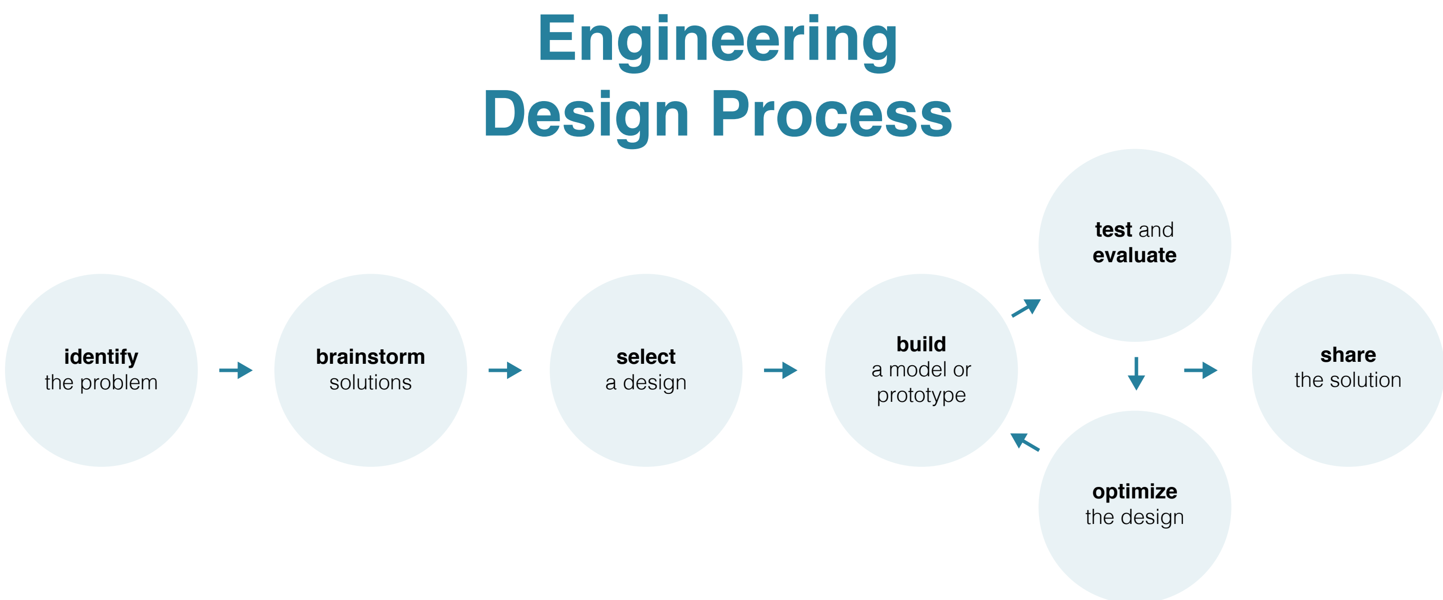
How are they alike?

How are they different?	

Name: ___________________________________

STUDENT HANDOUT

7 Step Engineering Design Process



Source: https://www.jpl.nasa.gov/edu/pdfs/engineering_design_process_light.pdf

Name: ____________________________________

STUDENT HANDOUT

Engineering Design Journal

The engineering design process involves a series of steps that leads to the development of new products or systems. In this design challenge, your team will complete each step and document your work as you propose a solution.

Step 1-Identify the Problem

1. What is the problem and/or the need that justifies the project?

2. Who is the target population and who will benefit from the solution?

3. How will the result of this solution impact peoples' lives, the educational community and/or the world?

Step 2—Research the Need

How will your team research the need or problem?

Step 3—Develop Possible Solutions

How will your team develop possible solution(s)?

Step 4—Solution

How will your team select the best possible solution(s)?

Step 5-Construct a Prototype

Based on what you have learned, use the grid below to sketch out your idea using a scale drawing (one in which all the dimensions are reduced or enlarged proportionally). Be sure to write the scale used and include units of measurement. Include a short explanation of the design elements that should be incorporated into your battery prototype. Include information from your internet research to support your recommendation.

Step 6—Test and Evaluate the Solution

How will your team test/evaluate the solution(s)?

Step 7—Communicate the Solution

How will your team communicate the solution(s)?

Step 8—Redesign/Critical Reflection

How will your team improve the design?