NAVIGATING™ NUCLEAR
Energizing Our World

Classroom Lesson

Topic

Fueling the Future

LEARNING OUTCOMES

- Students will compare and contrast nuclear fission and nuclear fusion.
- Students will think critically about various nuclear reactor designs and fuels.
- Should these include engineering outcomes?

Overview

In this activity, students first will watch a video explaining fission and fusion. Then, students will apply their knowledge of fission and fusion as they engage in a kinesthetic "Four Corners" activity, voting with their feet as they compare fission and fusion. Next, students will assume the role of nuclear engineers tasked with recommending a nuclear reactor design for a specific purpose/scenario. Each engineering team will present their scenario, answer research questions, and make a recommendation for a specific reactor type. The lesson includes several extension activities, including using an online interactive simulator to explore efficient nuclear reactor management, as well as exploring cutting edge advanced reactor technologies.

Grade level

9–12

Timing

- **Preparation**
  Up to one hour to gather materials, prepare suggested videos.
- **Activity**
  1 or 2 class periods, depending on class length and activities included.

Performance Expectation(s)

Students that understand the concept are able to:

HS-PS1-8. Develop models to illustrate the changes in the composition of the nucleus of the atom and the energy released during the processes of fission, fusion, and radioactive decay.

NGSS Standards

Science & Engineering Practices	Disciplinary Core Ideas	Crosscutting Concepts
• Planning and Carrying Out Investigations • Analyzing and Interpreting Data • Constructing Explanations and Designing Solutions	**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. **ETS1.C: Optimizing the Design Solution** • Criteria may need to be broken down into simpler ones that can be approached systematically, and decisions about the priority of certain criteria over others (trade-offs) may be needed.	• Patterns • Energy and Matter • Stability and Change

Essential questions

- How can you compare and contrast nuclear fission and nuclear fusion?
- What criteria need to be considered when designing a system to capture the binding energy released from fusion or fission to suit specific purposes?
- What are some applicable uses of fission and fusion?
- How do advanced nuclear options compare to the nuclear reactor designs in use now?

Learning outcomes

- Students will compare and contrast nuclear fission and nuclear fusion.
- Students will think critically about various nuclear reactor designs and fuels.

Prior Student Knowledge

This lesson will build students' appreciation of advanced nuclear reactors. At the heart of any nuclear power plant is the reactor. Inside the nuclear reactor there are nuclear fuel components where the nuclear reactions take place and heat is generated. Nuclear reactors serve three general purposes (civilian, military, and research). The chemical composition of the fuel, the type of coolant, and other details important to reactor operation dictate the reactor's design.

Prior to beginning the lesson, students should recall the following:

- The number of protons in a particular nucleus is called the atomic number (Z).
- The sum of the neutrons and protons is the mass number (A).
- Atoms that have identical atomic numbers, but different mass number values are called isotopes. We usually do not use the singular form *isotope* to refer to a particular member of a group of isotopes. Rather, we use the term nuclide.
- Unlike a chemical reaction, a nuclear reaction results in a significant change in mass and an associated change of energy, as described by Einstein's equation. Nuclear reactions are accompanied by large changes in energy, which result in detectable changes in mass. The change in mass is related to the change in energy according to Einstein's famous equation: $\Delta E = (\Delta m)c^2$, where ΔE is the change in energy, Δm is the change in mass and "c" is the speed of light constant (2.998×10^8 m/s).The energy corresponding to the change in mass is the nuclear binding energy, the amount of energy released when a nucleus forms from its component particles. In nuclear fission, nuclei split into lighter nuclei with an accompanying release of multiple neutrons and large amounts of energy. The critical mass is the minimum mass required to support a self-sustaining nuclear chain reaction. Nuclear fusion is a process in which two light nuclei combine to produce a heavier nucleus plus a great deal of energy. Because of the large binding energies involved in holding the nucleus together, both processes (fission and fusion) involve free energy changes more than a million times larger than those associated with common chemical reactions.

Lesson Plan

- Engage students by showing the following video and by using the Think-Pair-Share collaborative teaching strategy to frame instruction (show only the first 3 minutes 43 seconds): https://tinyurl.com/y6mzg2pc
- First, ask students to note their observations while watching the video.
- Following the video, ask students to pair with a partner and discuss their observations. Then, call on students using equitable calling strategies to share their thoughts and questions about the video. Further explanation and language could be lifted from the nuclear energy blog of fission vs. fusion May 2018

1. Next, tell students that they will get out of their seats to participate in a "Four Corners" activity, voting with their feet as they compare fission and fusion as a class.

   Materials (Teacher prepares these in advance):

   - Poster paper and markers to make signs for each corner of the room. Write the following on signs, and post each in a different corner:
     - Corner 1: Fission
     - Corner 2: Fusion
     - Corner 3: Fission AND Fusion
     - Corner 4: Neither Fission NOR Fusion
   - Statements to project or write on board. Examples of possible statements (with answers in red) include the following:
     - This process does not **normally** occur in nature **(FISSION)**.
     - This process produces more stable nuclides and is thus exothermic **(BOTH FISSION AND FUSION)**
     - Involves an energy change that is smaller than that associated with chemical reactions **(NEITHER FISSION NOR FUSION)**

- Involves combining two or more lighter atoms into a larger one **(FUSION)**
- Releases immense quantities of energy **(BOTH FISSION AND FUSION)**
- A high density, high temperature environment is required for this process **(FUSION)**
- Uses the energy stored in atomic particles in the energy production process **(BOTH FISSION AND FUSION)**
- Silicon is the nuclear fuel used in this process **(NEITHER FISSION NOR FUSION)**

Procedure for "Four Corners" Activity

- Project the first prepared statement that relates to fission and fusion (with the answer covered).
- Ask students to vote with their feet by going to the corner (either Fission, Fusion, Fission and Fusion, or Neither Fission nor Fusion) that they feel most accurately relates to the statement.
- After students have had the chance to vote, reveal the correct answer and address any misconceptions before moving on to the next statement. Repeat this process until all eight statements have been addressed, time permitting.
- Wrap up the activity by asking for students to volunteer their observations about fission and fusion. *What do fission and fusion have in common? How are they different?*

2. Next, tell students that they will assume the role of engineering teams*. (Form six groups of four to five students, depending upon class size). Their task will be to recommend a nuclear reactor design for a specific purpose/scenario after completing some online research as a group. Students can use the ***Fueling the Future*** handout to organize their work. After this activity, each engineering team will present their scenario, the answers to their research questions, and make a recommendation for a specific reactor type.

*Note: Helpful information (including a video) on the Engineering Design Process can be found at the following site: https://www.nasa.gov/audience/foreducators/best/edp.html

Materials needed:

- Devices connected to the Internet.
- Slips of paper with the six scenarios for random selection (one scenario per group), see below.
- List of reactor type choices (one per group), see below.

Provide students with the following list of the different types of reactors:

- Pressurized Water Reactor (PWR)
- Heavy Water Reactor (HWR)
- Small Modular Reactor (SMR)
- Radioisotope Thermoelectric Generator (RTG)
- Sodium-Cooled Fast Reactor (SFR)
- Kilopower Reactor (KR)

Next, inform students that each group will get a different scenario with a specific purpose for the reactor needed, as well as a fuel type to be used and any other relevant design constraints. Have a representative from each group of students randomly select a slip of paper with a description of a scenario.

Scenario 1	You are part of an engineering design team tasked with engineering a nuclear reactor that will produce the radio-isotope technetium-99m for medicine and research using natural uranium.
Scenario 2	You are part of an engineering design team tasked with engineering a nuclear reactor to be used in a nuclear-powered ship that generates steam outside the reactor. The reactor will need to use 5% UO_2.
Scenario 3	You are part of an engineering design team tasked with engineering a nuclear reactor that can be manufactured in a factory and shipped wherever needed. Your reactor will be used to provide power to an island nation in the Caribbean.
Scenario 4	You are part of an engineering design team tasked with engineering an advanced nuclear reactor that is capable of recycling depleted uranium and other fissile materials. The reactor will produce power for a public utility.
Scenario 5	You are part of an engineering design team tasked with engineering a reactor capable of producing multi-hundred watts of electricity to power a deep space probe using radioactive decay.
Scenario 6	You are part of an engineering design team tasked with engineering a fission reactor that can be employed to produce kilowatts of electricity for a colony on Mars.

Possible answers for nuclear reactor type listed next to each scenario:

Scenario 1: **HWR**

Scenario 2: **PWR**

Scenario 3: **SMR**

Scenario 4: **SFR**

Scenario 5: **RTG**

Scenario 6: **KR**

Resources that may be used for research include:

- How does a nuclear reactor work?
  https://www.energy.gov/ne/articles/nuclear-101-how-does-nuclear-reactor-work
- Advanced reactor technologies
  https://art.inl.gov/SitePages/ART%20TDO.aspx
  http://nuclearconnect.org/know-nuclear/technology/the-next-generation-of-reactors

- Propulsion powered by nuclear
  http://nuclearconnect.org/know-nuclear/technology/propulsion
- Radioisotope Power Systems
  https://rps.nasa.gov/
- Types of reactors
  https://www.nuclear-power.net/nuclear-power-plant/reactor-types/
- Pressurized water reactors vs boiling water reactors
  http://nuclearconnect.org/know-nuclear/technology/reactors
  https://nuclear.duke-energy.com/2012/03/27/pressurized-water-reactors-pwr-and-boiling-water-reactors-bwr
- Different types of coolants (water, molten salt, high temperature gas, and liquid metal)
  https://www.nrc.gov/public-involve/conference-symposia/ric/past/2019/docs/abstracts/mcdowellb-th32-hv-r1.pdf
- United States Nuclear Regulatory Commission (U.S. NRC)—Advanced Reactors
  https://www.nrc.gov/reactors/new-reactors/advanced.html
- Sodium Cooled Fast Reactors
  https://factsheets.inl.gov/FactSheets/sodium-cooled-fast-reactor.pdf
- Canadian Nuclear Association
  https://cna.ca/technology/energy/candu-technology/
- Fusion reactor progress
  http://nuclearconnect.org/know-nuclear/technology/fusion-progress

Explain to students that they will need to prepare a slide presentation using PowerPoint, Google Slides, or Prezi, etc. that includes the following components:

- **Slide 1**—Description of the scenario.
- **Slide 2**—Answers to the following research questions:
- What general type of reactor is appropriate for this application?
- What specific types of nuclear reactors might work?
  (List at least two types. If you can only come up with one, explain why only one is appropriate.)
- **Slide 3**—What are the advantages/disadvantages of these nuclear reactors?
- **Slide 4**—What is your recommendation for ONE specific reactor type your reasoning/justification?

Allow each group about five minutes to present. Following the presentations, have students share and discuss their thoughts and questions. Discussion questions might include: *What three general purposes do nuclear reactors serve? Can the same reactor be used for different purposes? If so, provide an example. What factors should be considered when designing a nuclear reactor?*

3. Extend the learning:

- Students will use an online interactive simulation to investigate the chain reactions that take place during nuclear fission and consider the significance of control rods. Also, they will experiment with different nuclear reactor settings as they try to design the most efficient nuclear fission reactor possible.
  - PhET Simulation – Nuclear Fission
    https://phet.colorado.edu/en/simulation/nuclear-fission

- Students will explore advancements in small modular reactors (SMRs), research and development in fusion reactor technology, and criteria for evaluating novel nuclear technologies by writing a summary analysis of the report below.
    - Congressional Research Service Report, April 18, 2019: https://crsreports.congress.gov/product/pdf/R/R45706

4. Evaluate the learning with the following:
    - Have students create an infographic comparing either nuclear fission and fusion or different nuclear reactor types.

Scenario Cards—Teacher Resource

TEACHER

Assign groups a different scenario by cutting the scenarios into strips and distributing randomly.

Scenario 1	You are part of an engineering design team tasked with engineering a nuclear reactor that will produce the radio-isotope technetium-99m for medicine and research using natural uranium.
Scenario 2	You are part of an engineering design team tasked with engineering a nuclear reactor to be used in a nuclear-powered ship that generates steam outside the reactor. The reactor will need to use 5% UO_2.
Scenario 3	You are part of an engineering design team tasked with engineering a nuclear reactor that can be manufactured in a factory and shipped wherever needed. Your reactor will be used to provide power to an island nation in the Caribbean.
Scenario 4	You are part of an engineering design team tasked with engineering an advanced nuclear reactor that is capable of recycling depleted uranium and other fissile materials. The reactor will produce power for a public utility.
Scenario 5	You are part of an engineering design team tasked with engineering a reactor capable of producing multi-hundred watts of electricity to power a deep space probe using radioactive decay.
Scenario 6	You are part of an engineering design team tasked with engineering a fission reactor that can be employed to produce kilowatts of electricity for a colony on Mars.

Fueling the Future

STUDENT HANDOUT

Did you know nuclear energy supplies 12 percent of the world's electricity and approximately 20 percent of the energy in the United States? Nuclear power can be obtained from nuclear fission and nuclear fusion reactions. We can design systems to capture the binding energy release from fusion or fission to suit specific purposes.

You will work as an engineering team to answer research questions and make a recommendation for a specific reactor type. Each team will have a different scenario and will need to think through the purpose of their reactor, the fuel type, and other relevant design constraints. Use the graphic organizer below to capture notes as you research. You will then need to prepare a slide presentation to share your ideas with classroom peers.

Description of scenario:		
What general type of reactor is appropriate for this application?		
What specific types of nuclear reactors might work? (List at least two types. If you can only come up with one, explain why only one is appropriate.)		
	Advantages:	Disadvantages:
What is your recommendation for ONE specific reactor type your reasoning/ justification?		