Energy and Matter – Changes in Nuclear Structure

Student Science Performance	
Grade Level: 9-12 Physical Science	**Title:** Changes in Nuclear Structure
Topic: Radioactive Decay	

SPS4. Obtain, evaluate, and communicate information to explain the changes in nuclear structure as a result of fission, fusion and radioactive decay.

a. Develop a model that illustrates how the nucleus changes as a result of fission and fusion.
b. Use mathematics and computational thinking to explain the process of half-life as it relates to radioactive decay.
(*Clarification statement*: Limited to calculations that include whole half-lives.)
c. Construct arguments based on evidence about the applications, benefits, and problems of nuclear energy as an alternative energy source.

Performance Expectations for Instruction:

- Collect data to develop a mathematical model for half-life as it relates to radioactive decay.
- Show that fission is the breaking apart of an atom and fusion is the merging of two isotopes.
- Demonstrate using 2D models that subatomic particles are given off and used in nuclear reactions.
- Demonstrate and model the concept of half-life with students mixing and drawing out pieces that have "decayed" (heads or tails) and calculating the half-life of the sample.
- Construct arguments about the uses of nuclear power.

Additional notes on student supports

Materials:

- Coins
- 100 candies (a plain hard-shelled chocolate candy that have a letter or symbol on one side)
- 100 candies (roughly same size and shape as above)
- Gallon sealable plastic bags
- Large bin, tub, or paper box top
- Paper towels

Engaging Learners	**Phenomenon:** **Consider one or both of the following scenarios:** If the Chernobyl nuclear meltdown happened in 1986, why are there still restrictions on people returning and restrictions on farming and hunting? If the Fukushima disaster happened in 2011, why is it still dangerous for people to be in the area near the meltdown? There are numerous sources online for videos and pictures of both accidents; Videos shown are not meant to explain completely how long dangerous isotopes remain in the area; this phenomenon should drive students towards constructing that explanation. Students complete a Claim-Evidence-Reasoning form as they are presented with this phenomenon. Most students understand that there is some type of contaminant, but the idea of time frame might be new. Some possible guiding questions to elicit student

	claims: • How can the area around where the accident happened still be dangerous even through the reactors are not even running? • How might authorities determine if/when it would be safe to return? • What could happen to people that stay in the closed areas? • How long does it take for the environment to become safe again? **Obtaining:** Half-life of Candium (Background and Pre-lab sections only) This activity serves as a model for half life and decay. It is important that students understand the nuclear accidents produced certain isotopes that are dangerous, but we can know exactly how long these isotopes last. The students will need to produce their own data tables for this portion of the activity. The students should make predictions about the number of each landing (heads/tails) before completing each round AND before sharing data. The idea here is that as the sample size increases, the probabilities of each landing type approaches 50%. **Communicating:** The initial communication about the phenomenon will occur on the CER template. With the Candium activity, students will record their prediction for their, hopefully changing, ideas about half-lives as they progress through the data collection for the activity. *Teaching Notes: The activity provides students with a definition of half-life in the background. However, many students interpret this definition to mean that half of the radioisotopes decay during the first half-life, and the remaining radioisotopes decay during the second half-life. The introductory/pre-lab has the students performing coin tosses to collect data on number of heads vs. tails. For a set of ten tosses, the students are unlikely to have 50% of each type. As the students increase the size of the data pool, the numbers of each landing should move toward 50%. This an effort to help them resolve their data for the "Candium" half-lives: as the number of radioactive nuclei increases, the probability of a decay approaches 50% for each individual nucleus during each half-life. It may be helpful to remind the students that a single gram of a radioactive substance will contain something on the order of* 10^{21} *atoms!* Additional notes on topic, focus, and phenomena.
Exploring	**Obtaining:** The students will seal their "Candium" in the bag and shake it for a few seconds. The "Candium" is then carefully dumped into the box lid or bin and the students begin sorting and counting. For each round, the group needs to make a prediction, prior to dumping the candy, about how many of the "Candium" nuclei will decay during that round. *These numbers should be decreasing each round as there will fewer radioactive*

	nuclei as the simulation progresses. **Evaluating and Communicating:** At the end of each round, the students will make a prediction for the decay in the upcoming round. During this process, they are making a mathematical model. This model will, most likely, evolve as the activity proceeds. It is useful, after the data collection phases, to bring the class together and engage in discussion about how their models/predictions changed during the lab. Students should revisit the initial CER from the phenomenon engage phase as they gain more experience with half-life. Challenge students to apply their mathematical model to the nuclear accident phenomenon. *Teacher Notes: The amount of candy required per group (3 students) is relatively low. A small bag of plain hard-shelled chocolate candies that have a letter or symbol on one side, like the ones found near the checkout in grocery stores, contains around 40 pieces. Have the students line their bin or box top with some paper towels to help keep the candy relatively clean. If the students provide their own candy, they may "dispose" of their edible materials as they see fit.* *Occasionally, a piece of "Candium" will land on its edge, held upright by another candy piece. Have the group gently shake the box lid so that the "indecisive" piece has an opportunity to fall on way or the other.* *It is typical for each group to have at least one "defective" candy that does not have a letter and, thus, will not decay. This is discovered during the last few rounds of dumping the candy. As a rule of thumb, if the students get three rounds with no candy decaying, have them inspect the candy with letters on one side - if there is no letter, have the group end their collection with the current round.* *The second misconception addressed by the activity is that, once the radioactive nuclei decay, they somehow "go away". During nuclear, the decay process transmutes the nucleus of one element into a nucleus of a different element - this may seem somewhat at odds with the idea of conservation of matter, which is observed during chemical and physical processes. The activity simulates this by having the students replace the radioactive isotopes which have decayed with a different piece of candy. The total number of nuclei in their sample will, however, remain constant.* *On the data table, the values in column B will gradually decrease, by roughly 50% each round. The values in column C are additive and should gradually increase in value. Column D, the sum of columns B and C, should always equal the groups initial number of pieces of "Candium" (~100).* *The students will produce two graphs for the data: group data and class data. To facilitate aggregating the group data), use the Excel spreadsheet: Half-life Data Spreadsheet - Class Totals (This is found on the Teacher Resource Link)* *An additional activity for exploring half-life modeling is HEADranium and MagTAILsium.*
Explaining	The students will make predictions and gather data for each round of the activity, and hopefully make connections to the pre-lab activity involving the coin tosses. The big idea here is for them to realize that during each "half-life" approximately one-half of

	the remaining, undecayed material should decay. The students will demonstrate their understanding of this idea by completing the post-lab questions. As students build understandings of half-life, consider reinforcing the ideas of fission and fusion. The candium activity only model fission, and students should still be producing models for fusion and other information concerning nuclear reactions. Consider these resources: • TedEd: Radioactivity: Expect the Unexpected • Fusion Energy • TedEd: Where Does Gold Come From? • Carbon Dating
Elaborating	The students are asked to produce two graphs of their collected data: individual group data and aggregated class data. In both cases, graphed the data should resemble exponential decay curves. The greater the number of data points, or initial nuclei, the more the curve will approach an exponential decay. In terms of calculating remaining, undecayed nuclei in the post-lab, allow student groups to derive their own equations/mathematical models. The simplest model involves the student simply dividing the initial number of nuclei (or mass) by 2 and repeating this process for each half-life that has passed. The formula that they are using in this case: $$n_{remaining} = \frac{n_{initial}}{2^x}$$ where n is the number (or mass) of undecayed nuclei, and x is the number of half-lives that have passed. After completing lab, students elaborate on fission reactions specifically to address part c of the standard where students are constructing arguments about nuclear energy. Arguments should include initial claims about the engage phenomenon (or revised claims). Additional research for arguments could provide students with the most prevalent isotopes that were released during the nuclear accidents, and the half-lives showing why certain areas are still unsafe. Models (2D or 3D) showing fission and fusion should be used as part of the argument as well. Students can use the Argument Template to organize their initial ideas. There are multiple online resources for students to consult as they develop their arguments; consider the following: • cK-12 Nuclear Power • TedEd: How Do Nuclear Power Plants Work?
Evaluation	**Assessment of Student Learning**

	Mastery of the concept of half-life is assessed, formatively, by completion of the activity including participation in the small group discussions which should take place during the data collection/prediction phases and completion of the post-lab questions. Alternatively, questions regarding half-life and nuclear decay are included in a summative assessment on energy as a whole. The evaluation of the nuclear energy portion of the unit is based on the written responses with argumentation template as well as the argumentation session where students (or student groups) exchange ideas and present arguments to others.
SEP, CCC, DCI	**Science Essentials**
Science and Engineering Practices	● Develop and use models ● Use mathematics and computational thinking ● Constructing explanations ● Engaging in argument from evidence
Crosscutting Concepts	● Patterns ● Cause and Effect ● Systems and System Models
Disciplinary Core Ideas	From A Framework for K-12 Science Education: 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.

Additional Supports for struggling learners:

The following supports are suggestions for this lesson and are not the only options to support students in the classroom. These supports target students that struggle with science material, this lesson or a previous lesson. These are generalized supports and do not take the place of IEP accommodations as required by each student's Individualized Education Program.

General supports for the following categories:

<table>
<tr>
<td>Reading:
1. Provide reading support by reading aloud or doing partner reads
2. Have the teacher model what they are thinking when reading the text
3. Annotate the text with students so that they may refer to it as they work through the lab</td>
<td>Writing:
1. The teacher can provide a sentence starter for the students.
2. The teacher can give students an audience to write to (i.e. Write a letter to your sibling explaining this topic).
3. The teacher can provide constructive feedback during the writing process to help students understand the expectations.</td>
<td>Math:
1. Provide calculators as needed.
2. Provide graph paper as needed.</td>
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Supports for this specific lesson if needed:

Performance expectations for instruction:

1. The teacher should provide information to students in various formats to reach as many students as possible.
2. The students should be given adequate time to complete each part of the lesson.
3. The students should be allowed to express their knowledge in various formats.
4. The teacher should be sure to provide multiple ways for the students to communicate their knowledge of the material.

Engage:

1. The teacher should consider using a video, article and images to reinforce the phenomena.
2. The teacher should consider providing questions in advance to struggling students. This will allow struggling students to formulate answers in advance of the discussion.
3. The teacher should explicitly explain data tables and show students how to record data in the data tables.

4. The teacher should carefully look for misconceptions during the engage section and decide how to address them.
Exploring: 1. The teacher should explain the directions for the lab and be prepared to repeat directions as needed. 2. The teacher should provide additional time for revisions of the claim after the students have collected data. 3. The teacher should consider providing a sample graph for students to compare their graph. Then students can make revisions as needed and explain why the graph needs to change.
Explaining: 1. The teacher should be walking around and looking at the answers of the post lab questions. This can be a good formative assessment for students. 2. The teacher can use this information to re-teach, review or enrich as needed. 3. The teacher should consider using articles, videos and interactives to help students understand half-life.
Elaborating: 1. The teacher should show students an exponential decay curve and have students explain why the data looks this way. Ask students to compare these curves to the data that they gathered in the lab. 2. The teacher may need to help students with the math. The students may need to see the math problem worked out to understand how this relates to data that they have collected. 3. The teacher should define scientific argument. Then provide the argument template to students to aid in the students setting up a scientific argument. 4. The teacher should consider giving resources to students to aid in developing scientific arguments.
Evaluating: 1. The teacher should be sure to check for understanding throughout the lesson and build in re-teaching, review and enrichment as needed by each student. 2. The teacher should provide tangible and constructive feedback for students throughout the lesson. 3. The teacher should provide multiple formats for students to express their knowledge. These formats could include writing, drawing or designing a play. 4. Students may need additional time to revise and present their arguments.

Claim-Evidence-Reasoning Template

Long after a nuclear accident, why is it still dangerous for people to be in the same area?	
Initial Claim	
Supporting Evidence	
Reasoning	

Return to Instructional Segment

Half-life of Candium: A Sweet Simulation

PURPOSE: To explore the idea of half-life and nuclear decay.

BACKGROUND:

As you have already learned, certain atomic nuclei are unstable and considered radioactive. These radioactive nuclei can undergo spontaneous decay, transmuting into a new nucleus and releasing ionizing radiation. The term ***half-life*** is defined as the amount of time it takes for one-half of the nuclei of a radioisotope to decay. The length of a half-life varies greatly and is unique for each radioisotope, ranging from microseconds to billions of years.

In this activity you will explore the idea of half-life using the made-up element, ***Candium***. Plain hard-shell plain chocolate candy will represent the radioactive nuclei. We have to use these as these candies have a letter printed on one side. Each time you dump your zip top bag, some of these radioisotopes will land face (letter-side) up and some will land letter-side down. Letter side up will be considered "decayed" and these pieces will need to be counted then replaced 1:1 with your second type of candy.

MATERIALS:

1 coin

100 candies (plain hard-shell plain chocolate candy with a letter or symbol printed on one side)

100 candies (roughly same size and shape as above)

Gallon zip top bags

Large bin, tub, paper box top

Paper towels

Graph paper

PRE-LAB QUESTIONS:

Using a coin, flip the coin ten times. For each time, record if the coin lands "heads" side up or "tails" side up. You may need to create a data table for you. Answer the following questions

1. In theory, how many heads or tails should you have observed after flipping ten times? What percent of each (heads/tails) do you predict?

2. Does the answer to number 1 match your observed data?

3. Calculate the "percent heads" for your data $\frac{\#\,of\ time\ heads\ up}{\#\,of\ coin\ tosses}\ x\ 100 = percent\ heads\ up$

4. Share your data with a group near you and pool your results. Your sample size is now 20. Calculate the "percent heads" for your new data.

5. Collect the results from each lab group in your class and determine the number of times (as a class) that heads up was observed. Calculate the "percent heads" for this data.

6. Imagine that you had 100,000 coin tosses. Heads up was observed 50,300 times. Calculate the "percent heads" for this data.

7. As the sample size increased, what happened to the "percent heads" values?

8. As the sample size increased, does the data become closer to or farther from matching your predicted values (in terms of percent) from question 1?

PROCEDURE:

1. Count your radioactive nuclei (plain chocolate hard shell candies). This is your initial data for row zero on your data table. Record this number as your number of **Undecayed, Radioactive Nuclei Remaining** (column B). This number is also your **Total Number of Nuclei** (column D).

2. With your partner(s), make a prediction as to how many of your radioactive nuclei will "decay" when you dump the bag. Record your prediction in column E on your data table.

3. Place your "radioactive nuclei" in a zip top bag, seal and shake for 5 - 10 seconds.

4. Pour the “nuclei” onto your paper towel. Separate the “nuclei” into two piles, one with the letter side up and the other with the letter side down and count the number of “nuclei” in each pile

5. In row 1 on your data table, record how many of your nuclei decayed (landed letter side up) in the column labeled **Decayed Nuclei (total)** (column C). Record the number of **Undecayed, Radioactive Nuclei Remaining** (column B) that remained letter side down. Finally, add the values from columns B & C together and record this as **Total Number of Nuclei** (column D)

6. Return only the **Undecayed, Radioactive Nuclei Remaining** to your bag. (You decide what to do with the “decayed nuclei,” or those with the letter side up.)

7. Replace each of the **Decayed Nuclei** (hard shell plain chocolate candy), 1:1 with your second candy. Place these new pieces in your bag with the **Undecayed, Radioactive Nuclei Remaining**. Your bag should now have a mixture of the two types of candy.

8. With your partner(s), make a prediction as to how many of your radioactive nuclei will “decay” when you dump the bag again. Record your prediction in column E on your data table, this time in row 2.

9. Pour the “nuclei” onto your paper towel. Separate the “nuclei” into three piles, one with the letter side up, one with the letter side down, and one of the second candy type.

10. Place all of the pieces of the second candy type back in your bag.

11. Count the number of **Undecayed, Radioactive Nuclei Remaining** (candy, letter side down) and record this value in row 2 (column B).

12. Count the number of **Decayed Nuclei** (candy, letter side up). Add this number to the value of **Decayed Nuclei** from the previous row on your data table and record the new value in row 2, **Decayed Nuclei (total)** (column C). Notice that this new number MUST be greater than or equal to the number in the row above.

13. For row 2, add the values from columns B and C together and record this as **Total Number of Nuclei** (column D).

13. Replace each of the **Decayed Nuclei** (hard shell plain chocolate candy), 1:1 with your second candy. Place these new pieces in your bag with the **Undecayed, Radioactive Nuclei Remaining**. Your bag should have a mixture of the two types of candy.

14. Repeat steps 8-13 until there are no **Undecayed, Radioactive Nuclei Remaining** (M&M or Skittle, letter side down) remaining. Be sure to replace the letter side up pieces each round with the second candy. You will know that you are done when your bag is filled with only your second candy. YOU MAY NOT NEED TO USE ALL OF THE ROWS ON YOUR DATA TABLE.

15. Take your data to your teacher so that they may help you pool each groups data to get a class set.

16. Once all groups are finished collecting data, record the class totals for each row, Columns B and C, in Data Table 2.

DATA ANALYSIS:

You will be producing two graphs to help analyze your data and look for patterns. For each graph, your X-axis will be **Bag Dump Number (column A)** and the Y-axis will be **Undecayed, Radioactive Nuclei Remaining** (column B).

Graph #1 will be created using your Group Data from data Table 1.

Graph #2 will be created using your Class Data from data Table 2.

POST LAB QUESTIONS:

1. In our activity we shook the bag of radioactive nuclei for 10 seconds before each toss. What was this period of time simulating?

2. How many total nuclei did you have at the end of each turn? What Law from Chemistry does this model or represent?

3. How does your group's data compare to the term "half-life" as defined in the Background information?

4. How does the class data compare to your group's data? Examine your two graphs. What are the similarities? What are the differences? Offer an explanation for why we pooled the group data and graphed class data?

5. Is there any way to predict when a specific piece of candy will letter marked side up or “decayed?” If you could follow the fate of an individual atom in a sample of radioactive material, could you predict exactly when it would decay? Explain.

6. If you started with a sample of 600 undecayed, radioactive nuclei, approximately how many *should* remain radioactive, undecayed after dumping your bag three times?

Date Table 1 – My Group

[A] Bag Dump Number	[B] Undecayed, Radioactive Nuclei Remaining	[C] Decayed Nuclei (total)	[D] Total Number of Nuclei	[E] Prediction for number of nuclei to decay this round
0		0		-------------------
1				
2				
3				
4				
5				
6				
7				
8				
9				
10				
11				
12				
13				
14				
15				

Date Table 2 – Class Data

[A] Bag Dump Number	[B] Undecayed, Radioactive Nuclei Remaining	[C] Decayed Nuclei (total)
0		0
1		
2		
3		
4		
5		
6		
7		
8		
9		
10		
11		
12		
13		
14		
15		

Return to Instructional Segment

HEADranium and MagTAILSium
Materials and Equipment
10 pennies, Graph paper, 4 different color pencils

Introduction
The decay of unstable isotopes is used to determine the age of materials. As unstable isotopes decay they become other elements. Measuring the quantity of each atom in the material can help to determine its age. The half-life is the amount of time it takes for half of the unstable isotope to decay into a different element.

Terms and Concepts
- Isotope
- Radioactive decay
- Half-life

Questions for Background Research
- What are isotopes?
- What is the half-life of an isotope?

Experimental Procedure
TRIAL 1

1. Place all pennies on your work space heads side up. This represents 10 atoms of the element "HEADranium," a radioactive isotope.
2. Pick up all 10 pennies.
3. Holding the pennies in one hand 6 inches above the work space, drop the pennies.
4. The pennies that landed tails side up represent atoms of a more stable element "magTAILSium."
5. Remove the magtailsium atoms from the work space. Count the remaining headranium atoms. Record this value in Table 1 under Drop 1.
6. Hold only the headranium atoms in your hand. Drop them back on the work space.
7. Remove the magtailsium atoms and place with the previously formed magtailsium atoms. Count and record the remaining headranium atoms in the Drop 2 column of Table 1.
8. Repeat steps 6 and 7 until all atoms have converted to headranium or until you have completed all 10 drops.
9. **TRIAL 2**
10. Repeat steps 1-8. Record your data in Table 2.
11. **TRIAL 3**
12. Repeat steps 1-8. Record your data in Table 3.
13. Calculate the average number of headranium atoms for each drop and record in Table 4.
14. Graph your results from Trials 1, 2, 3, and the average in Table 4.
    1. Place Tosses on the x-axis and the number of headranium on the y-axis.
    2. Use a different color pencil for each set of data.
15. Calculate the average half-life for headranium. This is the number of tosses it took for half of the pennies to "decay" to magtailsium.
16. Assume that there are 25 years between drops. Using your Table 4 data, how old would a fossil be with 3 headranium atoms and 7 magtailsium atoms?

Return to Instructional Segment

Argument Template for Nuclear Energy

Task: Construct arguments based on evidence about the applications, benefits, and problems of nuclear energy as an alternative energy source.	
How do nuclei change during these reactions? • **Give specific examples** • **Include a nuclear-level diagram**	
Applications	
Benefits	
Problems	

Return to Instructional Segment

Energy and Matter GSE: SPS4 a, b, c			
Anchoring Phenomenon: Long after a nuclear accident, certain areas remain dangerous due to isotope half-lives.			
Topic	**Focus**	**Lesson Phenomenon**	**GSE/Notes/Language**
Fission and Fusion	• Students will show that fission is the breaking apart of an atom and fusion is the merging of two isotopes. • Students will understand that these reactions only take place under very specific circumstances and with specific elements. • Student models (2D) should demonstrate that subatomic particles are given off and used in these reactions.	*Fusion reactions power the sun.* The sun is powered by perpetual fusion reactions, and, by extension, all life on earth is powered by this as well.	SPS4a. Develop a model that illustrates how the nucleus changes as a result of fission and fusion.
Radioactive decay	• Students will review isotopes from the previous instructional segments. • Students should understand how isotopes decay prior to exploring half-lives. • Simple activities with pennies or paper can be used to demonstrate the concept of half-life with students mixing and drawing out pieces that have "decayed" (heads or tails) and calculating the half-life of the sample.	*After a nuclear accident, like Chernobyl, isotopes with long half-lives contaminate areas for decades.* *Radioactive decay is used to date historical relics.*	SPS4b. Use mathematics and computational thinking to explain the process of half-life as it relates to radioactive decay. (Clarification statement: Limited to calculations that include whole half-lives.)
Nuclear energy	• Students should understand the benefits and drawbacks of nuclear power. • Students will describe (in general) how a nuclear power works	*Due to an earthquake and a resulting tsunami in Japan in 2011, a nuclear meltdown occurred at the Fukushima power plant.*	SPS4c. Construct arguments based on evidence about the applications, benefits, and problems of nuclear energy as an alternative energy source.

Return to Instructional Segment