

**Teacher’s Guide**

**Chernobyl’s Legacy**

***February 2020***

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Activate students’ prior knowledge and engage them before they read the article.

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These questions are designed to help students read the article (and graphics) carefully. They can help the teacher assess how well students understand the content and help direct the need for follow-up discussions and/or activities. You’ll find the questions ordered in increasing difficulty.

[Graphic Organizer 5](#_Answers_to_Reading)

Thishelps students locate and analyze information from the article. Students should use their own words and not copy entire sentences from the article. Encourage the use of bullet points.

[Answers 6](#_Answers_to_Reading)

Access the answers to reading comprehension questions and a rubric to assess the graphic organizer.

[Additional Resources 9](#_Additional_Resources_1)

Here you will find additional labs, simulations, lessons, and project ideas that you can use with your students alongside this article.

[Chemistry Concepts, Standards, and Teaching Strategies 10](#_Chemistry_Concepts,_Standards,)

# Anticipation Guide

Name: \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

**Directions: *Before reading the article*,** in the first column, write “A” or “D,” indicating your **A**greement or **D**isagreement with each statement. Complete the activity in the box.

As you read, compare your opinions with information from the article. In the space under each statement, cite information from the article that supports or refutes your original ideas.

|  |  |  |
| --- | --- | --- |
| **Me** | **Text** | **Statement** |
|  |  | 1. Most of the people who left Chernobyl after the nuclear plant explosion have returned. |
|  |  | 1. The accident at Chernobyl occurred during a safety test. |
|  |  | 1. Temperatures inside the reactor during the explosion were as hot as parts of the Sun’s atmosphere. |
|  |  | 1. The fuel in the reactor included U-238 from enriched uranium dioxide. |
|  |  | 1. A radioactive cloud blew across Northern Europe after the explosion. |
|  |  | 1. Isotopes of the same element have the same number of neutrons. |
|  |  | 1. When one mole of U-235 undergoes fission, the energy released can power about 400 average U.S. homes for a year. |
|  |  | 1. Nuclear reactors must have control rods to keep a chain reaction from occurring. |
|  |  | 1. Radioactive strontium can lead to bone cancer. |
|  |  | 1. The radioactive iodine released during the explosion still poses a health threat to people in Northern Europe. |

# Student Reading Comprehension Questions

Name: \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

**Directions**: Use the article to answer the questions below.

1. Why is there an exclusion zone in Chernobyl?
2. How many nuclear reactors did Chernobyl have?
3. What type of fuel was used in the reactors in Chernobyl?
4. Describe the function of control rods in a nuclear reactor.
5. Nuclear reactions involve the nucleus of an atom. Which two subatomic particles are found in the nucleus of an atom?
6. What are isotopes? Give an example not cited in the article.
7. List the three radioisotopes that can result from the decay of U-235 in order of their half-lives.
8. Describe the process of fission in U-235.
9. If you start with a 30 g sample of I-131, how many grams of I-131 would there be after 16 days?
10. Explain how half a pound of U-235 can generate enough energy to power 400 average U.S. homes for a year.

**Student Reading Comprehension Questions, cont.**

**Questions for Further Learning**

***Write your answers on another piece of paper if needed.***

1. In 1979, the U.S. experienced a nuclear accident at Three Mile Island. Do some research and compare and contrast the two events.
2. Th-232 undergoes decay by emitting the following particles: alpha, beta, beta, alpha, alpha, alpha, alpha, beta, beta, alpha. What is the resulting isotope? Write out the entire decay series.
3. Do some research to conclude why alpha radiation is dangerous when ingested, beta particles cause damage to skin, and gamma radiation damages human cells.
4. Develop a list of at least three drawbacks and three benefits for using nuclear power as an energy source. Examine your list and explain whether or not we should continue to use nuclear power. Read the *Open for Discussion* article in this issue to help you decide.

# Graphic Organizer

Name: \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

**Directions**: As you read, complete the graphic organizer below to describe what happened during and after the explosion of the nuclear power plant at Chernobyl.

|  |  |
| --- | --- |
|  | **Nuclear Explosion at Chernobyl** |
| **When did it happen?** |  |
| **Where did it happen?** |  |
| **What happened?** |  |
| **How could the explosion have been prevented?** |  |
| **What radioisotopes were produced?** |  |
| **What kind of radiation was emitted?** |  |
| **How were human beings affected?** |  |

**Summary:** In the space below, or on the back of this paper, write three new things you learned about nuclear power plants and/or nuclear radiation.

# Answers to Reading Comprehension Questions & Graphic Organizer Rubric

1. **Why is there an exclusion zone in Chernobyl?**

*The exclusion zone restricts access to the area around Chernobyl. The soil is still radioactively contaminated after the Chernobyl nuclear explosion.*

1. **How many nuclear reactors did Chernobyl have?**

*Chernobyl had four nuclear reactors.*

1. **What type of fuel was used in the reactors in Chernobyl?**

*Uranium dioxide, UO2, was the fuel in the reactors in Chernobyl.*

1. **Describe the function of control rods in a nuclear reactor.**

*Control rods slow chemical reactions because they absorb neutrons. This prevents the neutrons from reacting with additional uranium.*

1. **Nuclear reactions involve the nucleus of an atom. Which two subatomic particles are found in the nucleus of an atom?**

*Protons and neutrons are found in the nucleus of an atom.*

*s.*

1. **What are isotopes? Give an example not cited in the article.**

*Isotopes are atoms of the same element that have the same number of protons and electrons but different numbers of neutrons. To find more information about isotopes, visit the Isotopes Matter website at https://applets.kcvs.ca/IPTEI/IPTEI.html.*

1. **List the three radioisotopes that can result from the decay of U235 in order of their half-lives.**

*Iodine -131 half-life of eight days, strontium – 90 half-life of 29 years, cesium-137 half-life of 30* years

1. **Describe the process of fission in U-235.**

*In fission, the nucleus of a U-235 atom is bombarded by a neutron. This splits the nucleus to release a daughter nuclei, more neutrons, and energy.*

1. **If you start with a 30 g sample of I-131, how many grams of I-131 would there be after 16 days?**

*There would be 7.5 grams of I-131.*

1. **Explain how half a pound of U-235 can generate enough energy to power 400 average U.S. homes for a year.**

*When one atom of uranium goes through fission, the reaction releases a small amount of energy. When the reaction is repeated on the mole scale though, the self-sustaining reaction becomes significantly larger, producing exponentially more energy.*

**Student Reading Comprehension Questions, cont.**

**Questions for Further Learning**

1. **In 1979, the U.S. experienced a nuclear accident at Three Mile Island. Do some research and compare and contrast the two events.**

*Three Mile Island information can be found here:* [*https://www.thebalance.com/three-mile-island-nuclear-accident-facts-impact-today-3306337*](https://www.thebalance.com/three-mile-island-nuclear-accident-facts-impact-today-3306337)

***From the article:***At 4 a.m. on March 28, a cooling circuit malfunctioned, allowing the primary coolant to overheat. The reactor shut down immediately, and the release valve opened for 10 seconds, which allowed enough coolant to escape to reduce pressure and heat. But the valve got stuck in the open position, and as a result, all the coolant was released. Unfortunately, there wasn't an instrument that could have alerted engineers that this had happened.

New coolant rushed into the tank, but the engineers now thought that there was too much, so they reduced the flow. The remaining coolant turned to steam. The fuel rods overheated, melting the protective coating, which released radioactive material into the coolant. When the steam was released, the radioactive contaminant was released into the surrounding area. Fortunately, the amount released was not enough to harm local food supplies, animals, or people.

*Chernobyl scenario: Operator errors and design flaws in the reactor. A power surge caused the temperature and pressure of the reactor to rise dramatically creating a meltdown and explosion. Additionally, there were only eight control rods in the reactor when there should have been at least 15.*

1. **Th-232 undergoes decay by emitting the following particles: alpha, beta, beta, alpha, alpha, alpha, alpha, beta, beta, alpha. What is the resulting isotope? Write out the entire decay series.**

*Pb-208*

*23290Th 🡪 42α + 22888Ra*

*22888Ra 🡪 0-1β + 22889Ac*

*22889Ac 🡪 0-1β + 22890Th*

*22890Th 🡪 42α + 22488Ra*

*22488Ra 🡪 42α + 22086Rn*

*22086Rn 🡪 42α + 21684Po*

*21684Po 🡪 42α + 21282Pb*

*21282Pb🡪 0-1β + 21283Bi*

*21283Bi🡪 0-1β + 21284Po*

*21284Po 🡪 42α +20882Pb*

1. **Do some research to conclude why alpha radiation is dangerous when ingested, beta particles cause damage to skin, and gamma radiation damages human cells.**

*Alpha particles are two protons and two neutrons, so they are too large to penetrate human skin. If alpha particles are ingested through food or breathing contaminated air, the large particles can wreak havoc on the human body inside.*

*Beta particles are an electron expelled from a nucleus, so they are small high-energy particles that can penetrate pores in the skin.*

*Gamma rays are the most dangerous because it is pure energy, not matter. These rays can pass through human cells and cause damage.*

1. **Develop a list of at least three drawbacks and three benefits for using nuclear power as an energy source. Examine your list and explain whether or not we should continue to use nuclear power. Read the *Open for Discussion* article in this issue to help you decide.**

*Benefits: Source of low carbon energy, considered safe, produces a large amount of energy, low fuel costs*

*Drawbacks: Long-term waste disposal can be expensive, potential for nuclear accidents, initial building of nuclear reactor can be expensive*

**Graphic Organizer Rubric**

If you use the Graphic Organizer to evaluate student performance, you may want to develop a grading rubric such as the one below.

|  |  |  |
| --- | --- | --- |
| **Score** | **Description** | **Evidence** |
| 4 | Excellent | Complete; details provided; demonstrates deep understanding. |
| 3 | Good | Complete; few details provided; demonstrates some understanding. |
| 2 | Fair | Incomplete; few details provided; some misconceptions evident. |
| 1 | Poor | Very incomplete; no details provided; many misconceptions evident. |
| 0 | Not acceptable | So incomplete that no judgment can be made about student understanding |

# Additional Resources

**Labs and demos**

Twizzler Half-Life: In this lab activity students use licorice to understand and graph half-life and radioactive decay. <https://teachchemistry.org/classroom-resources/twizzler-half-life>

Fission Demonstration: In this demonstration, students use balloons to simulation fission. <http://nuclearconnect.org/in-the-classroom/for-teachers/what-is-fission>

Half-Life: In this lab, students visualize the random nature of atomic decay (or first order chemical reactions). It helps them answer the inevitable question of what happens when a decaying material reaches a single particle of the species. <https://teachchemistry.org/classroom-resources/half-life>

Using Dice to Explore Radioactive Decay: In this activity, students will use dice to simulate the radioactive “decay” of samples of two different elements with two different half-lives.<https://teachchemistry.org/classroom-resources/using-dice-to-explore-radioactive-decay>

**Simulations**

Half-Life Investigation: This simulation provides students with an opportunity to explore the decay of two unstable atom samples. <https://teachchemistry.org/classroom-resources/half-life-investigation-simulation>

Isotopes & Calculating Average Atomic Mass: <https://teachchemistry.org/classroom-resources/isotopes-calculating-average-atomic-mass-simulation>

**Lessons and lesson plans**

Nuclear Energy and the Three Mile Island Unit Two Accident: This set of lesson plans explores nuclear energy and the function of nuclear reactors. <http://www.efmr.org/edu/nuclear2009.pdf>

**Projects and extension activities**

Detecting Radiation in our Radioactive World: This teacher resource guide contains several hands-on activities designed to help students understand fission, radioisotopes, and decay chains. <http://nuclearconnect.org/wp-content/uploads/2015/04/ANS-Teacher_Resource_Guide.pdf>

Nuclear Energy Power Plants: In this activity, students will write a persuasive essay in which they state an opinion about whether the number of nuclear plants should be increased or decreased. <https://teachchemistry.org/classroom-resources/nuclear-energy-power-plants>

# Chemistry Concepts, Standards, and Teaching Strategies

**Connections to Chemistry Concepts**

The following chemistry concepts are highlighted in this article:

* Atomic Structure – Isotopes
* Nuclear Chemistry
  + Alpha/beta/gamma decay
  + Half-lives
  + Pros/cons of nuclear power
  + Radioactive isotopes
  + Radiation

**Correlations to Next Generation Science Standards**

This article relates to the following performance expectations and dimensions of the NGSS:

**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.

**HS-ETS1-3**

Evaluate a solution to a complex real-world problem based on prioritized criteria and tradeoffs that account for a range of constraints, including cost, safety, reliability, and aesthetics, as well as possible social, cultural, and environmental impacts.

**Disciplinary Core Ideas:**

* PS1.C: Nuclear Processes
* ETS1.C: Optimizing the Design Solution

**Crosscutting Concepts:**

* Cause and Effect: Mechanism and explanation
* Scale, Proportion, and Quantity
* Energy and Matter

**Science and Engineering Practices:**

* Constructing explanations and designing solutions
* Analyzing and interpreting data
* Obtaining, evaluating, and communicating information

**Nature of Science:**

* Science is a human endeavor.

Student Reading Comprehension Questions – connections to NGSS Crosscutting Concepts:

* Q7 + Q9: Scale, Proportion, and Quantity
* Q4: Structure and Function
* Further Learning Q2: Scale, Proportion, and Quantity

**Correlations to Common Core State Standards**

See how *ChemMatters* correlates to the[**Common Core State Standards**](https://www.acs.org/content/acs/en/education/resources/highschool/chemmatters/teachers-guide.html) at www.acs.org/chemmatters.

**Teaching Strategies**

Consider the following tips and strategies for incorporating this article into your classroom:

* Alternative to the Anticipation Guide provided: Before reading, ask students if they have heard about Chernobyl. If students have never heard of the nuclear accident at Chernobyl, tell them there was a serious accident at the nuclear power plant in Chernobyl and ask them what questions they have about the accident or its aftermath. As they read the article, students should look for answers to their questions.
* Encourage students to watch the video (What Exactly Happened at Chernobyl? [bit.ly/ACSReactions-Chernobyl](https://www.acs.org/content/acs/en/pressroom/reactions/videos/2019/what-exactly-happened-at-chernobyl.html)) *after* they read the article. The video summarizes much of the information in the article and presents some animation to help students understand what happened.
* After students read “Chernobyl’s Legacy,” ask them to read “Open for Discussion: Can Nuclear Power Save the Planet” on page 4 of this issue of *ChemMatters*. Then ask students to list (or debate) the pros and cons of nuclear power.
* Have students do the Radioactivity Puzzle on the next page.

**Radioactivity Puzzle**

**Sources of ionizing radiation**

A lot of radioactive elements are either mined in a quarry (like uranium) or made in a lab (like americium). But there are a lot of things in your everyday life that are sources of ionizing radiation. Unscramble the words and phrases below to find some of them.

1. UNS
2. PASS
3. CHEWSAT
4. ANABANS
5. BEANSTEMS
6. ARLBIZ STUN
7. COTTONPURSE
8. KOMES DECOTTERS

**Uses of ionizing radiation**

Radiation from unstable isotopes has more uses than you think. Unscramble these words and phrases to find a few of those uses.

1. AMBERSINUS
2. PROWE LTSNAP
3. PACES ORBSEP
4. KALE CITEDNOTE
5. ARCENC MATTRENTE
6. CLAIMED ADIOSSIGN
7. NUTRIMENTS INITIALZOSTER
8. ODOF INCANTATIONMODE

**Answers**

**Sources of ionizing radiation**

A lot of radioactive elements are either mined in a quarry (like uranium) or made in a lab (like americium). But there are a lot of things in your everyday life that are sources of ionizing radiation. Unscramble the words and phrases below to find some of them.

1. **Sun**  
   Fusion reactions in the sun’s core emit powerful gamma (γ) radiation that travels to the Earth. This radiation is responsible for generating a steady supply of radioactive 14C on the Earth’s surface. Since the sun’s rays cannot reach under the crust, scientists can measure the amount 14C in buried objects to determine their age in a process called carbon dating.
2. **Spas**  
   Radon occurs naturally as a result of the radioactive decay of uranium in the soil. Because it is the densest gas known, it tends to accumulate in underground spaces, such as mines and basements. In the 1950s, a number of abandoned gold and uranium mines were converted into health spas that supposedly treat a variety of ailments via exposure to the radon in the mines. Despite the well-known dangers of radon, some of these spas continue to do business today.
3. **Watches**   
   The original glow-in-the-dark watches were painted with radium and a “phosphor” (phosphorescent compound) to achieve their luminescent effect. As the dangers of radium became known, the paints were replaced with tritium- and promethium-based paints. While they are also radioactive, they emit very low-energy beta (β) radiation, which is easily contained in the small quantities of a watch.
4. **Bananas**  
   About 0.01% of all potassium is the radioactive 40K, which means that any high-potassium food, such as bananas, contains the radioactive isotope. However, your body only absorbs as much potassium as it needs and flushes the rest away. Even if you eat a truckload of bananas, your radiation exposure is about the same as eating one or two..
5. **Basements**  
   As mentioned above, radon occurs naturally in the soil, and it’s density means that it accumulates in enclosed, underground spaces. Inhaling it puts the alpha (α)-emitter in your lungs, where is the leading cause of lung cancer after smoking. Because it is also odorless, colorless, and tasteless, the EPA recommends testing your basement regularly for radon.
6. **Brazil nuts**Brazil nut trees have deep roots that absorb naturally-occurring radium from the soil. The radium accumulates in the nuts. Brazil nuts are also high in potassium, making them one of the most radioactive foods available. Fortunately, the radioactivity of Brazil nuts is closely monitored to ensure the ones you buy in the store are safe.
7. **Countertops**   
   Stone countertops, like granite and marble, may contain veins of radioactive uranium and thorium, which release radon in their decay products. While the composition of natural stone varies, the amount of radiation exposure from any given countertop is too small to measure by the average consumer.
8. **Smoke detectors**  
   Smoke detectors contain a small amount of 241Am, which emits a steady stream of α particles. When the stream is disrupted by the presence of smoke, an alarm is triggered. The plastic casing of the detector is more than enough to protect you from the radiation—just keep it intact!

**Uses of ionizing radiation**

Radiation from unstable isotopes has more uses than you think. Unscramble these words and phrases to find a few of those uses.

1. **Submarines**  
   Some US Navy submarines, and a few surface ships, rely on on-board nuclear reactors for power. These vessels can then run for 25 years or more without refueling, even at high speeds. In contrast, diesel- and battery-powered ships must refuel every few days or even hours. Due the expense of building and maintaining nuclear vessels, only about 140 exist today.
2. **Power plants**  
   There are about 400 nuclear reactors in the world that supply electricity to local communities. Nuclear energy is often considered an environmentally-friendly power source, because it emits no CO2. It is also energy-dense: a 10 g uranium fuel pellet produces the same power as 150 barrels of oil. However, disposing of nuclear waste is a common problem, and plant accidents can have huge impacts.
3. **Space probes**  
   Solar power is great for satellites that orbit the earth, but probes that go deep into space or behind planets or moons wind up too far away for it to be effective. Instead, a golf-ball sized nuclear reactor (usually powered by something like 238Pu) provides enough power to keep space probes going for decades, along with enough heat to keep the circuits from freezing over. Probes such as New Horizons, Voyager, and Curiosity, all run on nuclear power.
4. **Leak detection**   
   Gas & oil pipelines, metal welding, boilers, and vehicle parts are often inspected for cracks or leaks using 192Ir or 60Co. These isotopes emit γ rays that can be used like X-rays. Because radioactive decay is spontaneous, the detectors don’t need batteries to function; they are also small and can find leaks in tight corners.
5. **Cancer treatment**  
   Radioactive materials can cause cancer by damaging DNA in healthy cells, but they can also be used to destroy cancerous cells in the same manner. Radioactive elements that are picked up by specific organs can be given by injection or pill, such as 131I for thyroid cancer. Isotopes may also be attached to molecules that are attracted to the organ or type of cancer. Sometimes tiny “seeds” of a radioisotope are implanted in or near a tumor, such as 103Pd for treatment of early-stage prostate cancer.
6. **Medical diagnosis**  
   Radioactive isotopes can be injected into a patient, where they are taken up by certain organs. Scanners track then track the isotopes to provide a far more complete picture of the target organ than would otherwise be possible. For example, 99Tc can be used to image the heart, 131I for the thyroid, and 81Kr for the lungs.
7. **Instrument sterilization**  
   Humans can handle small amounts of radiation because our bodies can easily replace a few cells damaged by ionizing radiation. Single-celled organisms are not so lucky, which is why surgical equipment can be treated with 60Co to sterilize it.
8. **Food decontamination**  
   In the same way that 60Co sterilizes equipment, it can also be used to decontaminate food. The low amounts of energy needed to kill bacteria on food are not enough to damage the food itself or make it radioactive.