Module 1: The Atom
Student Instructions

Name: ______________________________

CHEM1.PS1.10 Compare alpha, beta, and gamma radiation in terms of mass, charge, and penetrating power. Identify examples of applications of different radiation types in everyday life (such as its applications in cancer treatment).

Directions:

1. **BEFORE reading the article** complete the "Me" column of the Anticipation Guide.

2. Read the article "Chernobyl's Legacy".

3. Complete the Anticipation Guide and the Student Reading Comprehension Questions.

4. Don't forget to complete the Questions for Further Learning.
   If Internet access is unavailable, you may skip questions 1 and 3 of this section.
   For help with question 1, Three Mile Island information can be found here:
   https://www.thebalance.com/three-mile-island-nuclear-accident-facts-impact-today-3306337

5. Complete the Radioactivity Puzzle.

6. Provide at least 1 type of nuclear reaction or particle that each of the words unscrambled in the Radioactivity Puzzle uses or produces. Also, identify the radioactive element(s) associated with each.
   If Internet access is unavailable, you may skip this question.

7. For additional learning you may wish to research how each is beneficial or dangerous in each situation.

8. Read the article "Open for Discussion: Can Nuclear Power Save the Planet".

9. Debate the pros and cons of nuclear power based on what you have learned from reading these two articles.

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.
		2. The accident at Chernobyl occurred during a safety test.
		3. Temperatures inside the reactor during the explosion were as hot as parts of the Sun's atmosphere.
		4. The fuel in the reactor included U-238 from enriched uranium dioxide.
		5. A radioactive cloud blew across Northern Europe after the explosion.
		6. Isotopes of the same element have the same number of neutrons.
		7. When one mole of U-235 undergoes fission, the energy released can power about 400 average U.S. homes for a year.
		8. Nuclear reactors must have control rods to keep a chain reaction from occurring.
		9. Radioactive strontium can lead to bone cancer.
		10. The radioactive iodine released during the explosion still poses a health threat to people in Northern Europe.

Chernobyl's Legacy

By Adrian Dingle

Chernobyl.

The name refers to both a town and a nearby, defunct nuclear power plant in what's now Ukraine. But to many people, the name has become synonymous with nuclear disaster and what can go horribly wrong in the world's quest to electrify cities with nuclear power.

The explosion of one of the plant's reactors exposed hundreds of thousands of people to radiation. It forced some 350,000 people in the surrounding areas to leave their homes, according to the International Atomic Energy Agency.

Access is still restricted to what's known as an "exclusion zone," which encompasses the land within 30 kilometers (18.6 miles) of the plant. But more than 100 people now live in or on the edge of the zone. Much of the soil remains contaminated with radioactive materials, but scientists monitoring the zone say that breathing the air is safe.

Details about the causes of the explosion have been well reported. But the world is still contending with its lingering effects and fears of another Chernobyl-like event. More than 30 years later, are the concerns still warranted?

What caused the explosion

In the spring of 1986, operators at the Chernobyl power plant set out to conduct a safety check to see if the plant could work safely if the main power source were interrupted.

As part of the safety test, one of the four reactors was reduced to a low power state. A series of operator errors coupled with the reactor's poor design led to a power surge at 1:24 a.m. on April 26.

The rush of energy was enormous: It caused thermal power to reach a level of 12 billion watts; the pressure inside the reactor shot up; and the temperature reached a staggering 4,650 °C (8,402° F)—about the same temperature as parts of the sun's atmosphere.

These conditions inevitably caused the reactor to meltdown, and an explosion blew the steel and concrete structure to bits. Metal, graphite, and lethal radiation was blown sky high. Winds blew a radioactive cloud across northern Europe.

How did the reactor work?

The reactor was a Soviet-produced RBMK (reaktor bolshoy moshchnosti kanalnyy), which translated from Russian means "high-power channel-type reactor." In the core of the reactor was the fuel—190 tons of enriched uranium dioxide, UO_2. The uranium is said to be enriched because it contains a higher percentage of the isotope U-235, the isotope used for nuclear power, than is found in naturally occurring uranium. Naturally occurring uranium has approximately 0.7% of U-235 and more than 99% of the heavier isotope U-238. Enriched uranium is 3% to 5% U-235.

When the nucleus of a U-235 atom is bombarded by a neutron, a nuclear reaction takes place. The neutron splits open the nucleus—a process known as **fission**—and releases new daughter nuclei, more neutrons, and energy. The reaction can play out in many ways, generating different products, depending on the conditions. The following reaction is one example of what can happen to U-235:

$$^{235}_{92}U + ^{1}_{0}n \rightarrow ^{92}_{36}Kr + ^{141}_{56}Ba + 3\ ^{1}_{0}n + \text{energy}$$

The reaction of a single atom of uranium does not release very much energy. The reaction above typically produces about 2.7×10^{-11} Joules (J). But repeated on the scale of the mole—that is, 6.02×10^{23} times, or 235 grams of U-235—the energy released becomes significant, about 1.6×10^{13} J. That's enough to power 400 average U.S. homes for an entire year, all from the reaction of about half a pound of U-235.

About Isotopes

Isotopes are atoms of the same element (meaning that the atoms contain the same number of protons and electrons) with different numbers of neutrons. For example, $^{235}_{92}U$ and $^{238}_{92}U$ are isotopes of uranium.

	U-235	U-238
Protons	92	92
Neutrons	143	146
Electrons	92	92

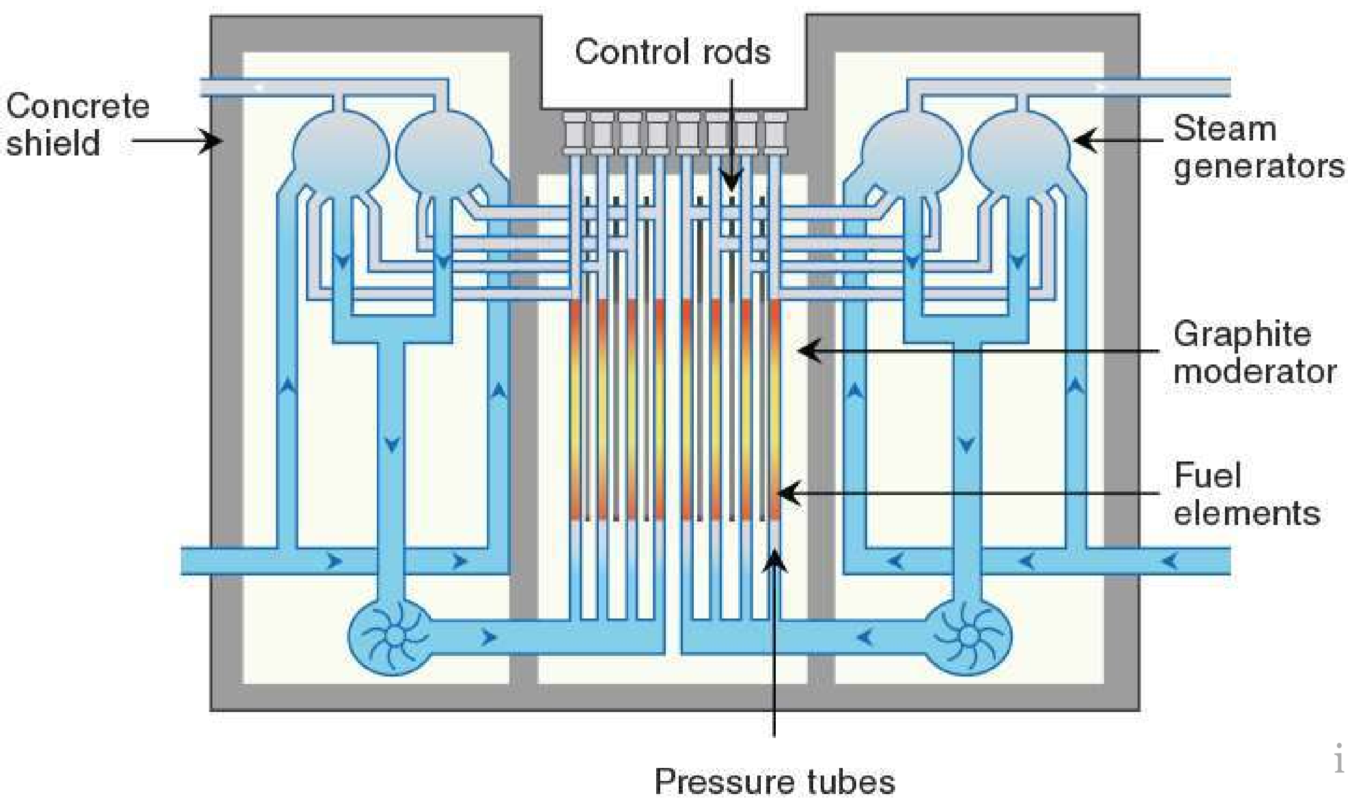
Controlling the reaction

Nuclear power is based on two properties of nuclear fission: 1) It produces a large amount of energy when scaled up; and 2) the neutrons that are produced can react with additional U-235 nuclei, breaking them apart and producing more neutrons. The result is a self-sustaining chain reaction.

The chain reaction produces a lot of energy very quickly. Without moderation, the process becomes dangerous. Careful monitoring and management are required.

One way to control the reaction is to lower control rods into a reactor's core. Control rods slow down nuclear reactions by absorbing neutrons, which prevents them from reacting with the uranium and generating more energy.

Chernobyl's RBMK reactor had 211 control rods. The accident investigation showed that at the time of the explosion, only eight control rods had been in the 7-meter tall core, when at least 15 should have been in place. This critical error along with subsequent missteps ultimately led to the explosion.



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What Happened at Chernobyl?

bit.ly/ACSReactions-Chernobyl

The human toll

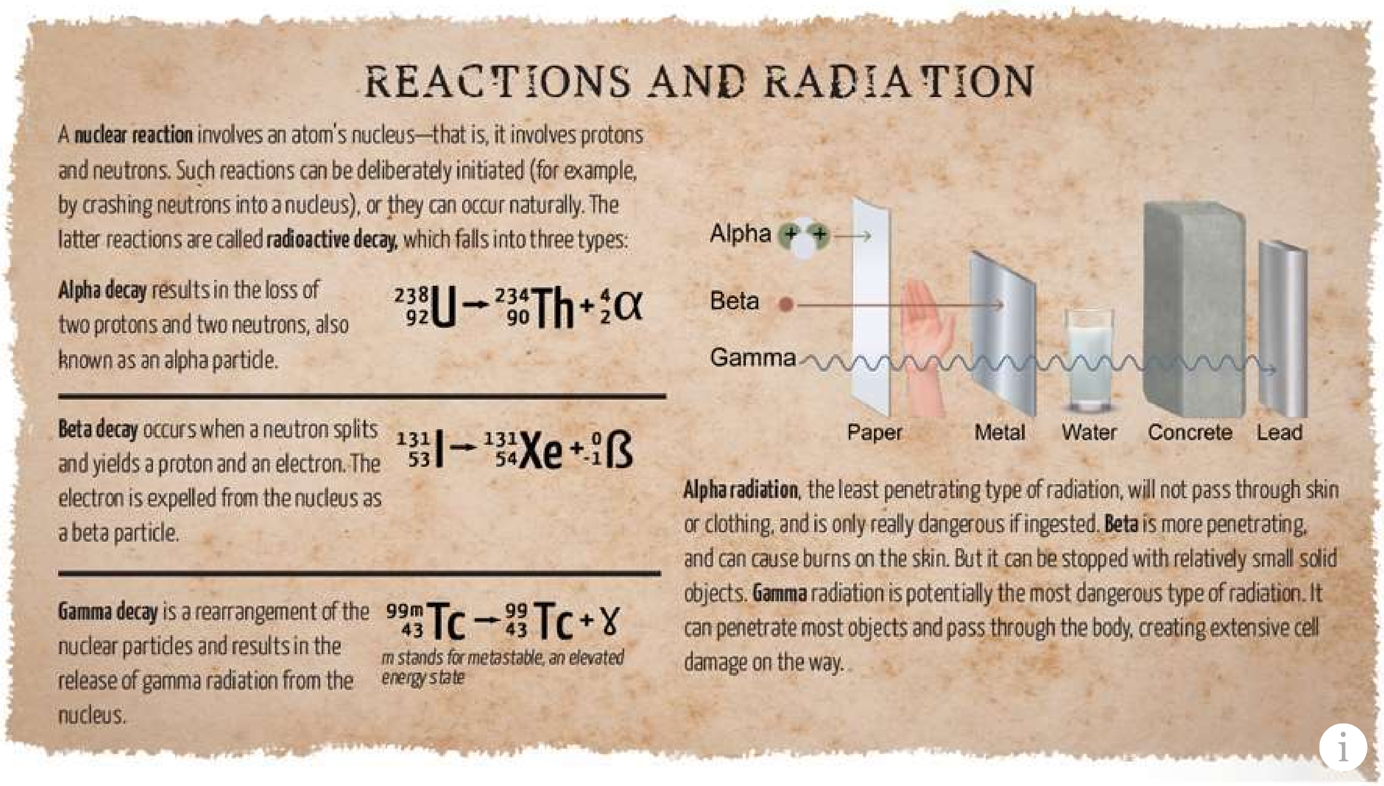
As a result of the initial explosion, two people were immediately killed. In the following two weeks, more than two dozen people died from acute radiation sickness (ARS), which occurs when exposure to radiation goes well beyond background levels. The ionizing radiation produced in nuclear reactions damages human cells. This leads to a host of symptoms, including vomiting, diarrhea, headaches, and fever. Over time, cancers, such as leukemia, can also result.

Long-term health effects can also result from the radioisotopes that the explosion spewed into the atmosphere and settled into the soil and water. As mentioned earlier, the nuclear fission of U-235 can yield many different, lighter products, which can undergo radioactive decay to create a mix of radioisotopes, such as iodine-131, cesium-137, and strontium-90.

These radioisotopes can cause a variety of health issues. For example, iodine-131 tends to concentrate in the thyroid gland and can cause cancer. Strontium-90 can mimic fellow Group 2 member calcium, accumulate in bones, and lead to bone cancer.

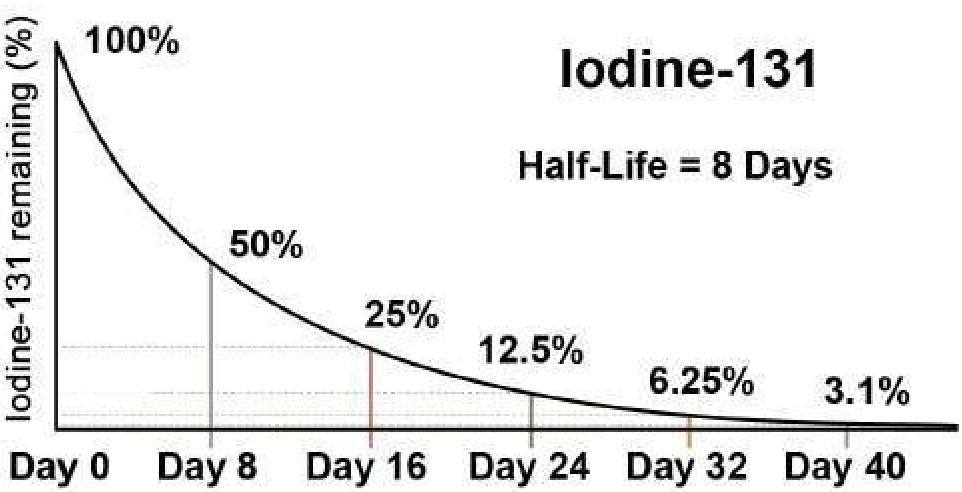
Iodine-131's effect is relatively short-lived with a half-life of only eight days. In contrast, cesium-137 with a half-life of 30 years and strontium-90 with a half-life of 29 years remain threats for longer periods of time.

The number of premature deaths that have resulted from Chernobyl, however, is difficult to determine. An estimated 600,000 "liquidators" were brought in to clean up the mess that resulted from the accident. Some of them died of cancer, or became terminally ill. In addition, an increase in thyroid cancer rates in the region has been reported.



Understanding Half-life

The half-life of a radioactive isotope is the time it takes for half of a sample's atoms to decay. For example, I-131 has a half-life of eight days. That means a sample of I-131 with an initial mass of 100 g would decay to 50 g of I-131 after eight days. After another eight days, the remaining I-131 would decay to 25 g, and so on, yielding an isotope of xenon and beta radiation.



Nuclear power today

After the Chernobyl disaster, RBMKs were redesigned, and no major incidents involving this type of reactor have been reported for two decades. The most recent nuclear meltdown occurred in 2011 in Japan when a tsunami flooded the Fukushima Daiichi power plant. No deaths or cases of ARS were reported.

Nuclear power continues to be an important contributor to low-carbon energy, although concerns about safety, long-term waste disposal, and high building costs have dampened the industry's growth. Moving forward, the world could become less reliant on it as renewable energy, such as solar and wind, continue to ramp up. Even then, the legacy of Chernobyl will endure.

Adrian Dingle is a science educator based in Indiana.

REFERENCES

Higginbotham, A. Midnight in Chernobyl: The Untold Story of the World's Greatest Nuclear Disaster; Simon and Schuster: New York, 2019.

The World Nuclear Association. Safety of Nuclear Power Reactors: Appendix I, The Hazards of Using Energy, updated March 2017: **https://www.world-nuclear.org/information-library/safety-and-security/safety-of-plants/appendices/safety-of-nuclear-power-reactors-appendix.aspx** (accessed Dec 2019).

Mettler, F. A. Jr. et al. Health Effects in Those with Acute Radiation Sickness from the Chernobyl Accident. *Health Physics* 2007, 93 (5), pp 462–9.

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.

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.

9) AMBERSINUS
10) PROWE LTSNAP
11) PACES ORBSEP
12) KALE CITEDNOTE
13) ARCENC MATTRENTE
14) CLAIMED ADIOSSIGN
15) NUTRIMENTS INITIALZOSTER
16) ODOF INCANTATIONMODE