#

# Nuclear Chemistry Lesson Plan

**Purpose:** This set of lessons is intended to introduce students to basic nuclear chemistry concepts through lessons linked to the Manhattan Project. This lesson series includes hands-on lessons for those willing to acquire the equipment, but also videos and data for use without a Geiger counter or other listed equipment.

**Time:** A three- to four-week unit if all lessons are done as written.

**Audience:** Middle or high school students who have been introduced to some chemistry.

**Student Prior Knowledge:**

* Atoms are composed of protons and neutrons in the nucleus and electrons in a cloud surrounding that nucleus.
* The type of element is determined by the number of protons and the isotope is determined by the number of neutrons, and these may be either stable or unstable.

**Teacher Background Resources and Videos:**

* [Go Figure: What bananas tell us about radiation](https://www.bbc.com/news/magazine-15288975) BBC article.
* [Nuclear Chemistry Crash course](https://youtu.be/KWAsz59F8gA) (can show this to the students after teaching balancing nuclear reactions and half-life, and a review).
* [For That Healthy Glow, Drink Radiation](https://www.popsci.com/scitech/article/2004-08/healthy-glow-drink-radiation/) article.

**Standards:**

* [**HS-PS1-8**](https://www.nextgenscience.org/sites/default/files/evidence_statement/black_white/HS-PS1-8%20Evidence%20Statements%20June%202015%20asterisks.pdf)**.** 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. [Clarification Statement: Emphasis is on simple qualitative models, such as pictures or diagrams, and on the scale of energy released in nuclear processes relative to other kinds of transformations.] [Assessment Boundary: Assessment does not include quantitative calculation of energy released. Assessment is limited to alpha, beta, and gamma radioactive decays.]

**Materials:**

Optional materials for hands-on experiments listed, however, these materials are not required to do the lessons, they just make them more engaging. Listed below is a number of sources that will provide a bit of background on some of the materials.

* Geiger Counter – both [civilian defense Geiger counters](https://en.wikipedia.org/wiki/Civil_defense_Geiger_counters) and [Vernier radiation monitors](https://www.vernier.com/product/vernier-radiation-monitor/).
* [Fiesta Ware](https://en.wikipedia.org/wiki/Fiesta_%28dinnerware%29) (strong emitter) – This dinnerware with a radioactive uranium oxide glaze, make a great radiation source. These are available online at websites such as eBay or antique stores. Note: must be Fiesta Ware predating 1972 or it will not register.
* [Thorium-containing incandescent mantle](https://www.orau.org/health-physics-museum/collection/consumer/products-containing-thorium/gas-lantern-mantles.html) – used for camp lanterns until the 1990s, when thorium was replaced with yttrium.
* Potassium chloride – “Light salt” is available at grocery stores. Trace amounts of potassium are radioactive.
* [Bananas](https://www.bbc.com/news/magazine-15288975) – high in potassium, also emit a small amount of radiation.
* [Brazil nuts](https://www.epa.gov/radtown/natural-radioactivity-food#:~:text=Like%20bananas%2C%20Brazil%20nuts%20contain,be%20confused%20with%20food%20irradiation.) – contain small amounts of potassium and radium.
* Meter stick or tape measure
* Various materials used as shielding, including, but not limited to:
	+ Paper
	+ Cardboard
	+ Glass
	+ Aluminum sheet
	+ Steel sheet
	+ Lead sheet
* Set of dominoes. Colorful children’s dominoes which are intended for building work well. The really cheap plastic dominoes do not work as they fall over too easily.

**Quick Links:**

* [Introduction to Isotopes](#_51bf436m5fg9)
* [Nuclear vs. Chemical Reactions](#_js85myfaer4)
* [Types of Nuclear Decay](#_fgaescpwa8cv)
* [Balancing Nuclear Equations](#_yyr4p8gudtrq)
* [Half-Life and Plutonium Production](#_a72dwykd23cs)
* [Hands on Nuclear Labs](#_m7ljmuimp2k8)
	+ [Radiation and Shielding](#_hzh08lqdiq8e)
	+ [Distance Vs. Exposure](#_a9ykjd7kcw8s)
	+ [Subcritical, Critical, and Supercritical Reactions](#_ihqjnkx1phgn)
* [Culminating Nuclear Poster Project](#_70xgu5m9uoyr)

# Introduction to Isotopes

**Essential Question:** Atomic mass, as written on the periodic table, is an average mass of the isotopes of a particular element. How is the average atomic mass calculated, and what notation is used to signify a particular isotope?

**Time:** 30 minutes depending on prior knowledge.

**Student Prior Knowledge:**

* Atoms are composed of protons and neutrons in the nucleus and electrons in a cloud surrounding that nucleus.
* The type of element is determined by the number of protons and the isotope is determined by the number of neutrons, and these may be either stable or unstable.
* Law of Conservation of Mass states that matter may neither be created nor destroyed in a chemical reaction.
* Elements contain valence electrons which interact to form different types of bonds. (This is not necessary, rather an extension.)

**Introduction Questions:**

* How is the mass of an element calculated?
* If protons have a mass of 1 amu and neutrons a mass of 1 amu, and electrons have an exceedingly small mass, why does magnesium have a mass of 24.5 amu?
* Why are isotopes important in the study of nuclear chemistry?

***Responses to questions: (Slightly simplified)***

* The masses of elements were originally determined by experiments in which one element was substituted for a second element using a single replacement reaction. By reacting lots of elements together in this way, early scientists determined the relative masses of the elements. These masses were based on the mass of a proton, which is 1 amu.
* Isotopes of an element are atoms of the elements which have the same number of protons, but different numbers of neutrons. To calculate the average mass of an element, the weighted average of the isotopes must be calculated as shown below.
* Isotopes are very significant in nuclear chemistry as different isotopes react differently. Some isotopes, like carbon-12 are very stable and do not decay, while others like iodine-131 decay very quickly.

**Isotope Notation**:

Look at the isotope notation below, then look at the periodic table. What is the upper number? What is the lower number?

$$ \_{6}^{12}C$$

*Yes, the upper number is the mass of the isotope, the lower number is the atomic number or number of protons. If you subtract the two numbers, you get the number of neutrons. How many neutrons does carbon-12 have? Carbon-14?*

**Calculation of Average Atomic Masses:**
Given the abundance and masses of the three most abundant isotopes of magnesium, calculate the average mass. have masses of 23.98504 amu, 24.98584amu, and 25.98259amu. What is the average mass of magnesium?

|  |  |  |
| --- | --- | --- |
| **Isotope** | **Isotope Mass** | **Isotope Abundance** |
| 24Mg | 23.98504 | 78.70% |
| 25Mg | 24.98584 | 10.13% |
| 26Mg | 25.98259 | 11.17% |

$$Average Atomic Mass (Mg) = \frac{(mass ^{24}Mg)(\% ^{24}Mg) + (mass ^{25}Mg)(\% ^{25}Mg) + (mass ^{26}Mg)(\% ^{26}Mg)}{100}$$

$$Average Atomic Mass (Mg) = \frac{(23.98504)(78.70) + (24.98584)(10.13) + (25.98259)(11.17)}{100}$$

**Stability of Isotopes:**

* Isotopes with atomic number >83 are unstable
* Isotopes with an atomic mass differing significantly from the mass on the periodic table are usually unstable.

**Slide example:**

Find “Isotope Slides” under the Materials section of the curriculum page.

**Student Misconceptions:**

* Average mass is not a whole number because of the mass of the electrons.
* Average mass is calculated by adding the masses and dividing by the number of isotopes, rather than calculating weighted averages.

 Name \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_ Date \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_ Period \_\_\_\_\_\_\_\_\_

# Isotope Practice

1. Here are three isotopes of an element: $ \_{38}^{84}Sr$ $ \_{38}^{86}Sr \_{38}^{87}Sr$ $ \_{38}^{88}Sr$
	1. Identify the element \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_
	2. The lower number, 38 refers to the \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_
	3. The upper numbers: 84, 86, 87 and 88 refer to the \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_
2. Complete the following chart:

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Isotope name | Atomic # | Isotope Mass | # neutrons | Isotope notation | Stability |
|  |  |  |  | $$ \_{55}^{137}Cs$$ |  |
| Uranium-235 |  |  |  |  |  |
|  | 5 |  | 6 |  |  |
|  | 1 | 3 |  |  |  |
| Polonium-\_\_\_ |  |  | 126 |  |  |

**Calculate average masses of the following.**

1. Magnesium has three isotopes: $ ^{24}Mg$ (78.99%), $ ^{25}Mg$ (10.00%), $ ^{26}Mg$ (11.01%). What is the average atomic mass of magnesium?
2. Uranium is 99.3% 238U, which is not fissile, so can’t be used in fission reactions and 0.7% 235U, which was the fissile material used in the Little Boy atomic bomb. Calculate its average atomic mass.
3. Iron is the most abundant element by mass on Earth. It consists of 4 naturally occurring and stable isotopes. What is the average atomic mass of iron if 91.7% of iron atoms have a mass of 56, 5.8% have a mass of 54, 2.2% have a mass of 57, and 0.3% have a mass of 58%?
4. Bromine has two stable isotopes, 79Br and 81Br. The average atomic mass of bromine is 79.90 amu. Based on these numbers determine the approximate relative abundance of the two isotopes.

Look at your answers to the isotope calculations and compare them to the periodic table. Do they make sense? If not, try again.

# Nuclear Vs. Chemical Reactions

**Essential Questions:** What differentiates a nuclear and a chemical reaction?

**Time:** 15-20 minutes depending on prior knowledge.

**Student Prior Knowledge:**

* Isotopes are atoms of the same element with different numbers of neutrons.
* The atom is composed of a central nucleus surrounded by electrons.
* The law of conservation of mass states that mass is neither created nor destroyed in a chemical reaction.
* A mole is a common quantity used in chemistry equal to 6.02x1023

**Introduction Questions:**

* How are nuclear reactions different from “normal” chemical reactions?
* Identify each of the following isotopes: $ \_{2}^{4}He$, $ \_{6}^{14}C$, …
* Write 3.56x108J in standard notation. Is this number less than or greater than 104.5J?

**Activity:** Pair cards that go together, then sort them based on which ones you think might pertain to nuclear reactions vs. chemical reactions.

**Cards:** Have cards cut out and ready to go. Or just have them write the information in their notebooks, but depending on the group of students, they may paste them into their notebooks. The answers are below, and student cutouts are on the next page.

|  |  |
| --- | --- |
| Chemical | Nuclear |
| Reactions involve rearranging the electrons in atoms | Reactions involve a change in the nucleus of atoms |
| Reactions produce a moderate amount of energy. (10-1000 kJ/mole)  | Reactions produce an enormous amount of energy. (108 kJ/mole)  |
| Law of Conservation of Mass holds. | Mass may change and E=mc2 is used to calculate the energy created when mass changes. |
| Isotopes do not matter. | Isotopes react differently |
| Elements in the products are always the same as elements in the reactants, just their bonds change. | Transmutation can occur, where one element can be changed into a different element. |

**Big Ideas:**

* Chemical reactions involve rearrangement of electrons, which nuclear reactions involve a change in the nucleus.
* Chemical reactions produce a modest production of energy due to formation of bonds, which nuclear reactions involve MUCH larger quantities of energy.

**Instructions:** Cut out the cards below. Group them based on whether the statement pertains to nuclear reactions or chemical reactions.

|  |  |
| --- | --- |
| **Nuclear Reactions** | **Chemical Reactions** |
| Reactions involve a change in the nucleus of atoms | Reactions involve rearranging the electrons in atoms |
| Isotopes do not matter. | Reactions produce an enormous amount of energy. (108 kJ/mole)  |
| Law of Conservation of Mass holds. | Mass may change and E=mc2 is used to calculate the energy created when mass changes. |
| Elements in the products are always the same as elements in the reactants, just their bonds change. | Isotopes react differently |
| Transmutation can occur, where one element can be changed into a different element | Reactions produce a moderate amount of energy. (10-1000 kJ/mole) |

Student handout below.

**Chemical Reactions Vs. Nuclear Reactions**

There are many differences between chemical and nuclear reactions. The six main differences are:

**Nuclear Reactions**

* Protons and Neutrons react inside the nucleus.
* Elements transmute into other elements.
* Isotopes react differently.
* Independent of chemical combination.
* Energy changes equal 108 kJ/mole.
* Mass changes are detectable. (E=mc2)

**Chemical Reactions**

* Electrons react outside the nucleus
* The same number of each kind of atom appears in the reactants and products.
* Isotopes react the same.
* Depend on chemical combination.
* Energy changes equal 10 – 1000 kJ/mol.
* Mass reactants = mass product.

Don’t get chemical reactions confused with nuclear reactions. An example of a nuclear reaction is an atomic bomb, while an example of a chemical reaction is combustion.

 vs. 

**Types of nuclear reactions:**

1. **Fission** - Energy produced by splitting of nuclei
	1. Often 235U
	2. Used in nuclear reactors & bombs
2. **Fusion** - Energy produced by combining of small nuclei
	1. Reaction that powers the sun (2 H -> He)
	2. More energy released than fission
3. **Types of radioactive decay:**
	1. Alpha - a helium nucleus is released
	2. Beta- a neutron breaks apart to for a proton and electron (atomic number increases by 1)
	3. Gamma - high energy gamma energy is released.

# Types of Nuclear Decay

**Essential Question:** What is the difference between nuclear fission and fusion? What are some of the basic types of nuclear decay used in the Manhattan Project?

**Time:** 30 minutes, depending on prior knowledge. This may quickly be followed by the balancing nuclear reaction lesson.

**Student Prior Knowledge:**

* Students must understand isotope notation.
* Understand the mass and charge units on protons, neutrons, and electrons. For example, an electron has zero mass, and a charge of -1.
* Preferred that student have been introduced to the electromagnetic spectrum.

**Introduction Questions:**

1. What is the meaning of the word, “decay?” What is meant when people talk about “nuclear decay?”
2. Identify each of the following isotopes: $ \_{2}^{4}He$, $ \_{6}^{14}C$, ​​$ \_{53}^{127}I$
3. What is the difference between fission and fusion?
4. What is the electromagnetic spectrum? Arrange the following from lowest energy to highest energy: light, microwaves, x-rays, IR radiation, gamma radiation, radio waves.

***Responses to questions:***

1. Students typically get that decay is to break down, therefore nuclear delay refers to the breakdown of the nucleus of the atom. This is a good starting point.
2. Covered in a prior lesson.
3. Fusion means to “fuse” or come together. Fission refers to a “fissure” or breaking.
4. Here is a visual for the [Electromagnetic spectrum](https://www.britannica.com/science/electromagnetic-spectrum).

**Introduction Activity:** Students are first introduced to the particles involved in nuclear reactions, through a sorting activity. Can have these sets in little baggies and have the students sort them. Note at the end, be sure students have the correct matches and record them in their notebooks.

|  |  |
| --- | --- |
| **Particle type** | **Isotope notation** |
| Alpha ($α$) / Helium nucleus | $$ \_{2}^{4} He$$ |
| Beta ($β$) / electron | $$ \_{-1}^{ 0} e$$ |
| Gamma ($γ$) | $$ \_{0}^{0} γ$$ |
| neutron | $$ \_{0}^{1} n$$ |
| proton | $$ \_{1}^{1} p$$ |
| positron | $$ \_{+1}^{ 0} e$$ |

***Big Idea:*** *Isotope notation is used both for elements and for subatomic particles. Using their understanding of the charge and mass (in AMU) of subatomic particles, students can match the isotope notation to the name. These will be used in the next section on Balancing Nuclear Reactions.*

**Types of Nuclear Reactions:** *(Notes)*

* ***Alpha Decay*** – a helium nucleus breaks away to form an alpha particle.
* ***Beta Decay*** – a neutron breaks apart to form a proton plus an electron. The electron leaves the nucleus at a high velocity as a “beta particle.” This reaction is cool as the daughter isotope has a higher atomic number than the parent isotope.
* ***Gamma Radiation*** – a high energy gamma ray is released from the nucleus. Neither atomic mass nor atomic number changes in this reaction.
* ***Neutron Bombardment*** – a neutron hits an isotope and results in a fission.
* ***Positron Emission*** – a positron, or a positive electron is emitted from the nucleus.
* Kind of Cool Fact: if a positron and an electron interact, they annihilate one another and form energy. Cool connection: Dark Lightning [video](https://www.youtube.com/watch?v=5RxdtqIyhEs), [article](https://interestingengineering.com/science/dark-lightning-uncovering-the-strongest-energy-discharge-on-earth).

**Big Ideas:**

* Fission occurs when a larger nucleus breaks apart, and fusion occurs when lighter nuclei combine. Both release energy.
* Unstable nuclei may change in multiple ways depending on the isotope and the surrounding high energy particles.

Student sheets below.

**Isotope Cards:** Cut out cards and match the particle type to the isotope notation based on what you now know about isotope notation. These isotopes will be the main players in the nuclear reactions we will be studying.

|  |  |  |
| --- | --- | --- |
| **Alpha (**$α$**)** (Helium nucleus) | **Beta (**β**)** (electron) |  **Gamma (**𝜸**)** (radiation) |
| **Neutron**   | **Proton**  | **Positron** |
| $$ \_{-1}^{ 0} e$$ | $$ \_{0}^{1} n$$ | $$ \_{+1}^{ 0} e$$ |
| $$ \_{2}^{4} He$$ | $$ \_{0}^{0} γ$$ | $$ \_{1}^{1} p$$ |

Name \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_ Date \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_ Period \_\_\_\_\_\_\_\_\_

# Types of Nuclear Decay

**Isotope Cards Sort:** After sorting the cards, record the radiation type and isotope notation. Make sure you understand how you matched the cards as you will need to know these particles as we move forward.

|  |  |
| --- | --- |
| **Particle Type** | **Isotope notation** |
| Alpha (hint - helium nucleus) |  |
| Beta (electron) |  |
| Gamma (no mass or charge) |  |
| Neutron (mass, but no charge) |  |
| Proton (both mass and charge) |  |
| Positron (an electron with positive charge) |  |

**
Directions:** Below nuclear reactions are written in isotope notation. Identify the type of reaction for each balanced nuclear reaction below.

|  |  |
| --- | --- |
| Balanced Nuclear Reaction | Reaction Type |
| $$ \_{88}^{226}Ra\rightarrow \_{86}^{222}Rn + \_{2}^{4}He $$ |  |
| $$ \_{6}^{14}C \rightarrow \_{7}^{14}N + \_{-1}^{ 0}e $$ |  |
| $ \_{43}^{99}Tc\* \rightarrow \_{43}^{99}Tc + \_{0}^{0}γ $ Technetium is going from an excited state (\*) to a ground state. |  |
| $$ \_{12}^{23}Mg \rightarrow \_{11}^{23}Na+ \_{+1}^{ 0}e $$ |  |
| $$ \_{79}^{197}Au + \_{0}^{1} n \rightarrow \_{79}^{198}Au + \_{0}^{0}γ$$ |  |

**Balancing Nuclear Reactions:**

Look at the reactions above. What do you notice about the subscripts on either side of the arrow? The superscripts. Cool. Just like in the law of conservation of mass in nuclear reactions, the mass numbers (superscripts) and charge numbers (subscripts) must balance before and after the reaction.

# Balancing Nuclear Reactions

**Time:** 30 minutes, depending on prior knowledge. This is likely part 2 of the Types of Nuclear Reactions Lesson.

**Student Prior Knowledge:**

* Students must understand isotope notation.
* Understand the mass and charge units on protons, neutrons, and electrons. For example, an electron has zero mass, and a charge of -1.
* Students should know types of Nuclear Reactions, using a reference sheet.

**Introduction Questions:**

1. What type of particle is emitted in alpha decay?
2. What does the atomic number (decrease/ increase/ stay the same) in beta decay?
3. What is a positron? What happens when it interacts with an electron?

**Activity:** Complete the worksheet.

**Video:**

[Khan Video Link](https://youtu.be/mzLOT6uOfO4)

Student worksheet below.

Name \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_ Date\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_ Period\_\_\_\_\_\_\_\_\_\_\_\_\_\_

**Balancing Nuclear Equations**

1. Alpha decay is a type of nuclear decay which occurs in large, unstable isotopes. Polonium was discovered by the Curies in 1898 and was named for [Marie Curie](https://www.nps.gov/people/manhattan-project-pioneers-marie-curie.htm)'s homeland, Poland. Write the balanced alpha decay reaction for Polonium.

$ \_{84}^{210}Po \rightarrow $ \_\_\_\_\_\_\_\_ + \_\_\_\_\_\_\_\_\_

1. Alpha decay is also used in smoke detectors. Americium is a synthetic nuclear isotope which was discovered in Berkley, California in 1944 by [Glenn Seaborg](https://www.nps.gov/people/manhattan-project-scientists-glenn-theodore-seaborg.htm), one of the scientists instrumental in the creation of the plutonium which was later used in the fat man bomb. Write the balanced alpha decay reaction for Americium.

$ \_{95}^{241}Am \rightarrow $ \_\_\_\_\_\_\_\_ + \_\_\_\_\_\_\_\_\_

1. Carbon-14 is a trace carbon isotope which is produced in the upper atmosphere. It undergoes beta decay and is used to radioactively date materials. Write the balanced beta decay reaction for carbon-14.

$ \_{6}^{14}C \rightarrow $ \_\_\_\_\_\_\_\_ + \_\_\_\_\_\_\_\_\_

1. Strontium-90 is a beta emitter which is used in radioisotope thermoelectric generators, or RTGs. These produce heat which is converted to electrical energy. Because strontium-90 is a waste product from nuclear reactions it is the most common isotope source of RTG power packs. Write the balanced beta decay reaction for strontium-90.

$ \_{38}^{90}Sr\rightarrow $ \_\_\_\_\_\_\_\_ + \_\_\_\_\_\_\_\_\_

1. Xenon-135 is a product of uranium fission which is extremely good at capturing free neutrons. It created a problem in the B-reactor during the production of plutonium by absorbing the available neutrons, thus halting the reactor. This problem was solved by [Leona Woods Marshall Libby](https://www.nps.gov/articles/000/leona-woods-marshall-libby.htm), the only female scientist in the Manhattan Project. Write the balanced nuclear bombardment reaction for this equation. (Hint, a neutron is on the left side of the arrow.)

$ \_{54}^{135}Xe$ + \_\_\_\_\_\_\_\_\_ $\rightarrow $ \_\_\_\_\_\_\_\_\_

1. Copper-61 is a radioisotope of interest for nuclear medicine. It has a short half life and is easy to produce. Copper-61 decays by positron emission. Write the balanced position emission equation for copper-61.

$ \_{29}^{61}Cu\rightarrow $ \_\_\_\_\_\_\_\_ + \_\_\_\_\_\_\_\_\_

Below are the steps in Plutonium production and some key steps from the Uranium decay chain. Complete the reactions or identify the radiation type in each reaction. The possible types of reaction are: alpha, beta, gamma, positron, and nuclear bombardment.

**Plutonium Production Reactions:**

|  |  |
| --- | --- |
| **Nuclear Reaction** – Remember these change the nucleus | **Type of radiation** |
| $$ \_{92}^{238}U + \_{0}^{1}n \rightarrow \_{92}^{239}U $$ |  |
| $$ \_{92}^{239}U \rightarrow ⎽⎽⎽⎽⎽⎽⎽ + \_{93}^{239}Np$$ | Beta Decay |
| $ \_{93}^{239}Np \rightarrow ⎽⎽⎽⎽⎽⎽⎽ + \_{-1}^{ 0}e$  |  |

**Undesirable Side Reaction**

Unfortunately, in plutonium production, the plutonium may be hit by a second neutron which produces plutonium-240. This isotope is undesirable as it has a short half-life, which means it is not as stable as plutonium-239 and can produce a small fissile reaction which can destroy the weapon. Because plutonium-240 is an isotope of plutonium, it cannot be chemically separated, but requires a much more expensive isotope separation. The uranium plugs were only left in the B Reactor for a relatively short amount of time preventing the production of plutonium-240.

**Complete the reaction below and identify the radiation type:**

$$ \_{93}^{239}Np + \_{0}^{1}n\rightarrow ⎽⎽⎽⎽⎽⎽⎽$$

**Nuclear fission results in different possible product.** Fill in the blank with the appropriate isotope: [(Source)](https://www.sciencedirect.com/topics/earth-and-planetary-sciences/plutonium-239#:~:text=Fission%20of%20plutonium%2D239%20or,these%20are%20termed%20activation%20products).)

|  |
| --- |
| **Possible fission products** |
| $ \_{92}^{235}U + \_{0}^{1}n \rightarrow ⎽⎽⎽⎽⎽⎽⎽ +2\_{0}^{1}n + \_{38}^{100}Sr$ + 212 MeV |
| $ \_{92}^{235}U + \_{0}^{1}n \rightarrow ⎽⎽⎽⎽⎽⎽⎽ +3\_{0}^{1}n + \_{36}^{89}Kr$ + 212 MeV |

[Decay chain of Uranium resource page from the Army Corps of Engineers](https://www.lrb.usace.army.mil/Portals/45/docs/FUSRAP/FactSheets/fusrap-fs-uranium-2008-09.pdf):

The total usable energy from fission is a little over 200 MeV or 32 pJ (1 MeV = 1.602 × 10− 13 J) for any of the three fissile materials 233U, 235U, and 239Pu. A gram of 235U contains 2.56 × 1021 atoms, and with the same number of fission reactions, 84.1 billion Joules energy is released. This is equivalent to the energy released by combusting 3.5 tons of coal, 2200 L of oil, or 2100 m3 of natural gas.

# Half-Life of Nuclear Decay

**Essential Question:** How radioactive is a particular isotope? How long will it continue to decay?

**Time:** 60 minutes,

**Student Prior Knowledge:**

* Students understand balanced nuclear reactions.
* Students can use exponents and make basic graphs.
* Students should know types of Nuclear Reactions, using a reference sheet.

**Introduction Questions:**

1. What is meant by the term “nuclear decay”?
2. Is something that decays quickly or slowly more dangerous? Justify your answer.
3. What is meant by the term “half live”?

**Activity:** [Half-Life of Candium](https://dixiemiddlescience.weebly.com/uploads/3/7/4/7/37477303/extension_radioactive_dating_m_m_lab.pdf)

* The activity linked is a template of an activity demonstrating half-life using M&M’s and peas. The idea of using the peas makes the point that radioactive materials do not disappear when they decay, but rather change to a different substance.
* Pennies can be used instead of M&M’s as the candy gets expensive with a full class.
* A version of this activity is often done in Earth Science, so an abbreviated version of this, a quick 15-minute activity before doing calculations, can be an option.
* There are many versions of this activity on the internet.
* Summarize findings and relate to real materials.

**Half-life Calculations:** (Student worksheet below.)

* Students work together to solve the problems. Go over the first problem to be sure they are all on the correct path.

Name \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_ Date \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_ Period \_\_\_\_\_\_\_\_\_

**Solving Half-Life Problems**

***mf = mi* (½)*n***

*mf* = final mass

*mi* = initial mass

*n* = # of half lives

Parent isotope – original isotope

Daughter isotope – product of the decay of the parent isotope.

1. Cesium-137 is a byproduct of plutonium production and has a half-life of 30 years and decays by beta emission.
	1. Write the balanced decay equation.
	2. Graph the percent parent and daughter isotopes as a function of time. (Be sure to label the axis, and the parent and daughter isotope lines.)



* 1. How many milligrams of a 130 mg sample will remain after 1 year?
	2. If soil is contaminated with 130 mg of cesium-137, how much would remain after 100 years?
1. 99% of uranium found in nature is uranium-238. This isotope is not fissile and decays by alpha emission to thorium-234 and has a half-life of nearly 4.5 billion years.
	1. Write the balanced decay equation.
	2. Graph the percent parent and daughter isotopes as a function of time.



* 1. If you start with 100.0 g of 238U, how many grams will remain after 1 year?
	2. Based on the half-life, how dangerous do you think Uranium-238 is? Explain.
1. Iodine-131 is a byproduct of nuclear fission during the production of plutonium in the B Reactor. It has a half-life of 8 days, and decays by beta emission.
	1. Write the balanced decay equation.
	2. What was the **original mass** if 0.160g of I-131 remains after 1 week? (Hint, this is a slightly different problem as you are asked for original mass.)
	3. When removed from the B Reactor, irradiated fuel was first allowed to sit in a cooling pond to thermally and radiologically cool for 2-3 months. Why would allowing the fuel to sit for this amount of time make a difference?

# Distance, Shielding, and Criticality Activities

**Essential Question:** How can you protect yourself from a radiation source? What type of material stops radiation? How does your distance from a source affect your exposure? Why are some sources explosive, while others can be held in your hands?

**Time:** 60 minutes (do this activity in stations)

**Student Prior Knowledge:**

* This is a culminating activity. Students should be familiar with types of decay, half-lives and balancing nuclear equations.

**Rotation Activity:** (Can do as a rotation activity, with each station requiring about 20 minutes to complete. Have two of each station for a total of 6 stations with 4-5 students per station.)

* **Radiation and Shielding Lab** – This can be done with just the data provided. If a radioactive source, such as Fiesta Ware or Coleman mantle, and a Geiger counter is available, it is really fun to collect data. If students are using a Geiger counter, show how to use it to the whole class prior to the activity. If only one Geiger counter is available, it can be used at the end to demonstrate.
* **Radiation and Distance Lab** – This lab can be done many ways. If a radioactive source and a Geiger counter is available, then students can collect data that way. Otherwise, it can also be demonstrated using a light source and some graph paper as shown in this [video](https://www.youtube.com/watch?v=5F_qDx7HYAs), which is intended for teachers. Worksheet provided assumes access to a station with a source and counter, or a demonstration of a source and counter by the teacher.
* **Subcritical, Critical, and Supercritical Activity** – This activity from Flinn Scientific uses dominoes to demonstrate criticality. Dominoes spread too far to hit another domino demonstrates a subcritical reaction. A domino train shows a critical reaction, and the template provided shows a supercritical reaction. Note: not all dominoes are equal. Sets designed for building are more likely to work better (lower quality ones may struggle to stay standing and frustrate the students). A multi-color set can be useful for keeping sets separate.

**Videos:**

* [Inverse square demonstration](https://www.youtube.com/watch?v=JW3tT0L2gpc) using a butter gun and bread.
* [Inverse square video](https://youtu.be/jQe8tBsMJw0?si=zlPO-3frvT5EBq9l) related to light related to satellites by Bill Nye.

Name \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_ Date \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_ Period \_\_\_\_\_\_\_\_\_

# Types of Radiation and Shielding Lab

Write the nuclear decay reactions for the following:

1. Radon-222 (alpha decay)
2. Iron-59 (beta decay)
3. Strontium-85 (electron capture and gamma decay)

Observe the following data:

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
|   |   |   |   | Activity (counts/sec) |   |   |
| Source | Type of Radiation | No shielding | Paper | 1 mm Cardboard | 1 mm Aluminum | 1 mm Lead |
| radon-222 | alpha | 270 | 0 | 0 | 0 | 0 |
| iron-59 | beta | 79 | 71 | 31 | 7 | 0 |
| strontium-85 | gamma | 39 | 39 | 39 | 39 | 21 |

1. What was the effect of shielding on the alpha particles? What kinds of materials would be sufficient protection for a person working with an alpha emitting source?
2. What shielding would be necessary for someone working with a beta source?
3. Based on the data, why is gamma radiation a major concern after a nuclear release?
4. X-rays are similar to gamma rays. Why is a “lead apron” used on people when they get an x-ray?
5. Observe the following data. Based on the number of counts, determine the type of radiation most likely released.

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
|   |   |   | Activity (counts/sec) |   |   |   |
| Source | No shielding | Paper | 1 mm Cardboard | 1 mm Aluminum | 1 mm Lead | Type of Radiation |
| potassium-40 | 80 | 70 | 30 | 7 | 0 |   |
| gallium-67 | 950 | 950 | 950 | 950 | 800 |   |
| iodine-125 | 30 | 30 | 30 | 30 | 23 |   |
| phosphorus-32 | 500 | 450 | 200 | 40 | 0 |   |
| polonium-210 | 260 | 0 | 0 | 0 | 0 |   |
| radium-226 | 40 | 40 | 40 | 40 | 30 |   |

**Radiation and Shielding Experiment:**

1. Turn on the Geiger counter and hold the detector near the source. (Do not touch the source with the counter or your hands.)
2. Hold the detector 5 cm from the source.
3. Have another person choose a material for shielding and place it between the detector and source. Record the number of counts.
4. Repeat with additional sources being careful to keep the distance constant.
5. Using your data, make a hypothesis about the type of radiation emitted by the source which is supported by your data.

**Note:** These lessons were based around a virtual lab from University of Colorado, Colorado Springs.

# Radiation and Distance

| Distance (cm) | Activity (counts/s) |
| --- | --- |
| 0 |  |
| 1 |  |
| 2 |  |
| 4 |  |
| 8 |  |
| 16 |  |
|  |  |
|  |  |

Using the Geiger counter and radiation source, collect data on the effect of distance on the activity.



1. What is the relationship between radiation intensity and distance?

| Distance (cm) | Activity (counts/s) |
| --- | --- |
| 1 | 1000 |
| 2 | 250 |
| 3 | 110 |
| 4 | 60 |
| 5 | 40 |
| 6 | 28 |
| 7 | 20 |
| 8 | 16 |
| 9 | 12 |
| 10 | 10 |

Graph the given data on the data table provided. Determine an equation which fits this line….



1. When a sample of phosphorus-32 (a beta-emitter used to treat leukemia and pancreatic cancer) was placed 1 cm from the detector was measured to be 491 counts per second. What would its activity be if it was moved to 2 cm from the detector? 5 cm?
2. X-rays are a type of ionizing radiation similar to gamma rays. Why does the X-ray technician leave the room when you receive an X-ray?
3. Ponder the picture. How does this help explain the relationship between distance and intensity?

 

# Subcritical, Critical, and Supercritical Activity

[Domino activity from Flinn Scientific](https://www.flinnsci.ca/api/library/Download/60ff8c8bdd9149de9d75ce60f14613bc) shows the difference between subcritical, critical, and supercritical nuclear activity. The template can be printed on large paper and taped to a tabletop. If available, consider covering it with plexiglass (or the like), so they have a flat surface. Even if it does not work perfectly, this activity gets the idea across to the students.

Recommended to use dominoes designed for building (wooden ones work well). The cheap plastic ones are not stable enough for this activity.

# Culminating Project – Nuclear Chemistry Research Poster

**Purpose:** To pull together the nuclear science we have been studying, and to gain a broader understanding of the history and the future of nuclear science.

**Format:** For this project have the students make an electronic poster. This approach is nice both because many students may not have used this format in the past, and because it is a format used in undergraduate and early graduate research. The students develop the poster on a single google slide (beware of “poster” generating programs) and then they present their research to the class. There are a number of science requirements, as can be seen in the rubric. A sample electronic poster is included. Google classroom can be used, which allows teachers to check the originality of the posters. Students have time throughout the nuclear unit to work on these posters.

**Research Topics:** Give students a list of research topics as they typically do not know enough about nuclear chemistry to come up with a good topic. Here is an example of a project list. Learn more from [Manhattan Project National Historical Park](https://www.nps.gov/mapr/index.htm).

Suggested topics:

* Hanford Nuclear Site
* ITER (fusion power)
* Nuclear power
* Chernobyl
* Nuclear in medicine
* Fukushima
* Stars, dark holes, space radiation
* Nuclear submarines
* Nuclear dating
* Use of nuclear in agriculture
* Bikini Atoll and nuclear test sites
* Uranium mining and processing (includes Moab and many other sites)
* Hiroshima and Nagasaki
* Nuclear in movies
* 3 Mile Island and INEL nuclear accident
* Effects of nuclear on living tissue
* Downwinders
* Nuclear Propulsion
* Demon core
* Recycling of nuclear fuel
* Nuclear in Russia/Ukraine
* Use of nuclear in civilian transoceanic travel and micro-reactors in remote locations

**Requirements:**

Below is an example of requirements. The goal of this project is to introduce students to a variety of topics in nuclear. Because of this, the focus is on the content more than on references. It is recommended that the students use the electronic poster format (depending on the teacher).

Suggested Requirements:

* Extremely interesting and engaging background/introduction is included.
* Connection to nuclear chemistry is a focus. Poster jumps off of what was learned in class and goes beyond the explanation being clear and understandable.
* Well researched topic shows thorough understanding of the topic. Evidence of multiple sources and in-depth coverage. Sources are cited using webpages (or desired format) and 6+ sources are included.
* Layout has engaging titles to pull in the reader, includes cool images and graphics, and text is concise and easy to follow.
* Super cool – anyone walking by would have to at least stop and check out your poster.
* Presentation talks go beyond the poster. It is engaging and shows evidence of exceptional understanding of the content. Presentation talks read directly from the slides or notecards with the same text as the slides well have a maximum score of a “C” in this category (grade determined by teacher).
* **Important**: you must use original text the only cut and paste allowed is pictures or direct quotes. If in doubt, ask before including a quote. All pictures and quotes must be cited properly.

**Nuclear Chemistry Electronic Poster Rubric:**

This rubric has students self-assess their poster. Collect the completed rubric prior to presenting, and then grade and write comments on it as they present. Grade each student independently, unless they all agree they truly worked as a group. This way if one student drops the ball, the other members can still receive a fair assessment. For this project, students can choose their teams, or they can be assigned. Topics can be chosen by the teams.

Find “Sample Rubric” under the Materials section of the curriculum page.