Lesson Title	14 Radiation in Medicine
Lesson Designer	Peter Dufner
Standards	☐ CCSS ☑ NGSS ☐ ASCA ☐ Other HS-PS2-6 Motion and Stability: Forces and Interactions Communicate scientific and technical information about why the molecular-level structure is important in the functioning of designed materials. HS-PS1-8 Matter and its Interactions 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.
Learning Objectives	Students will describe basic radioactive decay principles, and how they can be applied to the medical field through radiotherapy procedures.

Timeline	Duration
Day 1: radiation notes and worksheet. (45 minutes) Day 2: Radiation Activity (45 minutes) Day 3 (or homework): Radiation in Medicine (45 minutes)	2-3 days

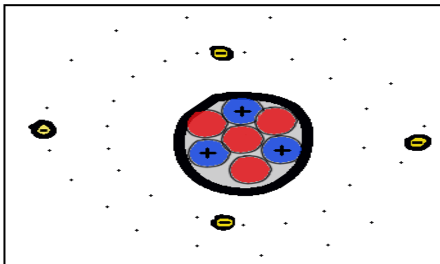
Teaching Strategies/Student Actions	Monitoring
Students can be given the notes sheet to read for information from, or the instructor can just use the notes as a basis for the necessary information. The radiation worksheet will test the students on basic radioactive decay principles such as alpha, beta, and gamma decay. The radiation activity uses an online simulation to help students gain a more hands-on understanding of atomic structure and radioactive decay. The final worksheet includes information on radiotherapy, linking student knowledge on radioactive decay to the medical field. This can be done as a class, or individually as either homework or classwork.	• Teacher monitors student progress • Teacher facilitates discussion • Teacher questioning

Product Description	
Evaluation	Students describe the process of nuclear decay, along with writing nuclear decay reactions through the completion of the activities and worksheets.

Resources and Materials	Additional Notes
• Radiation Notes • Radiation Worksheet • Radiation Activity • Radiation in Medicine Worksheet	

Radiation in Medicine Notes

Atoms are considered the smallest unique building blocks of matter, and are composed of two general regions; the nucleus and the electron cloud. The **nucleus** sits at the center of the atom and houses protons and neutrons. Around the nucleus is the **electron cloud**, where electrons orbit at increasing energy levels the farther from the nucleus they get. Each subatomic particle has a certain electrical charge and mass, as listed in the table shown. When we draw an atom, we often use the **Bohr Model** to show the proton and neutron values listed in the nucleus, along with each electron carefully placed in its respective "shell" within the electron cloud.



An atom is composed of a nucleus surrounded by electrons at varying orbital levels.

Subatomic Particle	Location	Charge (e)	Mass (u)
Proton	Nucleus	+1	1
Neutron	Nucleus	0	1
Electron	Electron Cloud	-1	(1822^{-1}) or 0

Notice that the masses and charges seem oddly convenient, this is because the subatomic particles are often measured in the units of "elementary charge (e)" for charge, and the "Dalton (Da or u)" for mass. The Dalton is currently accepted, and is approximately also equal to the "*atomic mass unit*" or (amu). These values simplify atomic math since they are tailored units meant for subatomic particles. Below is the data for the subatomic particles again, but this time using the SI units of kilograms and Coulombs.

Subatomic Particle	Location	Charge (C)	Mass (kg)
Proton	Nucleus	$+1.60 * 10^{-19}$	$1.66 * 10^{-27}$
Neutron	Nucleus	0	$1.66 * 10^{-27}$
Electron	Electron Cloud	$-1.60 * 10^{-19}$	$9.11 * 10^{-31}$

For each element, you will see a few key facts about the element on the periodic table. The **atomic number (Z)** is the smaller number, often seen in the top of the box on the periodic table. This atomic number represents the number of protons in the nucleus of this atom. An average atom will also have a number of electrons equal to the atomic number as well. The **atomic symbol** is the shorthand for the element name, and always starts with a capital letter and then (if there is a second or third letter) lowercase letters. Finally the largest number seen in the element box is the **atomic mass (A)**, which represents the cumulative mass of the atom. Since electrons have negligible mass, this is found by adding the mass of the protons and neutrons together. The formula to calculate the atomic mass of an atom is $Atomic\ mass = n_{protons}m_{proton} + n_{neutrons}m_{netron}$, but this is a little more complicated than it has to be if you are using the non SI unit of the Dalton or amu, since the mass of each proton and neutron is "1". If you are using the Dalton or amu, just add up the number of protons and neutrons in the atom to find the atomic mass.

6	***Z***	**8**
C	***x***	***O***
12.01	***A***	**15.99**

Each element is shown with its atomic number (Z), atomic symbol (x), and atomic mass (A). Carbon and Oxygen are shown here, alongside the variable form.

There are some special types of atoms called **Isotopes** and **ions.** An **isotope** is an atom with more or less neutrons than the standard form of the atom. Isotopes are the reason why the atomic mass listed on the periodic table is a decimal, since isotopes that are lighter or heavier than the average will move the average mass away from a round number. An ***ion*** is an atom with a non-zero charge. This means that unlike the standard atom, the number of protons and electrons is not the same. A positive ion has more protons than electrons and is called a **cation**. A negative ion has fewer protons than electrons and is called an **anion**. Charge can be calculated by using the formula $Q = q_{protons} + q_{electrons}$ where Q is the total charge of the atom, q_{proton} is the total charge of the protons in the atom and $q_{electrons}$ is the total charge of the electrons in the atom.

Write down ions with the charge shown as a superscript on the elemental symbol, and write isotopes with a dash followed by the isotope's mass. Remember that by definition an ion will not have the same amount of protons and electrons, instead it will have more or less electrons depending on the charge presented. The amount of protons is defined by the element and should not vary with charge. Isotopes have a different mass than other atoms of that element, but only because of additional or fewer neutrons, not protons or electrons.

Lithium Atom (standard)	Lithium $^{+1}$ Cation	Lithium-6 Isotope
$\mathbf{3}$ $\boldsymbol{Li}$ $\mathbf{6.94}$	$\mathbf{3}$ $\boldsymbol{Li^{+1}}$ $\mathbf{6.94}$	$\mathbf{3}$ $\boldsymbol{Li}$ $\mathbf{6}$

Sample Problem:

How many neutrons are found in the element Scandium, which has an atomic number of 21 and an atomic mass of 44.95 amu.

Given Information:

Atomic # (Z) = 21
Atomic Mass (A) = 44.95
 # neutrons = ?

Known Formula:

$$A = \#protons + \#neutrons$$

Solution:

We know that the atomic number of an element represents the number of protons found in the nucleus, which means this element has 21 protons. Since the proton and neutron both have a mass of 1 u, we know that we can use the formula above to solve for the number of neutrons.

First rearrange the formula to solve for the wanted variable.

$$A - \#protons = \#neutrons$$
$$44.95 - 21 = 23.95\ Neutrons$$

Since you cannot have a partial neutron, round the number to the nearest whole number before reporting your answer.

$\mathbf{24}$ *Neutrons* are in a Scandium atom

Some isotopes form and are **unstable**. If an isotope unstable, that means the attractive forces between the protons and the neutrons are not sufficient to hold the nucleus together. These atoms will begin to **decay**, and their nucleus will break apart until it reaches a stable state. What is released from a decaying nucleus is called **radiation**. We will focus on three types of radiation named alpha (α), beta (β), and gamma (γ) radiation.

The initial unstable nucleus is called the **parent**, while the newly created atom (not the radiation) is called the **daughter** atom. If the daughter is also unstable, it will release more radiation until it can reach a stable state. Remember that the atomic numbers of the radiation and the daughter atom must always add up to be equal to the atomic number of the parent atom and the atomic mass of the daughter and radiation must also sum to the atomic mass of the parent atom.

Parent Atom		Daughter Atom		Radiation
$\mathbf{20}$ $\boldsymbol{Ca}$ $\mathbf{47}$	$\longrightarrow$	$\mathbf{21}$ $\boldsymbol{Sc}$ $\mathbf{47}$	$+$	$\mathbf{-1}$ $\boldsymbol{\beta}$ $\mathbf{0}$

Alpha radiation (α) is two protons and two neutrons that are released from the nucleus during nuclear decay. This is the most massive type of radiation

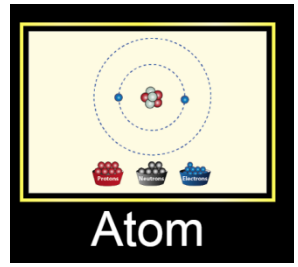
Beta radiation (β) is an electron that is emitted from the nucleus. This electron is actually ejected during the process of a neutron splitting and becoming an electron and a proton. The newly formed proton remains in the nucleus of the daughter atom while the electron is ejected as radiation.
Gamma radiation (γ) is the release of high energy gamma waves. This does not change the mass or structure of the parent atom, but it does release the excess energy that is stored in the atom.

Sample Problem:	
A Carbon-14 isotope emits radiation before forming a daughter atom of Nitrogen. What is the atomic mass of the new daughter atom and what type of radiation was released?	
Given Information:	Known Formula:
Parent = $\mathbf{{}^{7}_{14}C}$ **Daughter =** $\mathbf{N}$ **Radiation = ?**	$A_{Parent} = A_{daughter} + A_{radiation}$ $Z_{parent} = Z_{daughter} + Z_{radiation}$
Solution:	
Looking at the periodic table of elements, Nitrogen must have an atomic number of Z=8. This means that we can use the formula $Z_{parent} = Z_{daughter} + Z_{radiation}$ *to solve for the atomic number of the radiation. First rearrange the formula to solve for the wanted variable.* $Z_{radiation} = Z_{parent} - Z_{daughter}$ $Z_{radiation} = 7 - 8$ $Z_{radiation} = -1$ *The only radiation type that has a -1 atomic number* ***is β radiation****, which is an emitted electron. Since beta radiation has no mass change associated with it, the atomic mass of the* β *is 0.* $A_{parent} = A_{daughter} + A_{radiation}$ *Rearrange to solve for the mass of the daughter atom* $A_{parent} - A_{radiation} = A_{daughter}$ $14 - 0 = A_{daughter}$ $A_{daughter} = 14\,u$ ***The atomic mass of the daughter particle is 14 u.***	

Each radiation has a different structure and will act differently once ejected from the atom. Alpha radiation is the most massive, but this also leads it to having very poor penetration abilities. A sheet of computer paper or skin is sufficient to block most alpha radiation. Beta radiation is able to pass through paper or skin, but will be blocked by only a few millimeters of aluminum foil. Gamma radiation is very high energy, so it is able to penetrate both paper and thin metal, but is ultimately blocked by a few centimeters of lead of a concrete wall.

These forms of radiation are able to **ionize** the atoms found in living tissues as they collide with the atoms within the living tissue. This means that the radiation can "knock off" electrons in these atoms, forming ions in their place. This can be very harmful to living tissue if the genetic material in the DNA becomes damaged, leading to cancerous growths. Alpha particles have the most ionization ability, while gamma radiation is actually the least ionizing. Beta radiation is in between both alpha and gamma in terms of penetration and ionization ability.

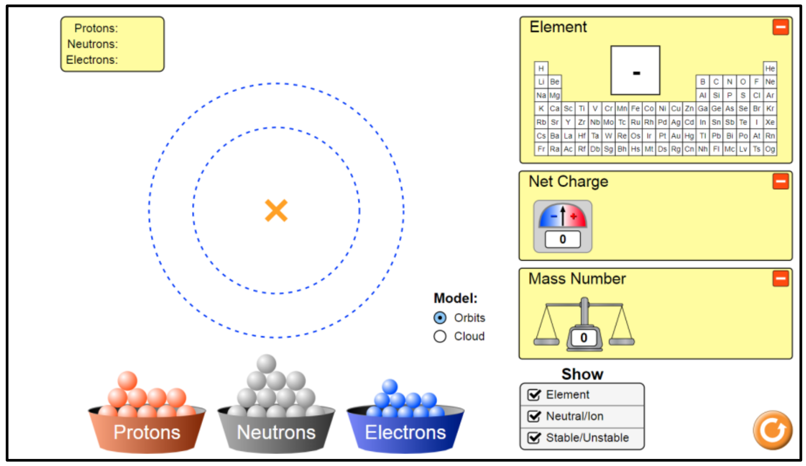
Radiation in Medicine Learning Task



1. Go to https://phet.colorado.edu/en/simulation/build-an-atom or search "PhET Build an Atom html5" and follow the link.

2. Click the "play button" to begin the simulation, and then click on the "atom" tab to start.

3. Click the green + next to "Net Charge" and "Mass Number", along with the check box next to "Stable/Unstable". Your screen should look like the screen shown.



4. Drag a red proton onto the atom.
   a. Where does the proton go in the atom?

   b. What happened to the net charge of the atom?

   c. What happened to the atomic number of the atom when you added the one proton?

   d. What happened to the atomic mass of the atom when you added the proton?

   e. What element have you created?

   f. Is this atom an ion, isotope, both, or neither?

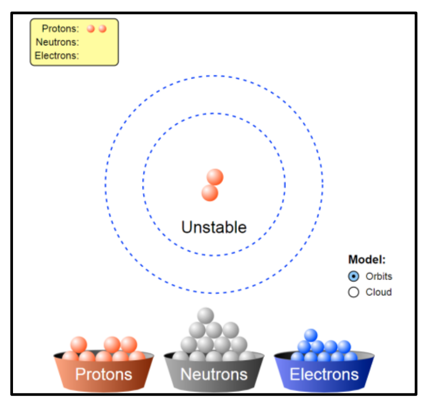
   g. Would this atom undergo radioactive decay? Why or why not?

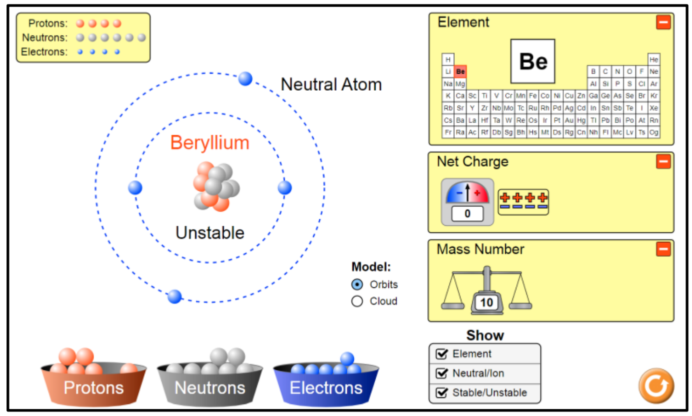
5. Drag another proton into the atom.
   a. What element have you made?

   b. Is this element an ion, isotope, neither, or both?

   c. Why is this element marked as "unstable"?

   d. Could this element undergo alpha decay? Why or why not?





6. Create a beryllium atom.
   a. How many protons, neutrons, and electrons are necessary to create a neutral, stable beryllium atom?
      i. Protons:

      ii. Neutrons:

      iii. Electrons:

   b. Add one neutron to create an unstable Be-10 isotope.
      i. What daughter atom will be formed if this Be-10 isotope undergoes gamma decay? Will this daughter atom be stable or unstable?

      ii. What daughter atom will be formed if this Be-10 isotope undergoes alpha decay? Will this daughter atom be stable or unstable?

      iii. What daughter atom will be formed if this Be-10 isotope undergoes beta decay? Will this daughter atom be stable or unstable?

7. Build your own unstable parent isotope that can undergo alpha decay to create a stable daughter atom. Write the reaction equation below in the format shown, but using your values for atomic mass (A) and atomic number (Z).

$$\begin{matrix} Z_p & & Z_d & & Z_r \\ X_p & \rightarrow & X_d & + & X_r \\ A_p & & A_d & & A_r \end{matrix}$$

8. Build your own unstable parent isotope that can undergo beta decay to create a stable daughter atom. Write the reaction equation below in the format shown, but using your values for atomic mass (A) and atomic number (Z).

$$\begin{matrix} Z_p & & Z_d & & Z_r \\ X_p & \rightarrow & X_d & + & X_r \\ A_p & & A_d & & A_r \end{matrix}$$

9. Why is it impossible for us to model gamma decay through this simulation?

10. Create a stable, neutral Boron atom.
    a. What happens when you remove an electron from the lowest electron shell?
    b. Why does this happen?
11. Create a stable, neutral atom of your choosing.
    a. Write the element you created here:
    b. What happens to the net charge as you add electrons?
    c. What happens to the stability of the atom as you add electrons?
    d. What happens to the net charge as you remove electrons?
    e. What happens to the stability of the atom as you remove electrons?
    f. How can you explain these results?
12. What conclusions about atomic stability can you draw from experimenting with this atom building simulation?

Radiation in Medicine Worksheet

Fill in the blanks in the following section using the words from the word bank provided. No term in the word bank should be used more than once.

Word Bank #1-#5		
Decay	Atomic Mass (A)	Beta (β)
Protons	Gamma (γ)	Unstable
Radiation	Nucleus	Alpha (α)

1. _________________ and neutrons are found in the _________________ of an atom.
2. An atom with a different _________________ than the average atom is considered an _________________
3. An _________________ isotope will undergo nuclear _________________ until it is stable.
4. Alpha, _________________ , and Gamma _________________ can be released from an unstable nucleus.
5. _________________ radiation has the highest penetrating ability, while _________________ radiation has the weakest penetrating ability.

Mark each statement as either (T) true or (F) false. If the statement is false, correct the statement as best you can to make it true.

6. _____ An ion will always have a total charge of 0 since it has equal amounts of protons and electrons.
7. _____ The proton is the lightest subatomic particle found in an atom.
8. _____ Electrons in the shell farthest from the nucleus have the lowest energy.
9. _____ Gamma radiation is a wave of energy that is released from the nucleus of an unstable atom.
10. _____ Alpha particles have the highest ionizing ability, but the worst penetration of all three types of radiation.

Answer the following questions by choosing the one best answer to each.

11. What is the charge of an atom with 8 protons, 8 neutrons, and 10 electrons?
    a. 18 e
    b. 0 e
    c. -2 e
    d. -10 e
12. Which type of radiation will cause the atomic number of an isotope to increase after it is released?
    a. α
    b. β
    c. γ
    d. σ
13. Using a periodic table for reference, which element will be created when carbon undergoes alpha decay?
    a. Nitrogen
    b. Carbon
    c. Beryllium
    d. Hydrogen
14. Which type of radiation is the most massive?
    a. α
    b. β
    c. γ
    d. σ
15. Which type of radiation will change the atomic mass of the atom when released?
    a. α
    b. β
    c. γ
    d. σ

Answer the following questions to the best of your ability, making sure to clearly mark your answer and show your work whenever possible.

16. An atom has 35 protons, 35 electrons, and an atomic mass of 79 u.
    a. What is the total charge of this atom?
    b. How many neutrons does this atom have?
    c. What element is this?
    d. Is this atom an ion? (yes/no)
    e. Is this atom an isotope? (yes/no)

17. A radioactive isotope has an atomic mass of 148 u and 84 neutrons.
    a. How many protons does this isotope have?
    b. What element is this isotope?
    c. If the radioactive isotope undergoes gamma decay, what will be the daughter atom?

18. A radioactive parent isotope of Americium has an atomic mass of 241.
    a. How many protons does Americium have?
    b. How many neutrons does this Americium isotope have?
    c. If the Americium undergoes alpha decay, what is the daughter atom formed?

19. A radioactive parent isotope undergoes beta decay and then alpha decay, forming a final daughter atom with 91 protons and 238 neutrons.
    a. What element is the final daughter atom?
    b. Undergoing both beta and alpha decay will change the atomic number of the parent atom by _______________.
    c. Undergoing both beta and alpha decay will change the atomic mass of the original parent atom by ______________.
    d. What was the original parent atom?

Radiation in Medicine Worksheet #2

Read this background information before answering the following questions.

Radiation can be used to harm living tissue, but it can also be used carefully to help preserve healthy tissue while destroying dangerous cancer cells. The use of radiation as a medical tool is called **radiotherapy**. This is a careful medical application of physics. The process can do more harm than good if too much radiation is used, the wrong type of radiation is used, or if the location exposed to the radiation is incorrect. We will focus on two different types of radiotherapy, **external beam radiotherapy** and **brachytherapy.**

External beam radiotherapy uses a radiation source outside of the body and directs the radiation to the location in need of treatment. When high atomic number materials are bombarded with electrons, radiation can be released from the material in the form of electrons or x-rays, and directed toward the patient. Depending on the energy and frequency of the radiation, the beam will penetrate a certain amount into the body. This allows for the surface or subsurface to be targeted, without much deeper exposure happening. If a patient moves while undergoing treatment, the beam will begin to effect the new area of exposure instead, so patients must be very still while undergoing external beam radiotherapy.

Brachytherapy is when a radiation source is placed inside the body, within or near the targeted zone. As the radiation source decays, it will release ionizing radiation around it, damaging the targeted cells. This allows high doses of radiation to be given to localized regions as safely as possible. These radiation sources are carefully chosen in size and location, otherwise the dose will affect more than just the target area. The source must also be anchored to prevent it from moving around the body.

For each of these procedures, the intensity of exposure will decrease with distance. As the radiation travels through the medium, whether it is air or body tissue, the radiation will spread out. The radiation will also be absorbed by some of the atoms it collides with along the way, causing the most intense radiation to be directly near the radiation source. This can be used to help predict how the radiation will affect surrounding tissues. Alpha particles are unable to travel more than a few inches through air, let alone body tissue. Beta radiation is able to travel a few feet and even penetrate the skin of the patient. Gamma rays will travel great distances through air and body tissue, so must be very carefully used.

Fill in the blanks in the following section using the words from the word bank provided. No term in the word bank should be used more than once.

Word Bank #1-#5		
Skin	Brachytherapy	Greatest
Unstable	Alpha	Source
Penetrate	Atomic number	Ionizing

1. ____________________ is the most massive and most ____________________ form of radioactive decay.
2. Gamma radiation will ____________________ through the most substances, while alpha radiation is stopped by a substance such as ____________________
3. Alpha decay will cause the ____________________ change in ____________________ out of all three types of radioactive decay.
4. An ____________________ nucleus will undergo radioactive decay until it becomes stable.
5. ____________________ involves placing a radiation ____________________ inside the body.

Mark each statement as either (T) true or (F) false. If the statement is false, correct the statement as best you can to make it true.

6. ______ External beam radiotherapy uses radiation to treat tissues at or near the surface of a patient.

7. _____ Gamma radiation has the highest ionizing power out of the three types of radioactive decay.

8. _____ Brachytherapy has the advantage of being able to expose a very localized area to high doses of radiation.

9. _____ External beam radiotherapy can be performed with x-rays.

10. ______ Any form of radiotherapy must be carefully calculated and delivered, or else there is a risk of exposing unnecessary healthy tissue to damaging radiation.

Answer the following questions by choosing the one best answer to each.

11. Which type of radiation is likely used for Brachytherapy?
    a. Alpha (α)
    b. Beta(β)
    c. Gamma(γ)
    d. Omega(Ω)

12. Which type of radiation is likely used for external beam radiotherapy?
    a. Alpha (α)
    b. Beta(β)
    c. Gamma(γ)
    d. Omega(Ω)

13. Which of the following situations would likely warrant external beam radiotherapy instead of brachytherapy?
    a. Brain tumor
    b. Skin cancer
    c. Cervical cancer
    d. Eye cancer

14. Which type of radioactive source would be the most dangerous to swallow unknowingly?
    a. Alpha (α)
    b. Beta(β)
    c. Gamma(γ)
    d. Omega(Ω)

15. A patient undergoes brachytherapy and has a radioactive "seed" placed inside them. Which of the following is not a reasonable result of the treatment?
    a. The patient's body is exposed to radiation centered around the radioactive seed.
    b. The cells near the seed experience damage to their DNA, causing them to die off.
    c. The patient's body now emits radiation.
    d. The radioactive seed undergoes radioactive decay until it is composed of stable atoms.

Answer the following questions to the best of your ability, making sure to clearly mark your answer and appropriate unit.

16. A radioactive source is placed in a vacuum chamber for days. After an undisclosed amount of time, the source is massed and found to have lost mass.
    a. What type of radioactive decay did this source undergo?

    b. If this vacuum chamber was made with paper walls, would the radiation have escaped the chamber?

c. If there was air or some other medium in the chamber instead of a vacuum, how would that have changed the intensity of radioactive exposure to the walls of the chamber?

17. Uranium-238 undergoes radioactive decay and becomes a Thorium isotope.
    d. What is the atomic number of Uranium?
    e. What is the atomic number of Thorium?
    f. What type of radioactive decay did this Uranium isotope undergo?
    g. Write the radioactive decay equation below.
    h. Why would this reaction not be used for external beam radiotherapy?

18. A radioactive seed is placed inside a patient's tumor where it undergoes radioactive decay. This seed eventually decays and becomes a Rhodium atom with 61 neutrons.
    i. How many protons does the Rhodium atom contain?
    j. If the radioactive seed underwent β decay to create the Rhodium, what was the original parent atom?
    k. Write the appropriate radioactive decay equation below.
    l. Where in the patient's body would they receive the highest exposure to the radiation released by this radioactive seed?
    m. Why would the patient not have to worry about the radiation reaching their other organs and tissues in their body?