

Uses of radioactivity

Introduction

Students do not find it easy to learn the science of radioactivity. This activity applies some of the important concepts to uses of radioactivity. Before doing the activity most groups will need an introduction to the science. Pages 168 to 171 in the text book would provide this. The sheets here, 'Essential Information' will be useful as a reference during this and other activities.

Method

Students should work in pairs, reading the applications and then consulting the table of isotopes to select the appropriate one.

If the conclusions are compared in a whole class discussion students get practice in talking about the properties of radioisotopes. The questions are also a revision of the concepts and might be used for homework.

Answers

Smoke alarm Americium-241: α particles easily stopped by smoke. Do not travel far in air so almost no irradiation. Long half life. Only risk is unsafe disposal.

Radiotherapy for thyroid cancer Iodine-131: β particles are damaging to cells. Patient not radioactive after two to three weeks.

Sterilisation of medical equipment Cobalt-60: gamma rays needed to penetrate. Long enough half life to remain effective.

Kidney scans Technetium-99: γ emitter. Short half life so patient only exposed to radiation for a short time.

Lung scans Krypton-81: γ emitter. Gas so can be breathed into lungs. Very short half life not a problem in this case as patient can breathe it in continuously. Prepared from Kr-82 when needed.

Pesticides in the environment Carbon-14: weak β easily detected with specialised equipment but contributes very little to background radiation. Long half life means long term studies possible.

Questions

1. Name two entries in the table that are isotopes of the same element.

Americium-241
Americium-239

2. If a sample of technetium-99 is emitting 1000 bequerels of radiation per second how much will it be emitting after

- (a) 6 hours 500Bq
(b) 12 hours 250Bq

3. Which would cause the least radiation damage if you swallowed it; Americium-241 or Americium-239?

References

Textbook
Chapter 13 and 14

Specification
10.5 Sources and Effects of Radiation
13.3 Radioactivity,
13.4 The Radiation Model of Action at a Distance

Resources

Information on medical uses
<http://www.world-nuclear.org/info/inf55.htm>

Details of the production of artificial isotopes and some of their medical uses
<http://uc.jinr.ru/SummerSchool/fisher/fisher.htm>

For detailed data on isotopes
http://www.hpschapters.org/northcarolina/nuclide_information_library.php3

Americium-239 because most of the γ radiation will pass out through the body. The α radiation is easily stopped and gives a much higher equivalent dose.

4. Which would cause the least radiation damage if you stood 1 metre away from a sample; Americium-241 or Americium-239?

Americium-241 because the α particles are stopped by the air and would never reach you.

5. Many applications of radioisotopes rely on the fact that ionising radiation kills living cells. Name two applications above that do not depend on this property.

Smoke alarm, kidney scan, lung scan, pesticides

6. If a patient has a procedure using iodine-131 they are allowed very little contact with other people for a week or more. If the procedure involves technetium-99 the restrictions apply for only a day.

(a) Explain the reason for the restrictions.

Because the patient is contaminated with the radioisotope as a necessary part of the procedure they are emitting ionising radiation.

(b) Explain the reasons for the difference in time.

The half life of the iodine is 8 days and that of the technetium is only 6 hours. After 12 hours the radiation from the technetium will have declined to one quarter of its original value and present no risk. It will take 16 days for the same decrease in the iodine radiation.

Essential information on radioactivity

Isotope

Atoms of the same element always have the same number of protons (and hence electrons) but may have different numbers of neutrons in the nucleus. Atoms of the same element with different numbers of neutrons are called isotopes. The total number of particles in the nucleus, protons plus neutrons, is indicated in the name of the isotope. Uranium-235 and uranium-238 are isotopes of uranium.

Radioactive decay

Radioactive decay is a change to the nucleus of an atom. The nucleus in some isotopes is unstable. It breaks down spontaneously, giving off ionising radiation. During radioactive decay the atom of one element becomes an atom of a different element.

Radioisotope

A radioisotope is an isotope that undergoes radioactive decay, it has an unstable nucleus.

Ionising radiation

Ionising radiation is radiation that is able to produce ions (atoms or groups of atoms with an electric charge) when it is absorbed by matter.

Half life

The half life of a radioisotope is the time taken for half the atoms in any sample to decay to a different element. The radiation emitted by the isotope at the end of a half life is half that emitted at the start. Half life is a property of the isotope and cannot be changed.

Types of ionising radiation

Radioactive decay can lead to alpha, α , beta, β , or gamma, γ , radiation.

Type of radiation	Description	Electrical charge	Penetration	Relative damage to living cells
alpha α radiation	fast moving α particles containing two protons and two neutrons	positive or a few centimetres of air of air	stopped by paper	most damaging
beta β radiation	fast moving electrons	negative material but are stopped by a few millimetres of metal	pass through thin	
gamma γ radiation	electromagnetic radiation, like light but with a much shorter wavelength and higher energy	none	very penetrating require thick lead or concrete to stop them	least damaging

Damage to living cells caused by ionising radiation

Because ionising radiation creates ions it damages the chemicals in living cells. At low doses cells can repair or recover from some kinds of damage but higher doses are fatal. Even low doses of radiation can damage the DNA in genes, causing mutations which lead to cancer. Of the three kinds of ionising radiation, for the same amount of energy, α causes the most damage and γ the least.

Equivalent dose - Sievert

Because not all radiation causes the same damage, human exposure to ionising radiation is measured as an equivalent dose, in Sieverts. This is a unit which measures the potential damage. Thus 1Sv of α , β , or γ radiation would cause the same damage.

Contamination or irradiation?

If you are exposed to a radioisotope you will be irradiated by ionising radiation. The effect will depend on the type of radiation and the distance. However once you move away you will no longer be affected and you will not be radioactive.

If a radioisotope enters your body you will be contaminated. Your body will be exposed to radiation but you will also irradiate others. This will go on happening until the isotope is expelled from the body or decays.

Uses of radioactivity

Introduction

Radioactivity is dangerous but used carefully it also has many uses in modern life, in industry, medicine and in the home. This activity tells you about a few of these uses and relates the uses to the properties of the isotopes.

If you have not already learned about radioactivity you should start by reading the textbook, pages 169 to 171 or the section of this activity **Essential Information on Radioactivity**. Keep this with you as you work through the activity.

Which isotope should they use?

Six applications of radioisotopes are given below. Choose which isotope should be used in each of these applications from the isotopes listed in Figure 1.

You will have to consider:

- The type of radiation emitted. Do we need maximum damage to cells, in which case we might choose an α emitter, but this may not penetrate far enough to reach the cells we want to kill.
- The half life. Is it important that the isotope remains active for a long time, or is it safer for a short half life isotope to be used?
- Contamination or irradiation. The type of radiation and the half life requirements will be different depending on whether we are using contamination or irradiation

Smoke alarm

A smoke alarm works by detecting ions formed by the ionising radiation emitted by the radioisotope. If there is smoke in the air this absorbs the radiation and less ions are formed. This sets the alarm off.

Requirements:

- Radiation easily stopped by smoke in air (*would α , β or γ be best?*)
- No risks of radiation reaching people in the room
- Half life of several years to maintain efficiency

Radiotherapy for thyroid cancer

The radioisotope is injected into the patient and travels specifically to the thyroid where the radiation kills the cancer cells gradually over a few days.

Requirements:

- Radiation that is effective at killing cells close to the source but does not damage other parts of the body (*which types of radiation do not penetrate far?*)
- Fairly short half life so that the patient is not radioactive for too long.
- Chemical substance that is naturally concentrated in the thyroid

Sterilisation of medical equipment

Medical equipment used to be sterilised by heating, but this harms some equipment. Ionising radiation is used to kill microbes, sterilising the equipment without heating.

Requirements:

- Radiation that is able to penetrate through packaging and reach the inside of the equipment
- High doses can be used because no other living organisms, only the microbes to be killed, are exposed
- Long half life so that the source does not need replacement all the time

Kidney scans

X-rays work well for images of bone but do not show soft tissue well. Certain compounds concentrate in the kidneys and are excreted in the urine. If one of these compounds is made radioactive and injected into the body it will travel to the kidneys. Pictures can then be taken with a gamma ray camera, showing details of the kidney and how it is functioning.

Requirements:

- An isotope that binds to biological molecules.
- Gamma emission
- Short half life

Lung scans

Detailed images of the lungs using gamma rays can be taken if a radioactive gas is inhaled.

Requirements

- Gamma emission
- Short half life
- Gas

Pesticides in the environment

It is important to find out what happens to pesticides in the environment after they have been applied to a field. Pesticides can be made containing very small amounts of a radioisotope and this isotope can later be detected in the environment using very sensitive radiation detectors.

Requirements

- Long half life
- Low risk from radiation
- An element such as carbon, hydrogen or oxygen that can be included in the pesticide

Questions

1. Name two entries in the table that are isotopes of the same element.
2. If a sample of technetium-99 is emitting 1000 bequerels of radiation per second how much will it be emitting after (a) 6 hours (b) 12 hours
3. Which would cause the least radiation damage if you swallowed it; Americium-241 or Americium-239?
4. Which would cause the least radiation damage if you stood 1 metre away from a sample; Americium-241 or Americium-239?
5. Many applications of radioisotopes rely on the fact that ionising radiation kills living cells. Name two applications above that do not depend on this property.
6. If a patient has a procedure using iodine-131 they are allowed very little contact with other people for a week or more. If the procedure involves technetium-99 the restrictions apply for only a day.
 - (a) Explain the reason for the restrictions.
 - (b) Explain the reasons for the difference in time.

Isotope	Most important emission	Half life	Other information
Americium -241	α	430 years	non-toxic in compound used
Americium-239	γ	12 hours	non-toxic in compound used
Carbon-14	β	5760 years	low energy radiation
Cobalt-60	γ	5.26 years	
Hydrogen-3 (known as tritium)	β	12.3 years	very low energy radiation
Iodine-131	β	8 days	concentrates in the thyroid
Iodine-123	γ	13 hours	concentrates in the thyroid
Krypton-81	γ	13 seconds	a gas (produced by the decay of rubidium-81)
Oxygen-19	β	27 seconds	
Radon-222	α	3.8 days	a gas
Technetium-99	γ	6 hours	easily combined with biologically-active substances

Figure 1 Properties of some radioisotopes