STEM AMBASSADOR

Nuclear Medicine: Separating Radionuclides

Objectives

Students will:

- Understand how nuclear materials are used for medical purposes.
- Understand why half-lives are important in nuclear medicine and how we separate different isotopes.

Fast facts

Subject: Chemistry

Age range: 16+ years old

Ambassador preparation time: 30 minutes

Demonstration time required: 20 minutes

Location: Science Fair

Overview

In 21st century medicine, radioisotopes play a huge role in cancer treatments and diagnostics.

As medicine develops the use of radioisotopes will increase.

This activity highlights how radionuclides with specific properties are separated and isolated for their use in cancer treatments. Specifically, a new type of treatment called Targeted Alpha Therapy (TAT) is considered.

Equipment

All the different items which can be used in this activity are listed at the end of the guide (Full Equipment List section).

Background

This demonstration has been designed for use at science fairs. It is designed to represent the rigs used by the Health and Nuclear Medicine (H&NM) team to extract yttrium from nuclear waste, which could then be used in medicinal applications. This activity is designed to be demonstrated after a brief introduction to nuclear medicine.

The concept of the demonstration is that the columns filled with cotton wool balls represent the real columns and ion exchange resin used by H&NM research teams. The white cotton wool balls at the start represent a clean ion exchange resin. As the black water, representing nuclear waste that contains many elements but this case specifically strontium, is poured in, the white cotton wool balls are stained black. This is to show the binding of the strontium to the ion exchange resin.

The second column filled with black cotton wool balls and skittles represents the column after time. The black cotton wool balls show that the strontium in the original nuclear waste (which turned the white cotton wool balls black) is still there, but some has decayed into new elements (the skittles). The new elements have weaker bonding to the ion exchange resin and can be washed off the column using acid. When adding the water to the second column, the colour should be washed off the skittles, highlighting that these daughter products can be removed, whilst the strontium remains.

The red coloured water can then be shown to be extracted and taken to be made into medicine.

Procedure

Before the science fair begins:

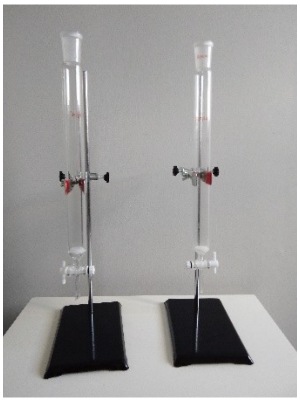
1. Ensure you are located close to a tap, if not collect some water using a jug or appropriate container.

2. Fill a jug with roughly 100 mL of tap water and add enough black food colouring to the water to get a dark black colour to the water. This represents the nuclear waste. Use this dyed water to dye some cotton wool balls black.

3. Fill one jug with water. This represents acid.

4. Set up two retort stands on an appropriate level surface, probably a table.

5. Clamp a chromatography column to each retort stand. Ensure the taps at the bottom are shut.



6. Fill one column with white cotton wool balls. This represents a pristine column of ion exchange resin.

7. Fill one column with a mixture of black cotton wool balls and skittles. This represents a column after a month of decay. Place a glass beaker beneath this column to collect the red dyed water (daughter isotopes).

Starting the demonstration:

1. Go through the background information with the students; the supporting slide pack can be used to help explain and visualise the demonstration. Highlight the white cotton wool balls showing that there is only hydrogen bound to the ion exchange resin. Pour the 'nuclear waste' black water into the column from the jug. Make sure the tap is shut before pouring in the water. Pour the black water into a level at which all the cotton wool balls are only just submerged ensuring the cotton wool balls do not float too much out of the water.

2. Whilst the cotton wool balls are absorbing the colour explain the columns filled with cotton wool balls represent the real columns and ion exchange resin used by H&NM research teams. The white cotton wool balls at the start represent a clean ion exchange resin. As the black water, representing nuclear waste that contains many elements but this case specifically strontium, is poured in, the white cotton wool balls are stained black. This is to show the binding of the strontium to the ion exchange resin.

3. After 3 / 4 minutes the cotton wool balls will have absorbed the colour. Open the tap and release the black water into a beaker. Show that the cotton wool balls are now stained black/grey, indicating strontium and other elements are now bound to the resin.

4. Show the second column containing the black cotton wool balls and skittles. Point out that the skittles represent daughter elements such as yttrium growing into the column, whilst undecayed strontium is still present.

5. Pour the jug of 'acid' (water) into the column containing the skittles, until all the cotton wool balls and skittles are submerged. Make sure the tap is closed before pouring in the water. Whilst waiting for the colour to wash off, explain that the second column filled with black cotton wool balls and skittles is supposed to represent the column after time. The black cotton wool balls show that the strontium in the original nuclear waste (which turned the white cotton wool balls black) is still there,

but some has decayed into new elements (the skittles). The new elements have weaker bonding to the ion exchange resin and can be washed off the column using acid. When adding the water to the second column, the colour should be washed off the skittles, highlighting that these daughter products can be removed, whilst the strontium remains.

6. After a few minutes the colour of the skittles should now be washed off, turning the water reddish. Explain that the yttrium was washed off the ion exchange column as it is less strongly bound.

7. Open the tap of the column and catch the red water into a beaker.

8. Show that the beaker full of red liquid now contains the isotopes we need to make the alpha therapy medicine explained in the slides. The black cotton wool balls show that there is still undecayed strontium in the column. Explain that this will also decay, and we can repeat the process of extracting yttrium multiple times. Finish the presentation by summarising that this is how we make medicine from nuclear waste

Clean up

A bucket is provided; empty all the waste contents into the bucket. The liquids can be disposed of down a sink and the solids into a bin or however else specified by the venue. The cotton wool balls can get stuck in the glass columns; tweezers are provided to help remove them. Dismantle and clean all the kit before returning it to the box. The glass columns are fragile so must be returned to the carboard boxes before being placed into the larger box.

Discussion and Real-World Application

Atoms are made up of a positively charged nucleus at their centre surrounded by negatively charged electrons. The nucleus contains both positively charged protons and neutrons, which have no charge. The stability of a nucleus depends on the balance between the number of neutrons and protons. Elements higher up in the periodic table, which have fewer protons, are stable if they have the same number of protons and neutrons in their nucleus. For example, carbon-12 is stable as it has 6 protons and 6 neutrons. However, for elements lower down in the periodic table, with an increasing number of protons, more neutrons are needed to keep the nucleus stable. For example, stable lead-206 has 82 protons and 124 neutrons.

Separating Radionuclides

Nuclei that have too many or too few neutrons are unstable and have a higher amount of energy. They can release some of the excess energy by emitting particles or waves. This process is called radioactive decay and the particles or waves released are types of radiation. Three types of radioactive decay processes are alpha decay, beta decay and gamma decay. In alpha and beta decay, a particle is emitted from the unstable nucleus, but in gamma decay a wave is emitted.

Isotopes of an element are atoms which have the same number of protons in their nuclei but a different number of neutrons. Radioisotopes are isotopes which have unstable nuclei which are therefore radioactive. In modern medicine, radioisotopes play an essential role in wide range or treatments and diagnostics. Diagnostic medical radioisotopes account for 95 % of all nuclear medicinal procedures undertaken each year.

Targeted Alpha Therapy (TAT) is a new area of cancer treatment and research in nuclear medicine. TAT involves the delivery of a radionuclide species to cancer cells using artificially made biological molecules. These biological molecules can selectively attach to the surface receptors of a cancer cell without affecting healthy tissue. Once attached to the cancer cells, the radionuclide decays, releasing an alpha particle. These alpha particles damage the cancer cells, leading to cell death. In most current cancer treatments both heathy and cancerous cells are attacked. However, in TAT, the use of the highly selective biological molecules combined with short range, highly toxic alpha particles can ensure that the dose delivered to the cancerous cells is maximised, while damage to the surrounding healthy tissue is limited.

Very specific radionuclides with appropriate half-lives are required for TAT. The half-life of an isotope is the time it takes for half the radioactive nuclei in a sample to decay to half of its original activity. For example, strontium-90 (Sr) has a half-life of 29 years. Therefore, the activity of any given sample of strontium would fall to 50% of its original value after 29 years. After another 29 years (58 years in total) the strontium activity would be 25% of its original value, etc...

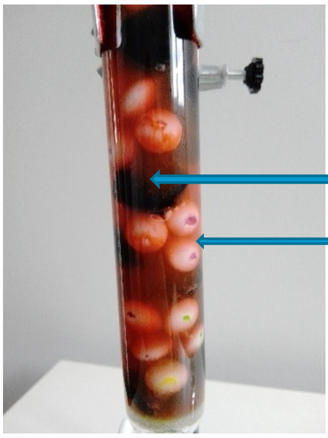
A radionuclide must have a relatively short half-life to be suitable for use in the body in cancer treatments and diagnostics. This is such that the radionuclide can exist in the body long enough to irradiate (treat) the cancerous tumour, but it is not around long enough to cause damage to healthy tissue. Strontium's half-life of 29 years is too long because after 58 years only 75 % of the strontium will have decayed away and there would still be 25 % of the initial strontium left. However, yttrium has a half-life of 3 days, and therefore it only takes 6 days for 75 % of the yttrium to decay away.

It is essential that scientists ensure that samples of radioisotopes used for TAT are pure, because the radioisotope is being put in the human body, and any other radioactive impurities could lead to long-lasting damage to healthy cells. A technique used for the separation and purification of radionuclides is extraction chromatography. Extraction chromatography is performed using a column. There are three main components: the inert support; the stationary phase and the mobile phase.

As described above, yttrium-90 has a half-life which makes it suitable to be used in TAT, but that of strontium-90 is far too long. As strontium-90 decays into yttrium-90, we must make sure that the yttrium-90 is separated successfully from the strontium-90 and there is no strontium-90 remaining.

Separating Radionuclides

To separate them, we load the strontium-90 into the inert support, and then when it decays into yttrium-90 we can use a mobile phase (usually an acid) to wash ONLY the yttrium-90 off.



Equipment List

• Glass chromatography columns

https://www.amazon.co.uk/gp/product/B082Y3SZLP/ref=ppx_yo_dt_b_asin_image_o03_s01?ie=UTF8&th=1

• Clamps and stands

https://www.amazon.co.uk/gp/product/B08B1MSBR4/ref=ppx_yo_dt_b_asin_image_o03_s00?ie=UTF8&th=1

• Cotton wool balls

https://www.amazon.co.uk/gp/product/B086ZW6G2M/ref=ppx_yo_dt_b_asin_image_o01_s00?ie=UTF8&psc=1

• Dark food colouring

https://www.amazon.co.uk/PME-100-Natural-Food-Colouring/dp/B00AZZ231E/ref=d_bmx_dp_i81folpo_sccl_2_2/258-9540456-5138321?pd_rd_w=Dsual&content-id=amzn1.sym.ce222b41-ab01-46b1-98f5-4cec49a59a08&pf_rd_p=ce222b41-ab01-46b1-98f5-

4cec49a59a08&pf_rd_r=1DB1BZ02KXZCF2NXM7XM&pd_rd_wg=h9w2f&pd_rd_r=ec1a9ea2-a8a0-4b76-9945-b5b0305954dc&pd_rd_i=B00AZZ231E&psc=1

• Skittles

https://www.amazon.co.uk/gp/product/B08G9Z14PT/ref=ppx_yo_dt_b_asin_image_o01_s00?ie=UTF8&th=1

• Glass beakers

https://www.amazon.co.uk/gp/product/B09Z5XSLGD/ref=ppx_yo_dt_b_asin_image_o00_s02?ie=UTF8&psc=1

• Plastic jugs

• Tweezers

https://www.amazon.co.uk/gp/product/B07QNZFXFN/ref=ppx_yo_dt_b_asin_image_o09_s00?ie=UTF8&th=1

• Dustpan and brush

https://www.amazon.co.uk/Faithfull-BRDUSTSET-Dustpan-Brush-Set/dp/B00601XFIM/ref=sxts_b2b_sx_reorder_acb_customer?content-id=amzn1.sym.e5b2eef0-5ac6-4452-a455-3ac580647cad%3Aamzn1.sym.e5b2eef0-5ac6-4452-a455-3ac580647cad&crid=SKE6C0QX4JL1&cv_ct_cx=dustpan+and+brush&keywords=dustpan+and+brush&pd_rd_i=B00601XFIM&pd_rd_r=b129a089-3a6c-408d-b3d0-5f65a24ed706&pd_rd_w=5imn8&pd_rd_wg=qoN9E&pf_rd_p=e5b2eef0-5ac6-4452-a455-3ac580647cad&pf_rd_r=N3YDPAA9B7ZRWP9YY3PB&qid=1692368187&s=diy&sbo=RZvfv%2F%2FHxDF%2BO5021pAnSA%3D%3D&sprefix=%2Cdiy%2C326&sr=1-1-c8a51df4-6015-4603-b82a-8c2c24cf7e97

• Cut-proof gloves

https://www.amazon.co.uk/gp/product/B07KSXDL33/ref=ppx_yo_dt_b_asin_image_o00_s01?ie=UTF8&th=1

• Bucket

https://www.amazon.co.uk/gp/product/B00FPMZ8VE/ref=ppx_yo_dt_b_asin_image_o07_s01?ie=UTF8&psc=1

• Disinfectant wipes

https://www.amazon.co.uk/gp/product/B09YM7KJXQ/ref=ppx_yo_dt_b_asin_image_o03_s02?ie=UTF8&psc=1

• Hand sanitiser

• Tissues

• Water supply nearby (if not possible a large 2 L bottle containing water)