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Nuclear-based science benefiting all Australians

[radioisotopes]

:/their role in society today/

◎Radioisotopes play an important role in Australian life. They are widely used in medicine and for scientific research:.◎

:>Radioisotopes are atoms

that contain an unstable combination of neutrons and protons.The combination can occur naturally, as in radium-226, or by artificially altering the atoms. In some cases, a nuclear reactor is used, in others, a cyclotron. Atoms containing this unstable combination regain stability by shedding radioactive energy, hence the term radioisotope. The process of shedding the excess radioactive energy is called decay. The radioactive decay process of each type of radioisotope is unique and is measured with a time period called a half-life.))

:>A radiopharmaceutical is a molecule

that consists of a radioisotope tracer attached to a pharmaceutical. After entering the body, the radio-labelled pharmaceutical will accumulate in a specific organ or tumour tissue. The radioisotope attached to the targeting pharmaceutical will undergo decay and produce specific amounts of radiation that can be used to diagnose or treat human diseases and injuries. The amount of radiopharmaceutical administered is carefully selected to ensure each patient's safety. Radioisotopes are an essential part of radiopharmaceuticals.))

:>A sealed radioactive source is an encapsulated quantity

of a radioisotope used to provide a beam of ionising radiation. Industrial sources usually contain radioisotopes that emit gamma or X-rays.))

:>Ionising radiation is radiation which can knock electrons out of atoms,

either by direct interaction with the atoms or by other methods. Alpha and beta particles, neutrons, X-rays and gamma rays are examples of ionising radiation.))

Radioisotopes are playing an increasingly important part in Australian life. They are widely used in medicine, industry and scientific research, and new applications for their use are constantly being developed. In many cases, radioisotopes have no substitute and in most of their applications they are more effective and cheaper than alternative techniques or processes.

Radioisotopes have been used routinely in medicine for over 30 years. On average, every Australian can expect at some stage in his or her life to undergo a nuclear medicine procedure that uses a radioisotope for diagnostic or therapeutic purposes. Some radioisotopes used in nuclear medicine have very short half-lives, which means they decay quickly; others with longer half-lives take more time to decay, which makes them suitable for therapeutic purposes.

Industry uses radioisotopes in a variety of ways to improve productivity and gain information that cannot be obtained in any other way. Radioisotopes are commonly used in industrial radiography, which uses a gamma source to conduct stress testing or check the integrity of welds – a common example is to test aeroplane jet engine turbines for structural integrity. Radioisotopes are also used by industry for gauging (to measure levels of liquid inside containers, for example) or to measure the thickness of materials.

Radioisotopes are also widely used in scientific research, and are employed in a range of applications, from tracing the flow of contaminants in biological systems, to determining metabolic processes in small Australian animals.

Medical radioisotopes : //

Nuclear medicine uses small amounts of radiation to provide information about a person's body and the functioning of specific organs, ongoing biological processes, or the disease state of a specific illness. In most cases, the information is used by physicians to make an accurate diagnosis of the patient's illness. In certain cases radiation can be used to treat diseased organs or tumours.

Nuclear imaging : //

Nuclear imaging is a technique that uses radioisotopes that emit gamma rays from within the body. To make a radiopharmaceutical, a radioisotope is attached to a pharmaceutical that is taken up by a specific organ or specific diseased tissues. The radiopharmaceutical is given orally, injected or inhaled, and is detected by a gamma camera which is used to create a computer-enhanced image that can be viewed by the physician.

There is a significant difference between nuclear imaging and other medical imaging systems such as CT (computerised tomography), MRI (magnetic resonance imaging) or X-rays.

Nuclear imaging measures the function (by measuring blood flow, distribution or accumulation of the radioisotope) of a part of the body and does not provide highly resolved anatomical images of body structures. PET scans are frequently combined with CT scans, with the PET scan providing functional information (where the radioisotope has accumulated) and the CT scan refining the location. The primary advantage of PET imaging is that it can provide the examining physician with quantified data about the radiopharmaceutical distribution in the absorbing tissue or organ.

The information obtained by nuclear imaging tells an experienced physician much about how a given part of a person's body is functioning. By using nuclear imaging to obtain a bone scan for example, physicians can detect the presence of secondary cancer 'spread' up to two years ahead of a standard X-ray. It highlights the almost microscopic remodelling attempts of the skeleton as it fights the invading cancer cells.

The main difference between nuclear imaging and other imaging systems is that, in nuclear imaging, the source of the emitted radiation is within the body. Nuclear imaging shows the position and concentration of the radioisotope. If very little of the radioisotope has been taken up a 'cold spot' will show on the screen indicating, perhaps, that blood is not getting through. A 'hot spot' on the other hand may indicate excess radioactivity uptake in the tissue or organ that may be due to a diseased state, such as an infection or cancer. Both bone and soft tissue can be imaged successfully with this system.

PET and SPECT imaging : //

PET, or Positron Emission Tomography, is one of the most sophisticated medical imaging technologies available today. The radioactive components of radiopharmaceuticals used in PET procedures are usually made in cyclotrons. At present, PET cameras are located in some hospitals of all major Australian cities.

PET cameras are extremely sensitive. They can be used to detect very early signs of disease and to map how organs such as the brain and heart are functioning. Most radioisotopes used with PET have short half-lives.

SPECT, or Single Photon Emission Computed Tomography, is the most commonly used form of tomographic imaging. SPECT cameras are usually used with radiopharmaceuticals that have longer half-lives than those used with PET. Facilities are located throughout the country in all major cities and towns.

Scanners which combine anatomical and functional imaging information are becoming widely used. Many hospitals have PET-CT scanners and their usage of the more recently developed SPECT-CT is expected to grow. Combination scanners improve the diagnostic accuracy of diagnosis for many diseases, enhance physicians' understanding of diseases, and also reduce the number of imaging appointments patients require.

:>X-ray technology lets doctors see straight through human tissue to examine broken bones,

cavities and swallowed objects with extraordinary ease. Modified X-ray procedures can be used to examine softer tissue, such as lungs, blood vessels or intestines. During an X-ray, a camera records the pattern of X-ray radiation that passes through the patient's body. A conventional X-ray image is basically a shadow – a piece of film on the other side of the X-ray source registers the bones' silhouette.))

:>CT, sometimes called CAT (Computerised Axial Tomography) scan,

uses special X-ray equipment to obtain image data from hundreds of different angles around, or 'slices' through, the body. The information is then processed to show a 3-D cross-section of body tissues and organs. Since they provide views of the body slice by slice, CT scans provide much more comprehensive information than conventional X-rays. CT imaging is particularly useful because it can show several types of tissue – lung, bone, soft tissue and blood vessels – with greater clarity than flat X-ray images.))

:>MRI uses radio waves and a strong magnetic field

(rather than X-rays) to provide remarkably clear and detailed pictures of internal organs and tissues. By exciting protons in the body (most abundant in the hydrogen atoms of water), the resulting image shows differences in water content and distribution within various tissues. This results in two or three dimensional maps of tissue types. MRI can also image blood flow, and provides an unparalleled view inside the body. MRI is a preferred method for the diagnosis of many injuries and conditions because it provides the ability to tailor each examination to obtain the specific information required.))

:>Diagnostic radiopharmaceuticals can be used to examine blood flow

to the brain, to assess functioning of the liver, lungs, heart or kidneys, to assess bone damage, and to confirm other diagnostic procedures.))

:>Neuroblastoma is one of the most common solid malignant cancerous tumours of childhood,

and most children diagnosed with this cancer are under five years of age. It can occur anywhere in the body, but most often occurs in the adrenal glands in the abdomen. Iodine-123 is made in a cyclotron and then attached to the drug MIBG (meta-iodobenzylguanidine), which is taken up by neuroblastoma cells, after being administred by injection. Attaching a small amount of radioactive iodine to the MIBG enables the tumours to be seen by a radiation scanner, producing high quality images pinpointing the location and size of the tumour. Treatment options include surgery, chemotherapy, and radiotherapy using MIGB.))

Diagnostic radiopharmaceuticals : //

Scientists have identified a number of chemicals that are absorbed by specific body tissues and organs. They are called targeting agents or molecules. The brain, for example, consumes large quantities of glucose. Using similar knowledge, radiopharmacists can choose the appropriate targeting chemical, label it with an appropriate radioisotope and use it as a radioactive tracer for a particular body tissue, organ or function. Once the substance has been tagged with a radioisotope and introduced into the body, it is incorporated into the normal biological processes and excreted in the usual ways.

Diagnostic radiopharmaceuticals can be used to examine blood flow to the brain; to assess functioning of the liver, lungs, heart or kidneys; to assess bone damage; and to confirm other diagnostic procedures. They are used in sports medicine to diagnose stress fractures, which are not generally visible in X-rays.

Radiopharmaceuticals are used in very small quantities for diagnostic work – just enough is administered to obtain the required information before the radiopharmaceutical decays or is excreted from the body. The radiation dose received is similar to that from diagnostic X-rays. The non-invasive nature of this technology, together with its ability to reveal organ function, makes it a powerful diagnostic tool.

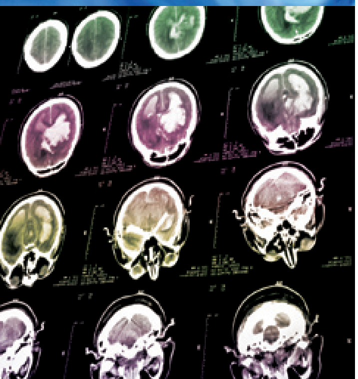
The most common radioisotopes used for diagnosis are technetium-99m, distantly followed by iodine-123, fluorine-18, thallium-201 and gallium-67.

Therapeutic radiopharmaceuticals : //

Rapidly dividing cells are particularly sensitive to damage by radiation. For this reason, some cancerous growths can be controlled or eliminated by irradiating the area. This is called radiotherapy.

With internal radiotherapy, the radioisotope that generates the radiation is localised in the affected organ. This is achieved by administering it as a radioactive element that is taken up by that part of the body, or by attaching the radioactive element to a biological compound, which lodges in the body at the disease site.

Iodine-131 is used for internal radiotherapy, to treat thyroid cancer and hyperthyroidism (an over-active thyroid).



Another radiopharmaceutical, incorporating samarium-153 and known commercially as Quadramet™, is used internally to reduce the pain from secondary bone cancers associated with breast, prostate and some other cancers. Quadramet™ is preferable to traditional pain killers such as morphine because it improves the patient's quality of life, allowing them to be more lucid during time spent with family.

Considerable research is being conducted worldwide into the use of radioisotopes attached to highly specific biological compounds. The eventual tagging of these compounds with a therapeutic dose of radiation may lead to the regression or even cure of some diseases, and many scientists are enthusiastic about the potential of these radioisotopes.

External radiotherapy and brachytherapy : //

External radiotherapy is carried out using a radioactive source that is outside the body. The radiation beam is directed towards the diseased tissue so the beam can deliver a high dose of radiation while sparing the surrounding healthy tissue.

Brachytherapy uses a source implanted in the body at the site to be irradiated. Brachytherapy sources can be placed on the skin or implanted internally, and can be temporary or permanently left in the patient.

Where the source is internal, various radioisotopes can be used. Iridium-192, for example, is produced in wire form and introduced through a catheter to the target area – usually in the head or breast. The implant is left in for the required time and then removed to shielded storage. The procedure is cheaper than using external radiation and gives less overall radiation to the body.

Prostate cancer brachytherapy is an increasingly popular form of treatment of prostate cancer. Low dose rate seeds of iodine-125 are implanted into the prostate and permanently left in the patient.

Biochemical analysis : //

Biochemical analysis is usually carried out *in vitro* (out of the body) and is used to quantify very small amounts of biological substances such as enzymes, hormones, steroids and vitamins in blood, urine, saliva or other body fluids. Radioisotopes are used in these tests because they can be used to label molecules of biological samples and are easy to detect, even in low concentrations. Known as radioimmunoassays, these procedures are commonly used to help diagnose diseases such as diabetes, thyroid disorders, hypertension and reproductive problems.

:>Technetium-99m: the workhorse radioisotope

Technetium-99m is a reactor-produced radiopharmaceutical that is used in more than 80% of nuclear medicine procedures worldwide. It can help diagnose various heart, kidney, lung, liver and thyroid conditions, and some bone cancers.

One of the typical diagnostic applications of technetium-99m is in myocardial perfusion imaging (or heart imaging), which can also be undertaken with the radiopharmaceutical thallium-201.

The primary use of heart imaging is to determine the adequacy of blood flowing to the myocardium or heart muscle. It can also diagnose heart wall motion, or the extent of heart tissue damage following a heart attack. This is often done in conjunction with exercise and stress testing to detect and evaluate coronary heart disease.

Nuclear scintigraphy is a procedure used for diagnosing stress fractures of long bones, as well as the pelvis, osteoarthritis, and tendon and ligament injuries. All of these conditions can be difficult or impossible to identify with other methods such as X-ray or ultra-sound. The technology is so successful at giving doctors not only a picture of structure but also of physiological function that it has been extended for use in horses.

Horses are injected with technetium-99m and hydroxy diphosphonate, which goes directly to the surface of the bone through the muscle and ligament layers. The radioisotope gives off small amounts of radiation – enough for the gamma camera to take a snapshot of the bone so that the horse's health can then be analysed.

_<A number of Melbourne Cup winners - including Saintly and Doreimus - have benefited from the procedure.}}

>research reactor-produced medical radioisotopes_//

Radioisotope	Half-life	Use
Chromium-51	27.7 days	Used to label red blood cells and quantify gastro-intestinal protein loss.
Iodine-131	8.02 days	Used to diagnose and treat various diseases associated with the human thyroid.
Iridium-192	73.83 days	Supplied in wire form for use as an internal radiotherapy source for certain cancers, including those of the head and breast.
Molybdenum-99	66 hours	Used as the 'parent' in a generator to produce technetium-99m, the most widely used radioisotope in nuclear medicine.
Phosphorus-32	14.28 days	Used in the treatment of excess red blood cells.
Samarium-153	46.7 hours	Used to reduce the pain associated with bony metastases of primary tumours.
Technetium-99m	6.01 hours	Used to image the brain, thyroid, lungs, liver, spleen, kidney, gall bladder, skeleton, blood pool, bone marrow, heart blood pool, salivary and lacrimal glands, and to detect infection.
Yttrium-90	64 hours	Used for liver cancer therapy.

:>Both reactor and cyclotron-produced radioisotopes are needed to service all of Australia's medical needs.))

Reactor and cyclotron-produced radioisotopes : //

The great majority of medically useful radioisotopes are made in a nuclear research reactor, however cyclotrons also produce radioisotopes that complement those manufactured in nuclear research reactors.

The nucleus of an atom contains two types of particles – neutrons and protons. Stable atoms have a stable ratio of neutrons and protons in the nucleus, while unstable atoms have an unstable ratio. Scientists make radioactive atoms by adding either extra neutrons or extra protons.

Atoms with extra neutrons in the nucleus are neutron-rich and are produced in a nuclear reactor. Atoms with extra protons in the nucleus are neutron-deficient and are produced in a particle accelerator such as a cyclotron. Neutron-rich and neutron-deficient radioisotopes decay by different means and thus have different properties and different uses. The end use of the radioisotope determines the radioactive properties required, and hence whether a nuclear reactor or a cyclotron is used to produce the radioisotope.

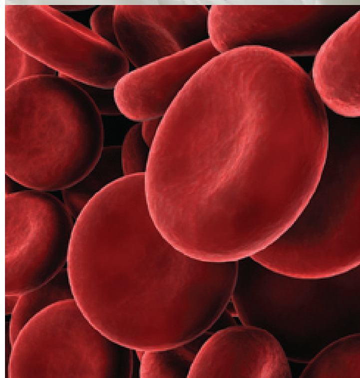
Both types of radioisotopes are needed to service all of Australia's nuclear medical needs. Over 80% of the radioisotopes actually used in medical procedures worldwide come from reactors. The most commonly used radioisotope, molybdenum-99 (which decays into technetium 99-m) can only be produced economically in a nuclear research reactor. Also, the emerging generation of therapeutic isotopes can only be produced in such a reactor.

Industrial radioisotopes : //

Industry uses radioisotopes in a variety of ways to improve productivity and gain information that could not otherwise be obtained. Sealed radioactive sources are used in mineral analysis, industrial radiography and gauging applications. Radioisotopes with high gamma ray levels are also used in the radiation sterilisation of medical supplies and food packaging.

Gamma radiography : //

Gamma radiography works in a similar way to the X-ray camera used to scan luggage at airports. A small pellet of radioactive material in a sealed titanium capsule is positioned on one side of the object being screened. A sheet of photographic film is placed on the other side. The gamma rays are beamed from the radioactive source and pass through the object to create an image on the film. Just as X-rays show a break in a bone, gamma rays show flaws in metal castings or welded joints. The technique allows critical components to be inspected for internal defects without damaging the component or making it radioactive.



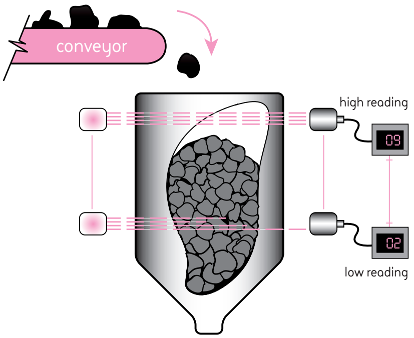
Gamma radiography has several advantages over an X-ray camera. X-ray cameras are large and cumbersome and require a high voltage electrical charge source. Radioactive sources, on the other hand, are small and do not require power. This means the radioisotopes can be transported easily to remote areas and used where there is no power. They can also be located inside equipment to produce photographs of internal joints or components without the need for dismantling.

Gauging : //

Radioisotope gauging is based on the principle that the radiation emitted from a radioisotope will be reduced in intensity by matter located between the radioisotope and a detector. The amount of this reduction can be used to gauge the presence or absence of the material, or even to measure the quantity of material between the source and the detector. The advantage of this form of gauging is that there is no contact with the material being measured.

One application is in the manufacturing of plastic film. The film runs at high speed between a radioactive source and a detector and the detector signal strength is used to control the thickness of the plastic film. A similar technique is used to measure the height of coal in hoppers feeding power station furnaces.

A variation on this technique is used to measure material coatings. When the intensity of radiation from a radioisotope is being reduced by matter in the beam, some radiation is scattered back towards the radiation source. Analysis of this 'back-scattered' radiation provides information about the material's coating.



^: Level gauges for the control of a coal hopper : //

Smoke detectors : //

In the chamber of smoke detectors with a small americium-241 source, atoms of air are ionised. The electronics in the smoke detector sense the resulting small amount of electrical current from the electrical supply. When smoke or steam enters the ionisation chamber, it disrupts this current. The smoke detector senses the drop in current between the plates and sets off the alarm.

These smoke detectors are installed in a large number of public areas and private homes. They are so widespread that they represent the largest number of devices based on radioisotopes used world-wide.

>cyclotron-produced medical radioisotopes_//

Radioisotope	Half-life	Use
Copper-64	12.7 hours	Used to study genetic disease affecting copper metabolism; in Positron Emission Tomography; and also has potential therapeutic uses.
Gallium-67	78.25 hours	Used in imaging to detect tumours and infections.
Iodine-123	13.2 hours	Used in imaging to monitor thyroid function and detect adrenal dysfunction.
Thallium-201	72.9 hours	Used in imaging to detect the location of damaged heart muscle.
Carbon-11 Nitrogen-13 Oxygen-15 Fluorine-18	20.3 minutes 10 minutes 122 seconds 1.83 hours	These are used in Positron Emission Tomography to study brain physiology and pathology; for detecting the location of epileptic foci; and in dementia, and psychiatry and neuropharmacology studies. They are also used to detect heart problems and diagnose certain types of cancer.

>naturally occurring radioisotopes used in industry and science_//

Radioisotope	Half-life	Use
Carbon-14	5 715 years	Used to measure the age of organic material that is up to 50 000 years old.
Chlorine-36	301 000 years	Used to measure sources of chloride and the age of water that is up to 2 million years old.
Lead-210	22.6 years	Used to date layers of sand and soil laid down up to 80 years ago.
Hydrogen-3 (tritium)	12.32 years	Used to measure the age of 'young' groundwater (up to 30 years old).

>artificially produced radioisotopes used in industry and science_//

Radioisotope	Half-life	Use
Americium-241 •	232.7 years	Used in neutron gauging and smoke detectors.
Cobalt-60 •	5.27 years	Used in gamma radiography, gauging, and commercial medical equipment sterilisation.
Caesium-137 •	30.07 years	Used in radiotracing to identify sources of soil erosion and depositing; also for thickness gauging.
Gold-198 •	2.7 days	Used to trace factory waste causing ocean pollution, and to trace sand movement in river beds and on ocean floors.
Gold-198 • Technetium-99m •	2.7 days 6.01 hours	Used to study sewage and liquid waste movements.
Iridium-192 •	73.8 days	Used in gamma radiography.
Iridium-192 • Gold-198 • Chromium-51 •	73.8 days 2.7 days 27.7 days	Used to trace sand to study coastal erosion.
Tritiated water (containing tritium)	12.32 years	Used as a tracer to study sewage and liquid wastes.
Ytterbium-169 •	32 days	Used in gamma radiography.
Zinc-65 † Manganese-54 •	243.87 days 312.1 days	Used to predict the behaviour of heavy metal components in effluents from mining waste water.

key: • reactor-produced † cyclotron-produced

: // only the more commonly used radioisotopes are listed here /

Use in mineral analysis and processing : //

Radioisotopes are used to analyse the content of mineral samples. Radioisotopes are also used widely as gamma sources in the continuous measurement of mineral slurry density, a vitally important factor in the control of mineral processing and hydrometallurgical operations (the use of liquid to separate a metal from its ore).

Gamma ray transmission or scattering can determine the water content of coal on conveyer belts. The measurements are based on the fact that gamma ray interactions vary according to the atomic number of the material being bombarded; atoms in water have a different atomic number to atoms in coal.

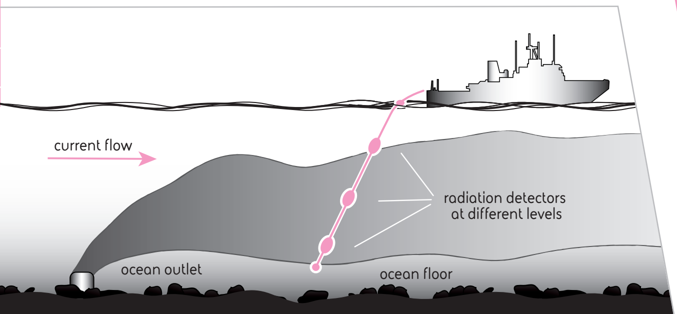
Scientific uses : //

Radioisotopes are used in many areas of research and science. The age of water from underground bores can be estimated from the activity of naturally occurring radioisotopes in the water, informing decisions regarding the use of groundwater for consumption. Open-air nuclear weapons testing in the 1950s and early 1960s nearly doubled the amount of carbon-14 in the atmosphere. Scientists can use the increased number of carbon-14 atoms in the environment as tracers to measure soil movement and land degradation. For example, by the amount of carbon-14 in organic material within sediments, scientists can determine if it was deposited in sedimentary layers before or since this period of weapons testing.

Levels of certain radioisotopes in environmental samples can be measured to check whether nations are in compliance with agreements concerning the development of nuclear weaponry. Nuclear activities may produce routine or accidental releases of radioactive material into the environment. Iodine-129 and uranium-236 can be measured in environmental samples, and are signatures of nuclear activities such as reprocessing irradiated nuclear fuel.

Radiotracer techniques are often used to validate mathematical models of sediment and contaminant transport in the coastal zone and so contribute to sustainable development.

Even minute amounts of radioactive material can be detected easily, which makes it ideal for use in tracing the movements of water, gases or even insects. Radioactive tracers mixed with sewage are used to track sewage dispersion. A similar technique is used to trace small leaks in complex systems such as power station heat exchangers. Flow rates of liquids and gases in pipelines can be measured accurately, as can the flow rates of large rivers, all with the assistance of radioisotopes.



^:Tracing of sewage dispersion from ocean outfalls//

The Australian Nuclear Science and Technology Organisation (ANSTO) is this country's nuclear research and development agency. We deliver market-leading products and services to public and private sector organisations in medicine, mining, aerospace, minerals, agriculture, manufacturing and the environment.

Our 900+ staff primarily conduct these activities at ANSTO headquarters, located on the outskirts of southern Sydney. This site contains the nuclear research reactor, OPAL, as well as many other leading-edge scientific facilities and instruments. We also operate the National Medical Cyclotron, an accelerator facility at the Royal Prince Alfred Hospital, near central Sydney.

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