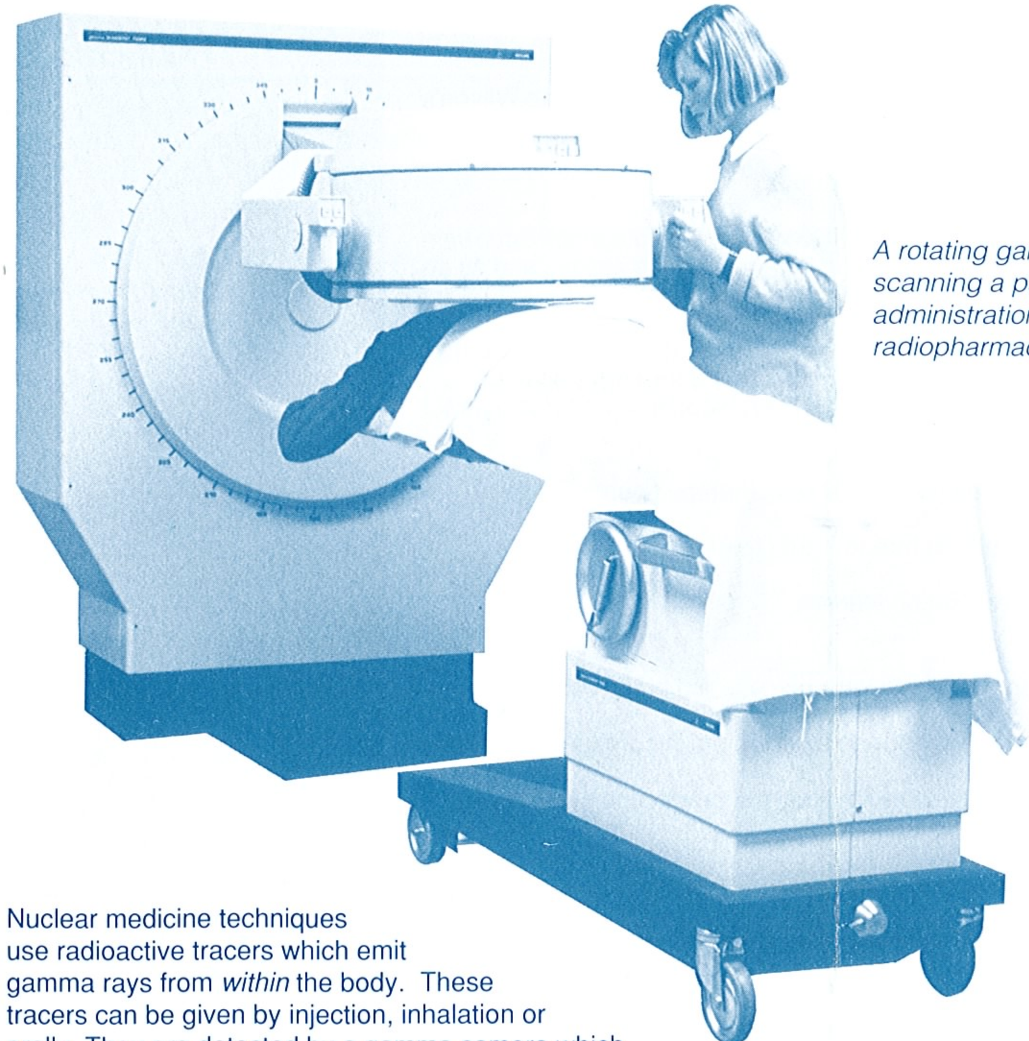
ansto RADIOISOTOPES in medicine

## Nuclear Medicine

*This is a branch of medicine that uses radiation to provide information about a person's anatomy and the functioning of specific organs. In most cases, the information is used by physicians to make a quick, accurate diagnosis of the patient's illness. The thyroid, bones, heart, liver and many other organs can be easily imaged, and disorders in their function revealed. In some cases radiation can be used to treat diseased organs or tumours.*



*A rotating gamma camera scanning a patient after the administration of a radiopharmaceutical*

Nuclear medicine techniques use radioactive tracers which emit gamma rays from *within* the body. These tracers can be given by injection, inhalation or orally. They are detected by a gamma camera which can view organs from many different angles. The camera builds up an image from the points from which radiation is emitted; this image is enhanced by a computer and viewed by a physician on a monitor for indications of abnormal conditions.

This positioning of the radiation source within the body makes the fundamental difference between nuclear medicine imaging and other diagnostic techniques such as x-rays. Gamma imaging provides a view of the position and concentration of the radioisotope within the body. Organ malfunction can be indicated if the isotope is either partially taken up in the organ (cold spot), or taken up in excess (hot spot). If a series of images is taken over a period of time, an unusual pattern or rate of isotope movement could indicate malfunction in the organ.

A distinct advantage of nuclear imaging over x-ray techniques is that both bone and soft tissue can be imaged very successfully. This has led to its common use in Australia where the probability of anyone having such a test is about one in three.

## Diagnostic Radiopharmaceuticals

Every organ in our bodies acts differently from a chemical point of view. Doctors and chemists have identified a number of chemicals which are absorbed by specific organs. The thyroid, for example, takes up iodine, the brain consumes quantities of glucose, and so on. With this knowledge, radiopharmacists are able to attach various radioisotopes to biologically active substances. Once a radioactive form of one of these substances enters 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, functioning of the liver, lungs, heart or kidneys, to assess bone growth, and to confirm other diagnostic procedures. Another important use is to predict the effects of surgery and assess changes since treatment.

The amount of the radiopharmaceutical given to a patient is just sufficient to obtain the required information before its decay. The radiation dose received is medically insignificant. The patient experiences no discomfort during the test and after a short time there is no trace that the test was ever done. The non-invasive nature of this technology, together with the ability to observe an organ functioning from outside the body, makes this technique a powerful diagnostic tool.

The radioisotope most widely used in medicine is technetium-99m. It is an isotope of the artificially-produced element technetium and it has almost ideal characteristics for a nuclear medicine scan. These are:

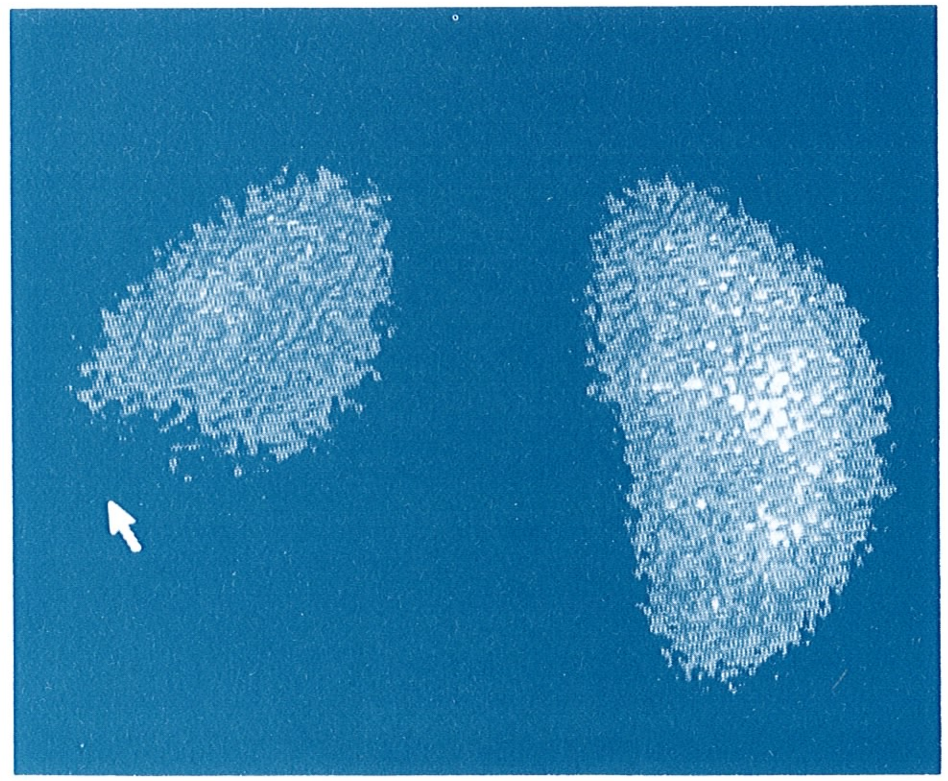
- It has a half-life of six hours which is long enough to examine metabolic processes yet short enough to minimise the radiation dose to the patient.
- Technetium-99m decays by a process called "isomeric transition" which emits gamma rays and low energy electrons. Since there is no high energy beta emission the radiation dose to the patient is low.
- The low energy gamma rays it emits easily escape the human body and are accurately detected by a gamma camera. Once again the radiation dose to the patient is minimised.
- The chemistry of technetium is so versatile it can be incorporated into a range of biomolecules which concentrate in different organs.

## Therapeutic Radiopharmaceuticals

For some medical conditions, it is useful to destroy or weaken malfunctioning cells using radiation. The radioisotope that generates the radiation can be localised in the required organ in the same way it is used for diagnosis - through a radioactive element following its usual biological path, or through the element being attached to a suitable biological compound. In most cases, it is beta radiation which causes the destruction of the damaged cells. *This is radiotherapy.* Although this is a less common use of radioactive material in medicine, up to 150 patients are being treated this way each week in Australia.

Iodine-131 and phosphorus-32 are examples of two radioisotopes used for therapy. Iodine-131 is used to treat the thyroid for cancers and other abnormal conditions such as hyperthyroidism (over-active thyroid). In a disease called Polycythemia vera, an excess of red blood cells is produced in the bone marrow. Phosphorus-32 is used to control this excess.

Considerable medical research is being conducted worldwide into the use of radionuclides attached to highly specific biological chemicals such as immunoglobulin molecules (monoclonal antibodies). The eventual tagging of these cells with a therapeutic dose of radiation may lead to the regression - or even cure - of some diseases.



*Scan indicating malfunction of the left kidney*

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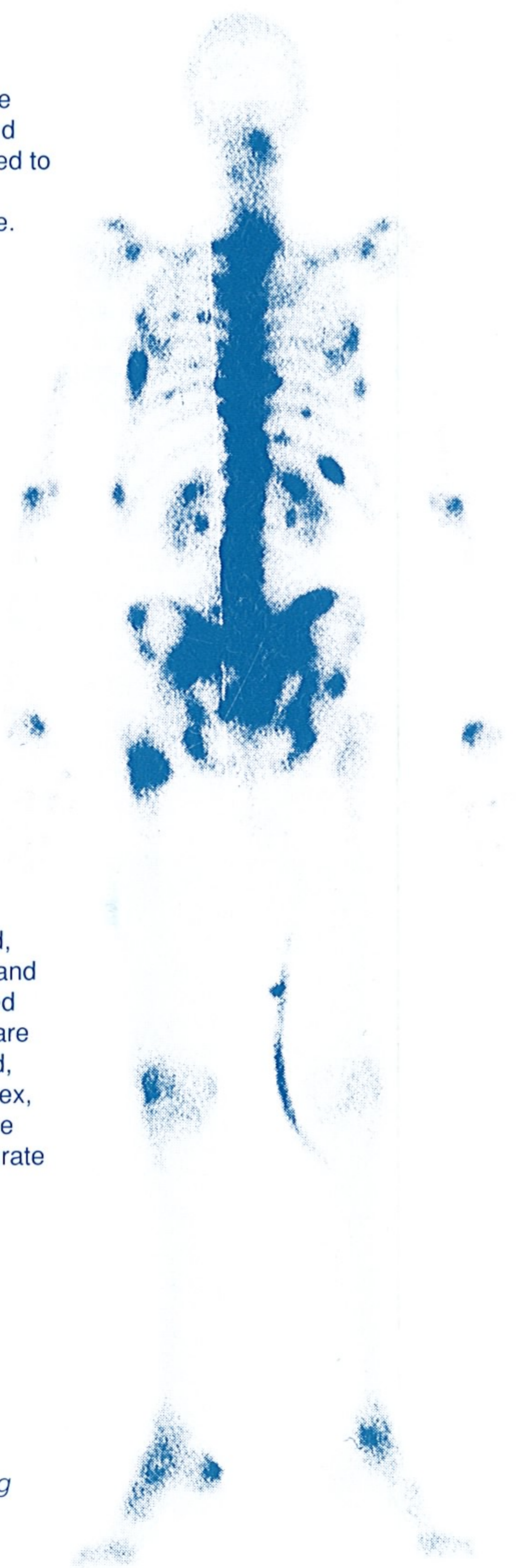
## Radiotherapy

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 containing the growth. This irradiation can be carried out using an external beam from a radioactive cobalt-60 source. This method is losing favour in developed countries to the much more versatile linear accelerators which are now being utilised as the radiation source.

Iridium-192 implants are now used frequently for radiotherapy. These are produced in wire form and are introduced through a catheter to the target area - usually in the head and breast. After a time period calculated to give the correct dose, the implant wire is removed to shielded storage. This procedure gives less overall radiation to the body, is more localised to the target tumour and is cost effective.

## Biochemical Analysis and Radioisotopes

It is very easy to detect the presence or absence of some radioactive materials even when they exist in very low concentrations. Radioisotopes can therefore be used to label molecules of biological samples *in vitro* (out of the body). Pathologists have devised hundreds of tests to determine the constituents of blood, serum, urine, hormones, antigens and many drugs by means of associated radioisotopes. These procedures are known as radioimmuno assays and, although the biochemistry is complex, kits manufactured for laboratory use are very easy to use and give accurate results.



*A whole body bone scan indicating multiple bone metastasis (spread of disease)*

## Isotopes used in Medicine

### Reactor Radioisotopes

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|---|---|
| Molybdenum-99 | Used as the 'parent' in a generator to produce technetium-99m, the most widely used isotope in nuclear medicine. |
| Technetium-99m | Used in scintigraphy to image the brain, thyroid, lungs (perfusion and ventilation), liver, spleen, kidney (structure and filtration rate), gall bladder, skeleton, blood pool, bone marrow, salivary and lacrimal glands, heart blood pool, infection and numerous specialised medical studies. |
| Chromium-51 | Used to label red blood cells and quantify gastro-intestinal protein loss. |
| Cobalt-60 | Used for external beam radiotherapy. |
| Copper-64 | Used to study genetic diseases affecting copper metabolism, such as Wilson's and Menke's diseases. |
| Ytterbium-169 | Used for cerebrospinal fluid studies in the brain. |
| Iodine-125 | Used to evaluate glomerular filtration rate of kidneys and to diagnose deep vein thrombosis in the leg. It is also widely used in radioimmuno assays and as an x-ray source for bone density measurements. |
| Iodine-131 | Widely used in functional imaging and therapeutic applications for the thyroid as in overactive and underactive thyroid, carcinomas and their secondaries; diagnosis of abnormal liver function, renal (kidney) blood flow and urinary tract obstruction. |
| Iridium-192 | Supplied in wire form for use as an internal radiotherapy source. |
| Iron-59 | Used in ferrokinetic studies of iron metabolism (spleen). |
| Xenon-133<br>Xenon-127 | Used for pulmonary (lung) ventilation studies. |
| Phosphorus-32 | Used in the treatment of polycythemia vera (excess red blood cells). |
| Potassium-42 | Used for the determination of exchangeable potassium in coronary blood flow. |
| Selenium-75 | Used in the form of seleno-methionine to study the production of digestive enzymes. |
| Sodium-24 | Used for studies of electrolytes within the body. |
| Yttrium-90 | Used for cancer therapy and as silicate colloid for the treatment of arthritis in larger joints. |

### Cyclotron Radioisotopes

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|---|---|
| Gallium-67 | Used for tumour imaging and localisation of inflammatory lesions (infections). |
| Thallium-201 | Used for myocardial perfusion imaging for diagnosis and location of myocardial infarction (heart muscle death). |
| Iodine 123 | Used for diagnosis of thyroid function. |
| Rubidium-81<br>Krypton-81m | Krypton-81m gas can yield functional images of pulmonary ventilation, e.g. in asthmatic patients, and for the early diagnosis of diseases and function of the lungs. |
| Indium-111 | Used for brain studies, infection and colon transit studies. |
| Carbon-11<br>Nitrogen-13<br>Oxygen-15<br>Fluorine-18 | These are used in PET for studying brain physiology and pathology, for localising epileptic focus, and in dementia, psychiatry and neuropharmacology studies. They also have a useful role in cardiology and in possible cancer detection. |

*Reactor isotopes put extra neutrons into a nucleus. A cyclotron produces radioisotopes which are neutron-deficient.*
*ANSTO owns and operates Australia's National Medical Cyclotron which is situated at the Royal Prince Alfred Hospital in Sydney.*

## What are radioisotopes?

Many of the chemical elements have a number of isotopes. The isotopes of an element have the same number of protons in their atoms (atomic number) but different masses. In an atom in the neutral state, the number of external electrons also equals the atomic number. These electrons determine the chemistry of the atom. The atomic mass is the sum of the protons and neutrons. There are 82 stable elements and about 275 isotopes of these elements.

When a combination of neutrons and protons, which does not already exist in nature, is produced artificially, the atom will be unstable and is called a radioactive isotope or radioisotope.

Radioisotopes can be manufactured in several ways. The most common is by neutron activation in a nuclear reactor. This involves the capture of a neutron by the nucleus of an atom resulting in an excess of neutrons (neutron rich).

Radioisotopes can also be manufactured in a cyclotron in which protons are introduced to the nucleus resulting in a deficiency of neutrons (proton rich).

The nucleus of a radioisotope usually becomes stable by emitting an alpha and/or beta particle. These particles may be accompanied by the emission of energy in the form of electromagnetic radiation known as gamma rays. This process is known as radioactive decay.

Radioisotopes have very useful properties: radioactive emissions are easily detected and can be tracked until they disappear leaving no trace. Alpha, beta and gamma radiation, like x-rays, can penetrate seemingly solid objects, but are gradually absorbed by them. The extent of penetration depends upon several factors including the energy of the radiation, the mass of the particle and the density of the solid. These properties lead to many applications for radioisotopes in the scientific, medical, forensic and industrial fields. Radioactive products which are used in medicine are referred to as *radiopharmaceuticals.*

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