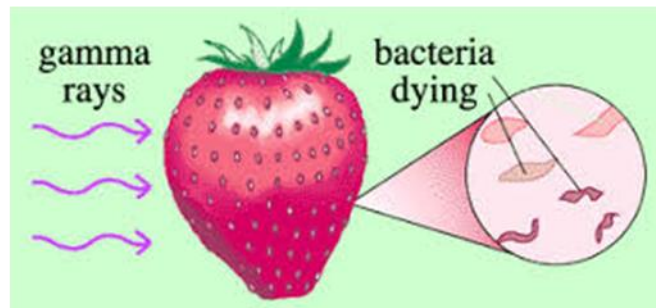
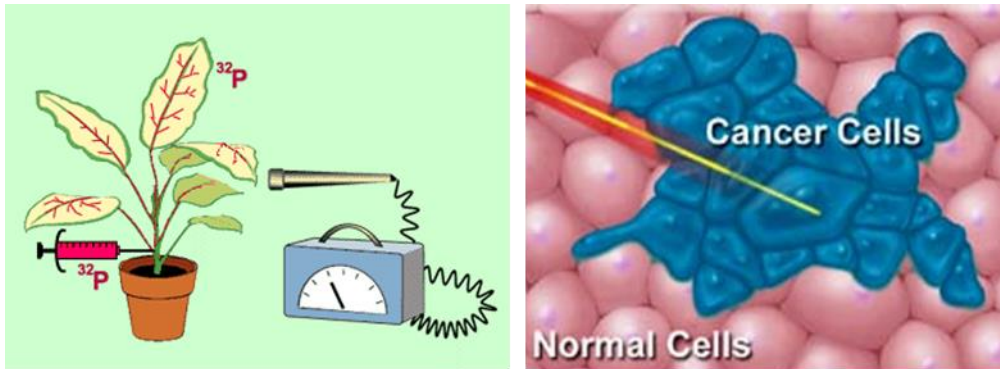


VISUAL PHYSICS ONLINE

PUTTING RADIOISOTOPES TO WORK



An advantage of fission reactors is that they can be used to produce radioactive isotopes for a number of special applications. The radioisotopes are produced by bombarding appropriate elements with neutrons in the reactor. Alternatively, radioisotopes can be produced by bombarding appropriate elements with various sub-atomic particles in a particle accelerator.

MEDICAL APPLICATIONS

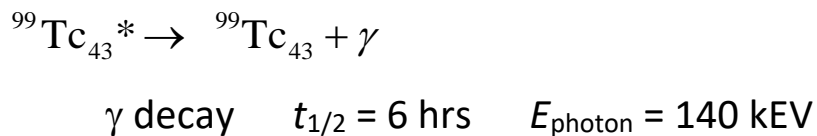
Radioisotopes are used in medicine for both **diagnosis** and **therapy**. In diagnosis, the principle use is to locate abnormal tissue such as tumours. In therapy, radioisotopes are used to destroy abnormal cells within the body.

Diagnosis

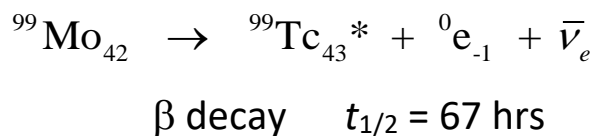
A drug containing the radioisotope to be used is taken orally or intravenously. The drug carries the radioisotope to the affected organ. Radiation detectors are then used to measure the concentration and distribution of the radioisotope to detect any abnormalities. The radioisotopes are short lived to minimise harm to the body. Most diagnostic radioisotopes are gamma emitters, since gamma radiation is the only natural radiation with sufficient penetrating power to escape from the body in detectable quantities.

A typical example of a diagnostic radioisotope is **technetium-99m** (m implies a metastable state – the nucleus remains in an excited state for some interval of time). The element technetium is very useful because it can combine with a large variety of compounds.

The compound that is labelled with $^{99m}\text{Tc}_{43}$ is chosen so that it will be concentrated in the organ to be examined. This isotope $^{99m}\text{Tc}_{43}$ has a half-life of 6 hours (short, but not too short) and decays through the emission of a gamma ray to form the stable isotope $^{99}\text{Tc}_{43}$.



Hospitals are sent Tc-99m generators, consisting of the molybdenum-99 isotope, which decays with a half-life of 67 hours to Tc-99m.



The Tc-99m so obtained is then injected into the body and used to scan for brain, bone, liver, spleen, kidney or lung cancer, as well as for blood flow anomalies. As the Tc-99m de-excites to Tc-99, the emitted gamma radiation is recorded and measured using a gamma ray camera. High or low radioactivity measured may represent overactivity or underactivity of the organ or in another case may represent a tumour or lesion.

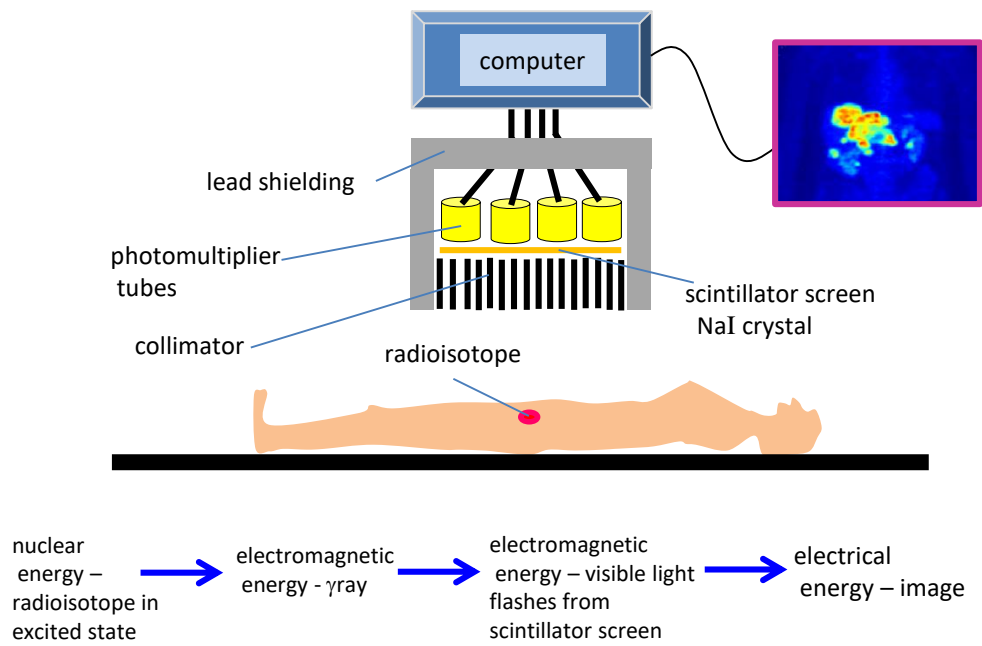


Fig. 1. Gamma ray camera scans the body to give a display of the accumulation of a radioactive isotope in an organ. The collimator is necessary so that only the γ rays that come in a straight line from the patient are detected, otherwise γ rays from all parts of the body could strike the scintillator producing a poor image.

Radiation therapy

Exposure to radioactivity and high energy electromagnetic radiation can produce cancers in our bodies. It can also be effectively used to treat cancers. High energy radiation is used to cause localised radiation damage to cancerous cells and kill them because rapidly growing cancer cells are especially susceptible to destruction by radiation. However, large doses are required to kill the cancer cells and in this treatment, some of the surrounding normal cells are inevitably killed as well. The radiation beam is directed towards the tumour as it rotates around the person receiving treatment. The beam passes through the person so that only at the tumour site receives the maximum dose.

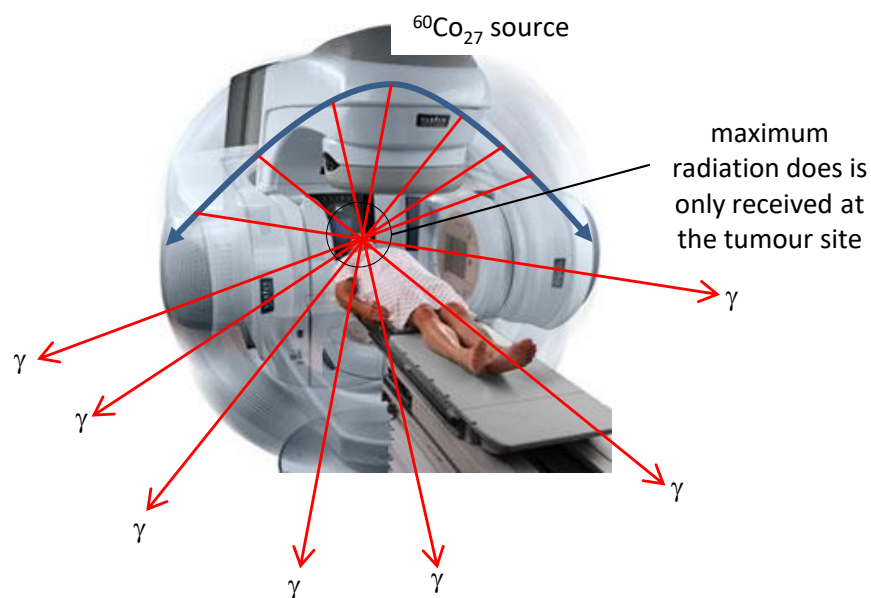


Fig. 2. The radiation source $^{60}\text{Co}_{27}$ rotates in an arc around the patient so that the γ ray beam always passes through the diseased area but with minimum dose to the rest of the body.

Also, the radiation can be implanted in the tumour in the form of a thin wire so that it can release the gamma radiation over a period of time. For example, the radioactive isotope $^{131}\text{I}_{53}$ is used to treat thyroid cancer. The thyroid gland tends to concentrate iodine from the blood and so after $^{131}\text{I}_{53}$ is injected into the blood it will then accumulate in the thyroid gland and in particular it will concentrate in the abnormal growth area.

A typical radiation source is cobalt-60, $^{60}\text{Co}_{27}$. Also, X-rays in the range of 200 keV to 5 MeV can be used. Protons, neutrons, electrons and pions which are produced in particle accelerators are also being used in cancer therapy.

Tomography

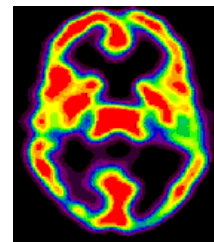
Tomography uses radioisotopes to display three-dimensional images of just about any part of the body so that abnormalities can be found and for testing functional characteristics of organs.

There are many types of tomography including:

Single-photon emission computer tomography (SPECT)

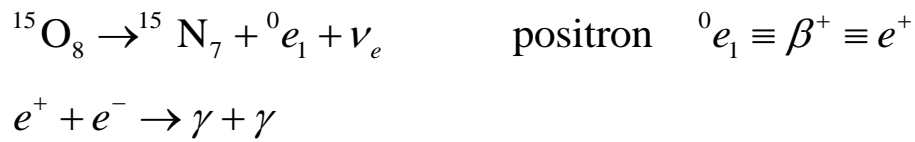
Images are created using computer tomography techniques from the γ ray emissions of a

radioactive tracer in a single plane or slice through the body. The radioactive intensity from the tracer at many points and angles are detected by a gamma camera that is moved around the patient.



Positron emission tomography (PET)

A radioactive isotope such as $^{11}\text{C}_6$, $^{13}\text{N}_7$, $^{15}\text{O}_8$ and $^{18}\text{F}_9$ which are positron (e^+) emitters is combined with a compound that when injected into the patient will accumulate in the region of the body to be studied. When the nuclide undergoes β^+ decay the emitted positron travels at most a few millimetres before it collides with a normal electron. In this collision, the positron (e^+) and the electron (e^-) annihilate each other, producing two γ rays, each having an energy of 511 keV.



In the annihilation process energy and momentum are conserved, so the two γ rays fly off in opposite directions.

Because the γ rays travel along the same straight line in opposite directions, they are detected simultaneously by a ring detector which establishes this line along which the emission took place.

PET is used to measurement of blood flow in the brain for an evaluation of strokes, brain tumours and other brain lesions.

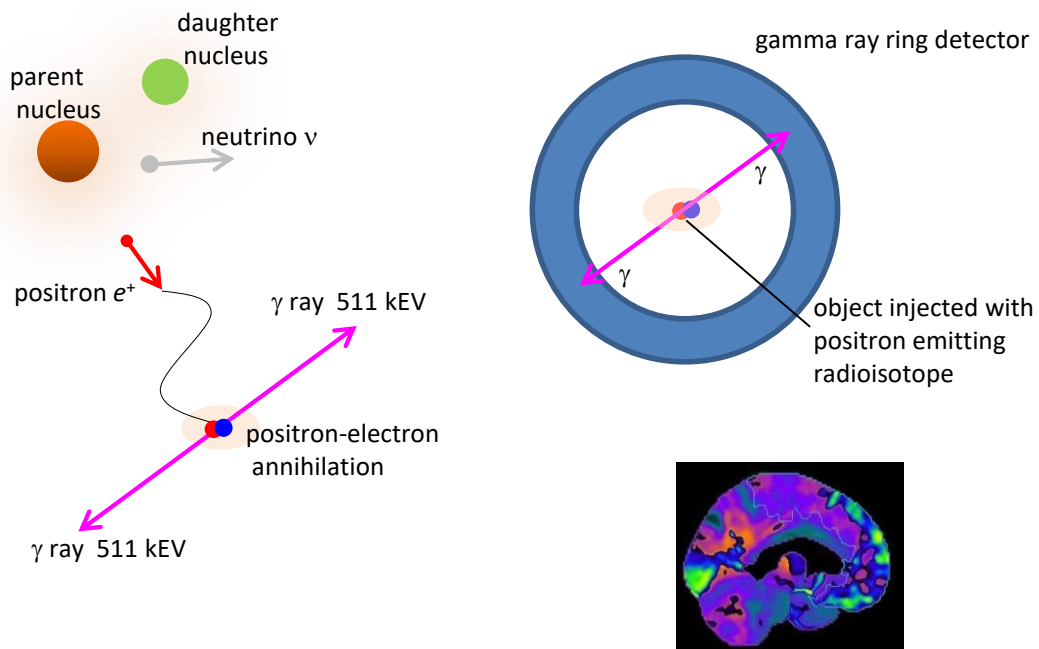


Fig. 3. Positron emission tomography in medical diagnosis.

Magnetic resonance imaging (MRI)

Magnetic resonance imaging is used to get detailed and clear pictures of the body's **soft tissues** so that tumours and other disorders of the brain, muscle, organs and connective tissue.

The patient is placed into a large magnetic field produced by a superconducting magnet. A radiofrequency pulse of electromagnetic radiation is then applied to the patient.

This electromagnetic pulse causes nuclei (mainly hydrogen) to jump from a lower energy state to a higher energy state. These same coils then detected the radio waves emitted from the excited nuclei as they decay back into their lower energy state. The information gained from the detected radio signals can be used to generate two and three-dimensional images using standard mathematical techniques of computer tomography.



INDUSTRIAL & OTHER APPLICATIONS

There are many industrial applications of radioisotopes. The most widely used radioisotope is the gamma ray emitter $^{60}\text{Co}_{27}$.

- The measurement of the thickness of metal, plastic, glass, paper, etc, during manufacture is done by measuring the amount of radiation passing through the material. The amount of the absorption of the gamma radiation is a function of the thickness of the material through which it passes. If the material becomes too thick or thin, the detector senses the change in radiation and the machine's control circuits can then adjust the machine's settings to ensure the correct thickness.
- Smoke detectors use the alpha particle emitter **americium** $^{241}\text{Am}_{95}$. The $^{241}\text{Am}_{95}$ ionises the air between two parallel plates to produce a current. If there is smoke in the air, smoke particles are attracted to ions in the air, reducing the current. This reduction in the current between the plates causes an alarm to be turned on.
- All radioisotopes generate thermal energy as they decay. This heating effect can be used to generate an emf. The radioisotope plutonium-238 is used to generate the electricity that runs certain types of cardiac pacemakers.

- Small amounts of radioisotopes can be used as tracers to find leaks in pipes; wear on bearings (piston rings in car engines) and sliding surfaces.
- Radioisotopes are placed in oil carrying pipes when the product in the pipes is changed. Exploration for oil and gas - a source and detector are inserted down a drill hole to inspect the material at different depths.
- **Radioactive dating** is used to estimate the age of materials such as glass, pottery, stone used in ancient times.

- **Neutron activation** is a technique where thermal neutrons from a nuclear



reactor are absorbed by the material under investigation. For example, a painting is exposed to the neutron beam and several elements in the painting become radioactive. An X ray film placed over the painting is sensitive to the emission of beta particles from the radioactive elements. Neutron activation is useful in crime detection. A sample is bombarded by neutrons from a nuclear reactor causing some of the elements of the sample to become radioactive. These elements can then be identified. Examination of gunshots are made by measuring the trace amounts of barium and antimony in the gunpowder. Amounts as small as $0.005 \mu\text{g}$ of barium and $0.001 \mu\text{g}$ of antimony can be detected by measuring the energy of the gamma ray emitted by the created radioactive elements. Examination

of hair in neutron activation can detect small amounts of arsenic and mercury and help provide information of the poisoning of a person.

AGRICULTURAL APPLICATIONS

- **Phosphorus-32** $^{32}\text{P}_{15}$ is a beta particle emitter ($T_{1/2} = 14.3$ days) used in agriculture for tracking a plant's uptake of fertilizer from the roots to the leaves. The $^{32}\text{P}_{15}$ is added to soil water and its passage through the plant can be traced and the tagged fertilizer's uptake mapped.
- The β^+ emitter $^{11}\text{C}_6$ has been used to study photosynthesis in plants.
- The β^+ emitter $^{13}\text{N}_7$ has been used to study the uptake of nitrogen by plant roots as well as the movement of nitrogen through the plant.
- The shelf-life of food can be dramatically increased by irradiating the food with gamma rays. The food irradiated by $^{60}\text{Co}_{27}$ gamma rays last much longer; onions (100%); potatoes (80%); prawns (600%). More than 30 countries allow the use of irradiation to preserve more than 35 types of food. Also, medical supplies, cosmetics and spices are often irradiated.

NEUTRON SCATTERING

The neutrons released in a nuclear reactor can be used for many scientific and technical investigations. Beams of neutron that originate in a reactor vessel are mainly used in scattering experiment to find answers to fundamental questions about the structure and composition of materials used in medicine, mining, transportation, building, engineering, food processing and scientific research.

Neutrons have zero electrical charge and penetrate materials more effectively than X-rays. Neutrons penetrate most materials to depths of several centimetres. In comparison, X-rays and electrons probe only near the surface. The de Broglie wavelength of thermal neutrons is comparable to X-rays and the spacing of atoms in the atomic lattices of solids. These properties make neutrons an especially useful tool in industrial materials analysis.

X-rays and electrons are scattered by atomic electrons whereas neutrons are scattered by atomic nuclei. This results in a number of differences, perhaps the most important being in the scattering from light elements. Whereas one electron on a hydrogen atom can be hard to find by X-ray or electron diffraction, the hydrogen nucleus scatters neutrons strongly and is easily found in a neutron diffraction experiment.

Hence, neutron beams are useful in determining the structure of solids containing hydrogen bonds found in organic molecules.

Neutrons, though electrically neutral, act as small magnets, and are uniquely powerful in the atomic scale study of magnetism.

Neutrons are also uniquely suited to the study of the dynamic processes (e.g. thermal vibrations) in solids.

Neutron scattering is used in many different scientific fields.

Neutrons can be used to study the dynamics of chemical reactions at interfaces for chemical and biochemical engineering, in food science, drug synthesis and healthcare. Neutrons can probe deep into solid objects such as turbine blades, gas pipelines and welds to give microscopic insight into the strains and stresses that affect the operational lifetimes of crucial engineering components. Neutron studies of nanoparticles and magnetism are used for the development of next-generation computer and IT technology, data storage, sensors and superconducting materials.

Neutron scattering is a delicate and non-destructive measurement technique, making it ideal for use in heritage science.

Understanding magnetism

The neutron is capable of seeing both the nuclei of atoms and at the same time the magnetic interactions of their electrons.

Neutron scattering has made seminal contributions to our understanding of magnetism – from the early demonstration of anti-ferromagnetism in simple systems through to the complex magnetic structures found in hard magnets or the synthetic multilayer structures used for data-storage applications.

Investigating polymers

Neutrons have been used to investigate polymers since the early 1970s. Originally, neutron research unveiled the structure and formation of polymers to understand how they assembled and bonded. Now neutron science is studying the dynamics of thin polymer films, further increasing their range of applications into areas such as anti-reflective coatings and time-release medications. The significant difference in the neutron scattering cross-section between hydrogen and deuterium allows selective “labelling” of chemically specific parts of complex molecular systems, giving a unique insight; this powerful technique is used for almost all soft-matter studies.

Revealing invisible worlds

Neutron diffraction has been used to reveal the molecular structure of both crystalline and disordered materials since the early days of the discipline. Powerful computational modelling applied to neutron data allows accurate structures of pharmaceutical compounds to be derived, material structures in fuel-cell and battery electrodes to be optimised, and the orientation and packing of molecules in liquids and glasses to be understood. When materials bend, break or disintegrate it is their atomic structure that changes. Neutrons are used in a wide range of engineering applications to test the strength and suitability of materials under certain conditions, from studying the performance under strain of materials in aeroplane wings or train wheels to safely extending the operating life of nuclear power stations.

Biophysics: neutrons and the body

A real understanding of the essential processes of life requires knowledge of how proteins and other macromolecules perform their roles. This is giving new insight into the way drugs and medicines move through the body and how they can be controlled and delivered to the specific area of concern. Neutron science continues to break new ground in investigating how drug-delivering polymers can move through membranes, how antibodies are structured and how active parts of medicines interact with lipids and proteins.

Unlocking the potential of hydrogen

Hydrogen has the largest scattering interaction with neutrons of all the elements in the periodic table. Early experiments showing how hydrogen diffuses in simple metals have been built on to provide data supporting the development of materials for fuel cells and hydrogen storage. Hydrogen has been identified as a fuel with great potential for providing clean energy for transport, but its use is constrained by our inability to store it in a dense enough form suitable for vehicles. Neutron studies, currently being undertaken, will facilitate the understanding and development of materials that can store hydrogen safely and efficiently.

Unveiling our heritage

The delicate, sensitive and deeply penetrating nature of neutron beams enables heritage scientists to determine unique information from historic objects, museum artefacts or geological fossils with no risk to their value or integrity. Adapting techniques from crystallography and engineering, analysis of crystal structures in ceramic or pottery fragments can determine the period and region of manufacture and reveal ancient trade routes, while texture analysis of metal objects can identify manufacturing techniques and forgeries.

[VISUAL PHYSICS ONLINE](#)

If you have any feedback, comments, suggestions or corrections
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