Physics with Synno – Radiation-Health – Lesson 3

NM.5 Radiation for Diagnosis and Treatment

NM.5.1 X-rays

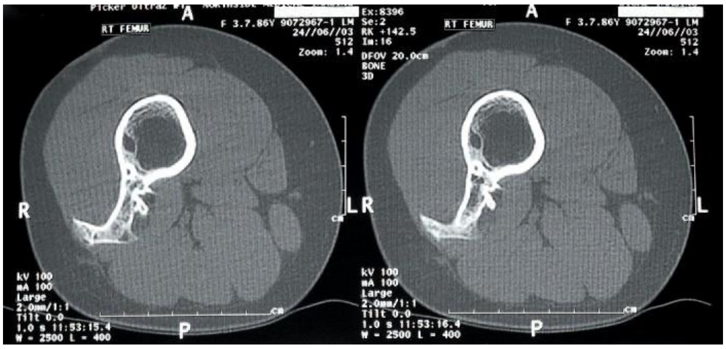
As we learnt earlier X-rays can be used to image parts of the body, in particular bones. High energy X-rays can also be used to treat a tumor. In this process a beam of X-rays is directed towards a particular location from different directions.

NM.5.2 CT Scans

During the 1970s a new diagnostic imaging technique that utilised X-rays was developed called computer tomography (CT) scans. The word tomography comes from the Greek term tomos meaning slice or knife. CT scans are an image of a slice of the body.
A CT scanner consists of an X-ray tube that is rotated around the patient being imaged. The tube and detection mechanism are mounted on a frame called a gantry. The part of the patient's body being scanned is positioned in a gap in the gantry.

An image is obtained in the plane being examined. The patient, on a bed, is moved slowly through the gantry so that a series of images of 'slices' through the body may be obtained.

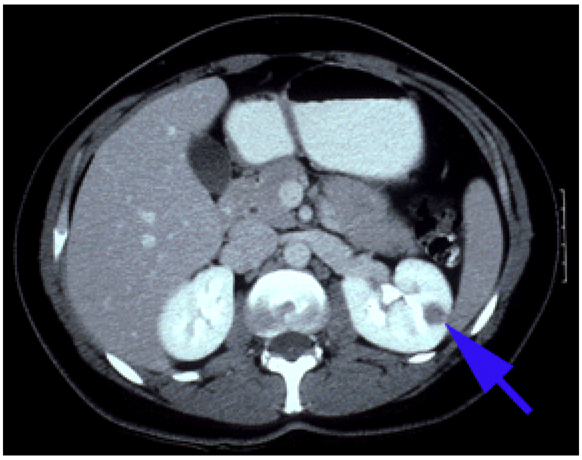
Scan showing the 'slices'



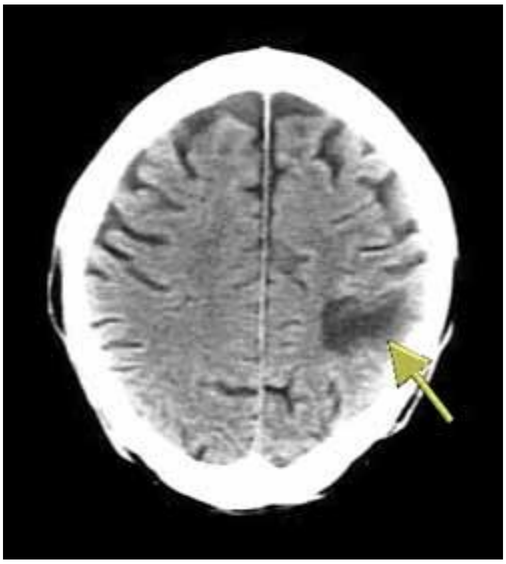
Two of the 'slices' showing the location of a tumour.

The main principles behind obtaining a CT scan image are the same as for X-rays. The X-rays are detected by an array of several hundred detectors. The detectors convert the X-radiation directly into electrical signals. The data from the scan is collected, reconstructed and displayed using a powerful computer and software. The computer analyses the absorption of the X-rays at each measured point in the slice and allocates a corresponding shade of grey. This is the result of around one million computations. The image can be displayed on a TV screen or stored in the computer memory and used with other data.

This 'slice' of the abdomen shows the organs and bones in different shades of grey. In this case a abnormal spot is seen on the kidney.



By taking X-ray images from many angles in a CT scan, the material along the path of the X-ray beams can be distinguished clearly. The method of obtaining and analysing the image makes it possible to see behind bone using a CT scan.



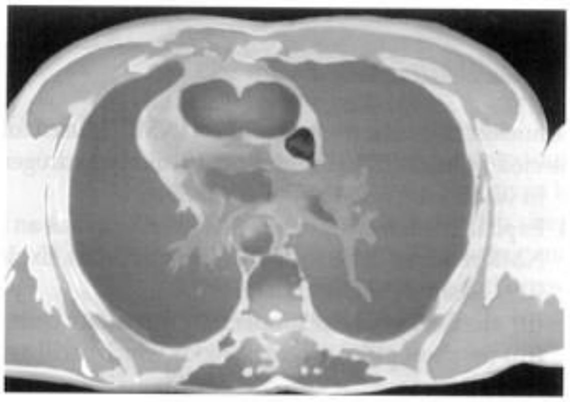
CT Scan

While CT scans provide much more detailed images for doctors, the doses of radiation received by the patient are much higher.

NM.5.3 MRI (Magnetic Resonance Imaging)

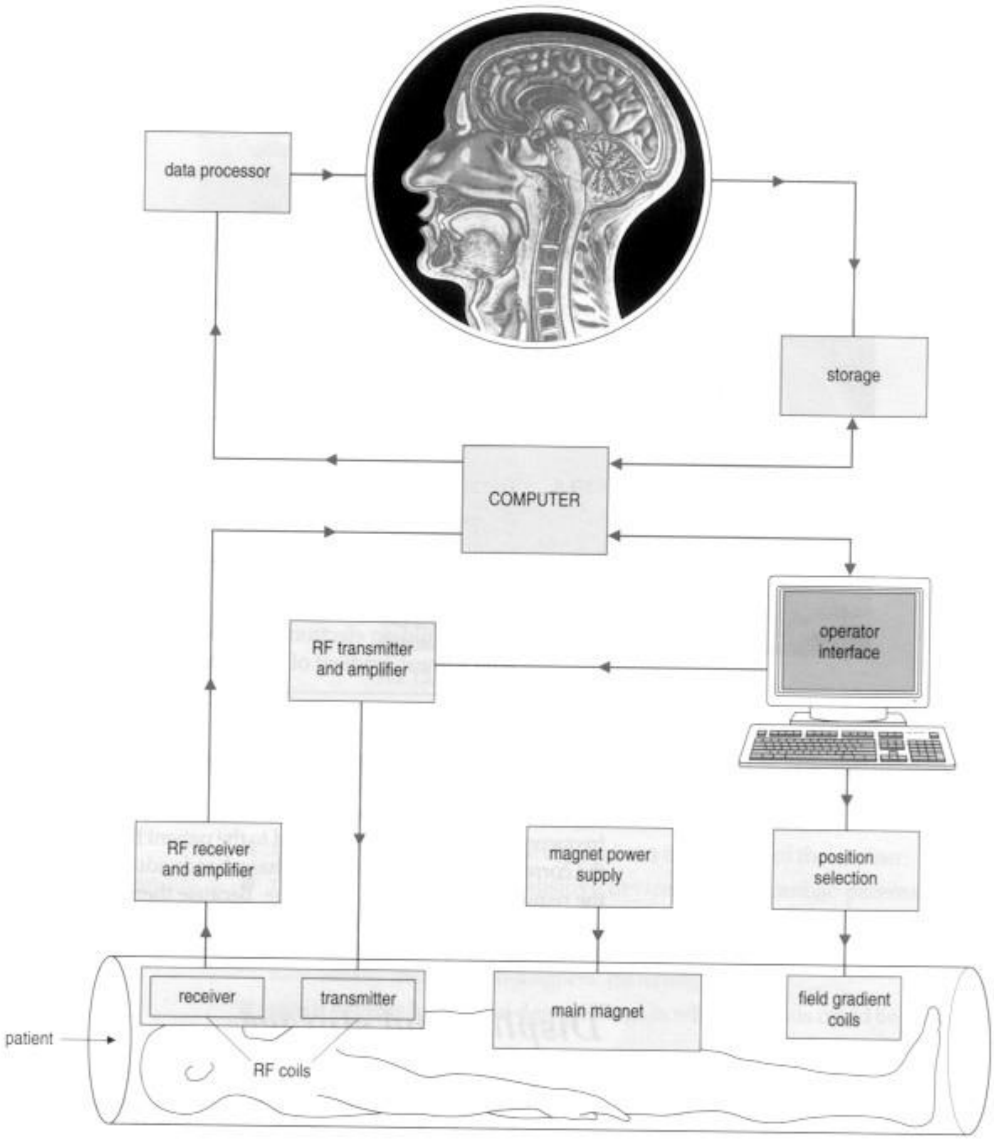
Magnetic resonance imaging (MRI) is method of imaging which has become a more important diagnostic tool over the last ten years. It is based on the phenomenon of nuclear magnetic resonance, where protons interact with strong magnetic fields. Research into MRI began in the 1950's, but the first images of patients were produced in the late 1970's. The images produced look very similar to those of X-rays and CT scans. MRI is particularly good for soft tissue imaging.

Although the equipment is complex and expensive, it has the advantage over X-ray and CT in that there is no radiation hazard.



Heart, Lungs

As with CT scanning a powerful computer is essential for the processing of data and the production of images.



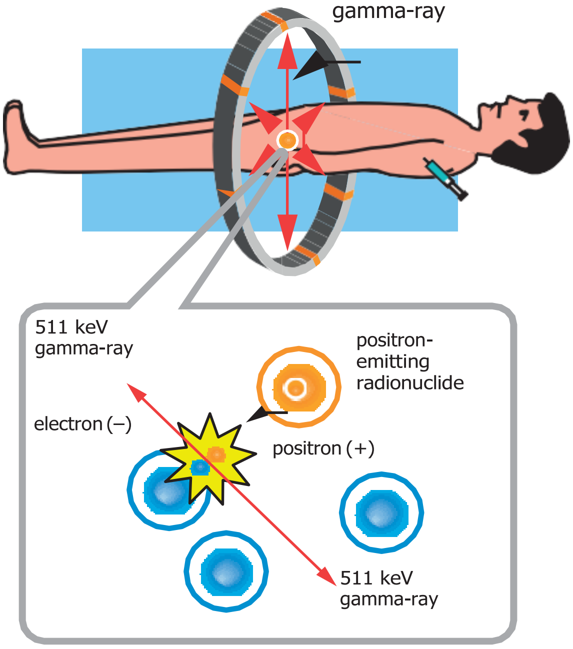
Components of a MRI scanner

MRI is particularly useful in applications which are difficult using other scanning techniques. It was developed originally for neurological investigations, where detailed 3-D imaging is ideal for detecting tumours and other abnormalities in the brain and spinal chord.

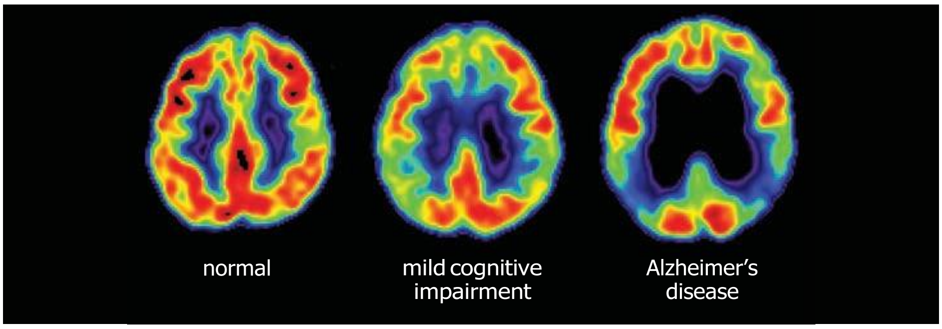
Bulging disc putting pressure on the spinal chord

NM.5.4 Positron Emission Tomography (PET)

Positron Emission Tomography (PET) scanning uses beta+ emitting isotopes.
The isotope decays emitting a **positron** (which is a positive 'electron', also called a beta+ (β^+) particle, and is a particle of antimatter).
The positron can only travel about 1mm before losing its energy and slowing down.
When it slows down enough, it will meet a negative electron from a nearby atom, and they will 'annihilate', leaving no particles.
Their energy is converted into **two gamma rays** which travel in opposite directions so that momentum is conserved.



A PET scanner has a ring of detectors so that both gamma rays are seen, and is connected to a computer which can work out where the gamma rays came from and produces an image.



A Pet scan gives us information about how an organ is functioning.

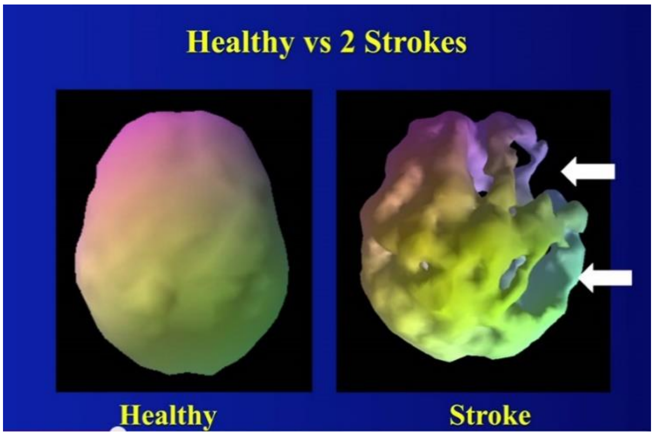
NM.5.5 SPECT Scans

A single-photon emission computerized tomography (SPECT) scan lets your doctor analyze the function of some of your internal organs. A SPECT scan is a type of nuclear imaging test, which means it uses a radioactive substance and a special camera to create 3-D pictures.

While imaging tests like X-rays can show what the structures inside your body look like, a SPECT scan produces images that show how your organs work. For instance, a SPECT scan can show how blood flows to your heart or what areas of your brain are more active or less active.

The most common uses of SPECT are to help diagnose or monitor brain disorders, heart problems and bone disorders.

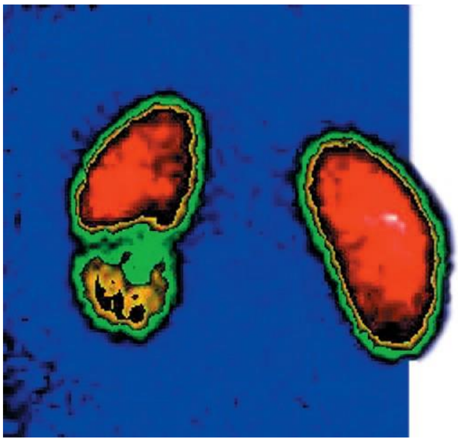
SPECT scan results can be in colour or shades of grey. The varying shades or colours show your doctor which cells in your body are absorbing more or less of the radioactive tracer



NM.6 Radioisotopes in Medicine

NM.6.1 Radioactivity as a Diagnostic Tool

We generally think of the use of radioactive materials in medicine as a treatment for cancer. Radioactive materials can also be used, commonly as tracers, to diagnose disease.



An image, taken using a radioactive tracer, shows cancer of the lower section of the left kidney.

To some it may seem very risky to use radioactive material within the body. With careful selection of isotope the process is a safe and effective means of diagnosis.

During our radioactivity topic we learned that there were three types of radiation, alpha (α), beta (β) and gamma (γ). The table below summarises the properties of these radiations.

Property	α particle	β particle	γ ray
Mass	heavy	light	none
Charge	+2	−1	none
Typical energy	~5 MeV	~1 MeV	~0.1 MeV
Range in air	a few cm	1 or 2 m	many metres
Penetration in living tissue	One layer of skin	a few mm	Many cm
Ionising ability	high	reasonable	poor

Another property that is taken into account when choosing an isotope is its half-life. Recall that the half-life of a radioactive isotope is the time taken for half the nuclei (atoms) present to decay into another element. The radioisotope is removed from the patient's body by processes such as respiration, urination and defecation.

The use and production of radioisotopes within Australia is overseen by ANSTO (Australian Nuclear Science and Technology Organisation). For a radioisotope to be used for diagnostic imaging it must:

- have a short half-life (hours), which is appropriate for the time taken for the diagnostic procedure.
- not emit alpha or beta radiation, because these particles would be trapped in the patient's tissues and they would not be detected externally. They are used in therapy but not diagnosis.
- emit gamma radiation of an energy that can be detected by a gamma camera.
- be available in the highest possible activity, but not be toxic to the patient or react with drugs used at the same time.

Thus the most useful radioisotopes for nuclear medicine are those that emit gamma radiation only. Technetium-99m and iodine-123 are two such isotopes. The 'm' denotes a metastable state.

The table below summarises the details of some radioisotopes used for diagnosis.

RADIOISOTOPE	PRODUCTION SITE	HALF-LIFE	FUNCTION
Chromium-51	Nuclear reactor	27.70 days	To label red blood cells and measure gastro-intestinal protein loss
Iodine-131	Nuclear reactor	8 days	To diagnose and treat various diseases associated with the thyroid gland; used in the diagnosis of the adrenal medullary; used for imaging some endocrine tumours
Iodine-123	Cyclotron	13 hours	To monitor thyroid function, evaluate thyroid gland size and detect dysfunction of the adrenal gland; to assess stroke damage
Molybdenum-99	Nuclear reactor	65.94 hours	Used as the 'parent' in a generator to produce technetium-99m, which is the most widely used isotope in nuclear medicine
Technetium-99m	'Milked' from molybdenum-99	6 hours	To investigate bone metabolism and locate bone disease; assess thyroid function; study liver disease and disorders of its blood supply; monitor cardiac output, blood volume and circulation clots; monitor blood flow in lungs; assess blood and urine flow in kidneys and bladder; investigate brain blood flow and function; estimate total body plasma and blood count
Thallium-201	Cyclotron	3.05 days	To detect the location of damaged heart muscles

Images are obtained by measuring the amount of gamma radiation coming out of the patient's body using a gamma camera.

The gamma camera is stationary and collects gamma radiation over a large area. It converts the gamma rays into light flashes which are transformed into amplified electrical signals. These signals are decoded and converted to an image on a computer screen.

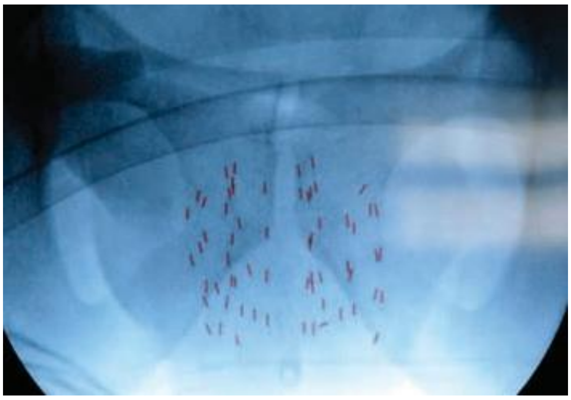
NM.6.2 Treatment with Radioisotopes

Cancer is a general term that actually incorporates hundreds of different diseases. The term tumour describes the growth of abnormal cells. Tumours are not all cancerous. Benign tumours are abnormal, but not spreading, and often grow slowly.

It is well accepted that exposure to radiation can cause cancer, but it can often also provide a cure. A common method of cancer treatment is the use of ionising radiation to destroy the cancerous cells. Cancerous cells are rapid growth cells and they are more susceptible to being destroyed by radiation.

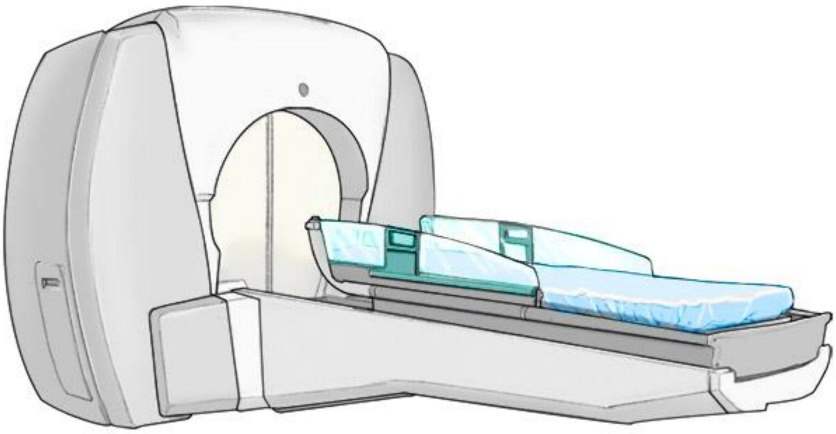
Radiation therapy programs must be designed to provide the optimal dose of radiation to the cancerous cells while minimising the exposure of healthy cells. The radiation can be applied internally or externally.

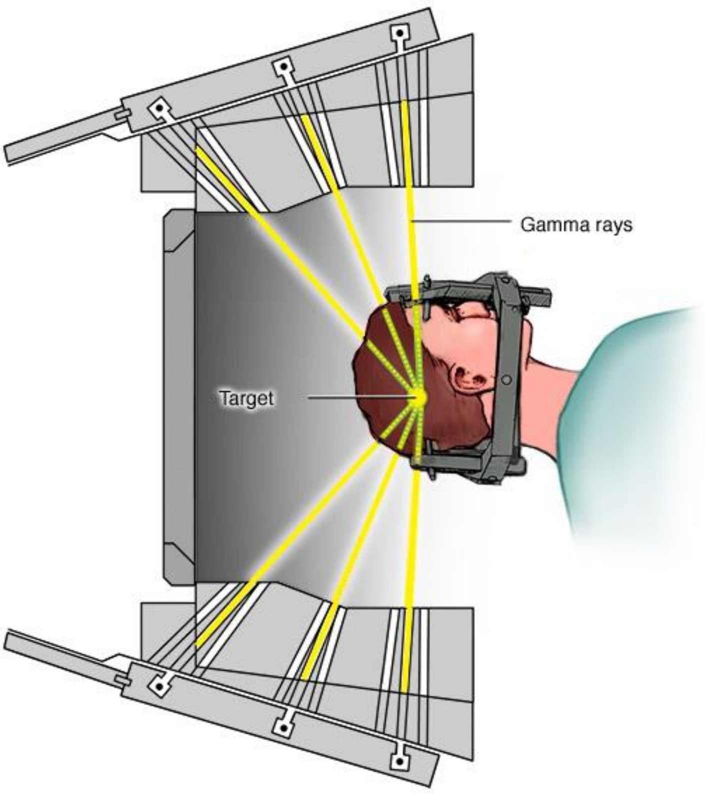
When using radioisotopes internally, the source of the ionising radiation is placed inside the body; it is localised in the affected organ. When selecting isotopes for use internally, the isotopes used internally should be sources of alpha and beta radiation. These are ionising radiations and need to be of sufficient energy to penetrate the diseased section of the body only. Chemotherapy and Brachytherapy are examples.



Numerous iodine-125 (I-125) wire seeds can be seen in this X-ray of a prostate cancer patient.

When the radiation is applied externally the radioisotope must be a gamma emitter. The gamma knife is an example. Gamma Knife radiosurgery uses specialized equipment to focus about 200 tiny beams of radiation on a tumour or other target with very high accuracy. Although each beam has very little effect on the brain tissue it passes through, a strong dose of radiation is delivered to the place where all the beams meet. It is used to treat tumours, vascular malformations and other abnormalities in the brain.





Gamma Knife unit and radiation delivery

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