Nuclear Medicine

Saving lives internationally

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by Mapula Letsoalo

People shrug at the mention of the words ‘nuclear’ and ‘radiation’. Yet the history of the use of radioisotopes for peaceful purposes is filled with the names of Nobel Prize winners. Names such as Henri Becquerel; and Pierre Curie and Marie Curie, come to mind. These three scientists were jointly awarded the 1903 Nobel Prize in physics. One half was awarded to Antoine Henri Becquerel *“in recognition of the extraordinary services he has rendered by his discovery of spontaneous radioactivity”*, and the other half jointly to Pierre and Marie Curie, *“in recognition of the extraordinary services they have rendered by their joint researches on the radiation phenomena discovered by Professor Henri Becquerel”*.

Since then, more work has been carried out on radioisotopes which are used in medicine. Research reactors, accelerators, production technologies, and hospital scanning equipment have all been built and are well established in countries around the world. Many ways to use radioisotopes have been developed in medical therapy, diagnosis and research. Today millions of patients worldwide benefit from this fascinating technology.

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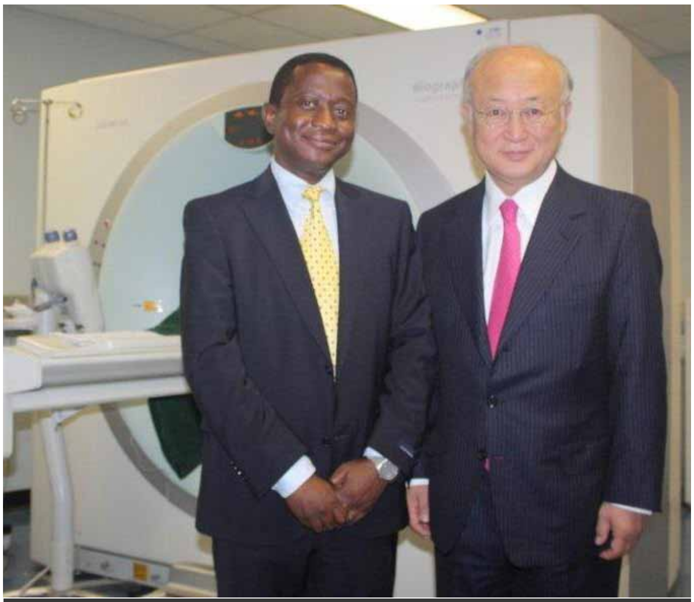


Prof Mike Sathege Head of Nuclear Medicine at the Steve Biko Hospital in Pretoria, with the Director General of the International Atomic Energy Agency (IAEA), Mr Yukiya Amano after showing him the nuclear medicine unit. They are standing in front of a PET nuclear scanner.

What is radiation... and what are radioisotopes?

Nuclear Radiation is energy in the form of waves or particles which comes from the nucleus of an atom, and which travels through material or space. The term ‘radiation’ includes electromagnetic radiation, which ranges in wavelength from radio waves, through infrared heat waves, visible light, ultraviolet light, X rays, diminishing in wavelength down to Gamma Rays, which form part of nuclear radiation.

Gamma rays are often written using the Greek letter γ and are written as γ-rays.

Radioisotopes are isotopes that are unstable and give off nuclear radiation spontaneously.

What is nuclear medicine?

Nuclear medicine is a medical specialty involving the application of radioactive substances to people, in both the diagnosis and the treatment of disease.

In nuclear medicine procedures, radioisotopes are combined with other chemicals or pharmaceutical compounds to form radiopharmaceuticals. These radiopharmaceuticals, once administered to the patient, migrate through the body and localise in specific organs or cellular receptors. This property provides nuclear medicine with the ability to image the extent of a disease process in the body, based on the cellular function and physiology, rather than relying only on physical changes in the tissue anatomy.

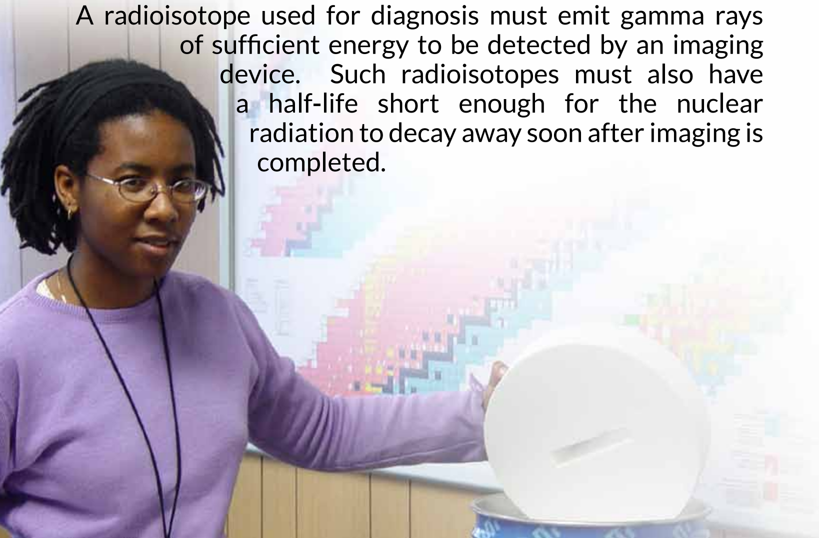
Diagnosis of a Medical Condition

Nuclear medicine can be used to examine such diverse conditions as blood flow to the brain, functioning of the liver, lungs, heart or kidneys, to assess bone growth, and to confirm results gained from other diagnostic procedures. Another important use is to predict the effects of surgery, and to assess changes which have taken place since treatment started.

The quantity of a radiopharmaceutical given to a patient is designed to be just sufficient to obtain the required information, before the radiation decays away. The radiation dose received by the patient 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 actually functioning, from outside the body, makes this technique a powerful diagnostic tool.

Half-life is a very commonly used term in nuclear physics. It is used to describe the time taken for radioactive material to lose its radioactivity. Radioactive atoms undergo radioactive decay as they emit their radiation. The measure 'half-life' is the amount of time required for the radiation to fall to half its initial value. After each successive half-life the radiation keeps dropping by half until there is a negligible amount left.

A radioisotope used for diagnosis must emit gamma rays of sufficient energy to be detected by an imaging device. Such radioisotopes must also have a half-life short enough for the nuclear radiation to decay away soon after imaging is completed.



The actual principle of diagnostics using a radiopharmaceutical is that a chemical is designed to travel to some site, such as a cancer, and as it travels it carries the radioactive atoms along, just like passengers in a bus.

In the case of therapy using radiopharmaceuticals the same applies, but in this case a pre-determined radioactive dose is deposited at the target site, which it then bombards with radiation for as long as the medical specialist has planned.

Examples of the most frequently used radioisotopes in medicine are: Iodine-131, Technetium-99m, Fluorine-18 and Gallium-68.

Iodine-131 is one of the oldest radiopharmaceuticals in nuclear medicine. In use since the 1940's, Iodine-131 is administered as a capsule taken orally. Because of its unique connection to the thyroid gland, Iodine-131 is most valuable in the diagnosis of thyroid gland abnormalities. It is used to study the functioning of the thyroid gland, and it behaves in the body just as natural non-radioactive iodine does, but the radioactivity allows observation of the organ from outside the body, using a gamma camera. Stronger doses of Iodine-131 are used in radioactive therapies aimed at dealing with thyroid cancers.

The most widely used radioisotope in nuclear medicine, employed in about 80% of all nuclear medicine procedures, is called **Technetium-99m** and this isotope accounts for more than 40 million procedures per annum worldwide.

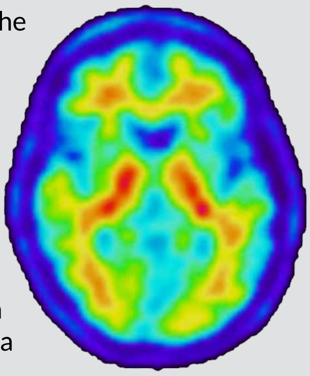
At least 200 000 procedures are performed in South Africa annually using this radioisotope.

Technitium-99m has very good characteristics which are ideal for a nuclear medicine scan. It has a half-life of 6 hours, which is long enough to allow the physician to do the scan, yet short enough to minimise radiation dose to the patient. Its chemistry is so versatile that it can be bound to different chemicals, which allows the technitium-99m to be targeted to specific organs. It can be used for imaging and for functional studies of various body organs such as the brain, myocardium, lungs, liver, and skeleton.

In nuclear physics, many elementary particles have anti-particles, which are the 'opposite' of the initial particle. This property is not yet fully understood.

The well-known negatively charged electron has an anti-particle which is known as a positron, and is in effect, a positively charged electron. The positron is extremely rare. According to the famous Einstein equation, $E=mc^2$, when a particle meets its own anti-particle they annihilate each other, to produce pure energy.

In the case of the medical procedure of Proton Emission Tomography (PET), positrons and electrons are beamed into a patient. When the particles meet each other they annihilate each other and produce two specific gamma rays which travel in opposite directions. These gamma rays produce a real-time image of excellent resolution.



Treatment of a Medical Condition

The radioisotope which generates the radiation must be localised in the required organ, in the same way that it is used for diagnosis. However in the case of treatment, the aim is to destroy or weaken malfunctioning cells, using radiation. So it is intentional that the radiation stays active in the body for some time. It is the task of the medical specialist to design the dose so that the desired result is delivered.

Although most isotopes used in nuclear medicine are for diagnostic purposes, there are isotopes such as Iodine-131, **Lutetium-177** and **Rubidium-82** which are also used for the treatment of diseases.

Rubidium-82 is used in the treatment of heart disease. Lutetium-177 is a newer radioisotope. Peptides labelled with Lutetium-177 are also used in the treatment of neuroendocrine tumors and prostate cancer.

Benefits far Outweigh the Risks

Nuclear medicine uses extremely small quantities of radioisotopes, therefore the patient is exposed to a very low level of radiation and it is safe. The techniques are non-invasive and painless, except for the small prick of the syringe needle as the doctor injects the liquid containing the radioactive isotope. The procedures are quick, and result in a rapid diagnosis and subsequent treatment of various diseases.

Nuclear medicine allows the physician to determine how the organ is actually functioning (physiology), and this approach is often better than using X-ray, MRI and CT methods which can only tell the doctor the shape (morphology) of the organ, at the moment that the scan is taken. Nuclear medicine gives an accurate diagnosis and allows for early pre-emptive treatment, planning and monitoring of the patient's condition. In some disease scenarios nuclear medicine provides better treatment options due to its ability to directly target unhealthy cells, thus not affecting surrounding healthy cells.

Positron Emission Tomography

*One of the fastest growing nuclear medicine techniques is Positron Emission Tomography (PET), which requires special large instruments called PET tomographs. This technique allows physicians to track organ function at a molecular level, thereby revealing complex health changes much earlier in individual patients than other diagnostic techniques. For PET imaging, the main radiopharmaceutical used is Fluorodeoxyglucose (FDG), incorporating **Fluorine-18** which has a half-life of just under two hours. FDG is a good indicator of cell metabolism and is used for diagnostic imaging, most commonly for the reliable and accurate diagnosis, staging and restaging of cancers, as well as for monitoring and assessing the impact of therapeutic interventions. It is a powerful tool in patient management in oncology, neurology and cardiology, as well as in the management of infection and inflammation. Fluorine-18 is a cyclotron-produced isotope, in contrast to Iodine-131 and Technetium-99m which are both reactor-produced isotopes.*

Gallium-68

Gallium-68 is one of the newest radioisotopes produced from a Germanium-68/ Gallium-68 generator. Gallium-68-labelled peptides are used in PET scans for diagnosis, and also for the staging and restaging of tumors such as neuroendocrine tumors and prostate cancer. It is also currently used in various clinical trials in the US and Europe, which may reveal more new uses.

A PET scanner

The South African Perspective...

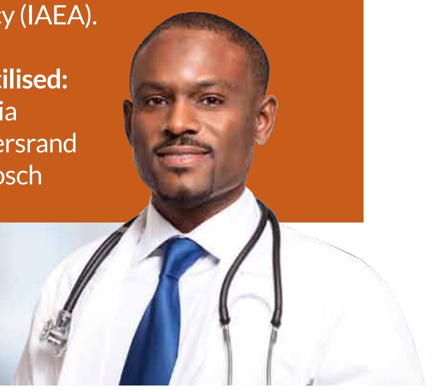
South Africa is one of the world's top three leading producers of Molybdenum-99, which is the parent radionuclide for producing Technetium-99m. Molybdenum-99 is produced at NTP Radioisotopes SOC Ltd, a subsidiary company of the South African Nuclear Energy Corporation (Necsa) based at Pelindaba, west of Pretoria. The production of Molybdenum-99 wouldn't be possible without the research reactor SAFARI-1 at Pelindaba. This reactor was commissioned in 1965 and is currently considered to be the most effectively utilised nuclear reactor of its type, in the world.

An additional facility has been built at NTP Radioisotopes for the production of the advanced medical isotope, Lutetium-177. Lutetium-177 occupies a unique niche in the world of radiopharmaceuticals and is used in the preparation of radiopharmaceuticals for the treatment of neuroendocrine tumors and prostate cancer.

There are four cyclotrons in South Africa, dedicated towards the production of medical radioisotopes. The largest one is located at iThemba LABS in the Western Cape. This cyclotron is amongst the few in the world which can produce Germanium-68, the parent nuclide for Gallium-68. The same cyclotron can produce Strontium-82 used in the production of Rubidium-82, for the treatment of cardiac diseases.

South Africa is the nuclear medicine training country for Africa, as designated by the International Atomic Energy Agency (IAEA).

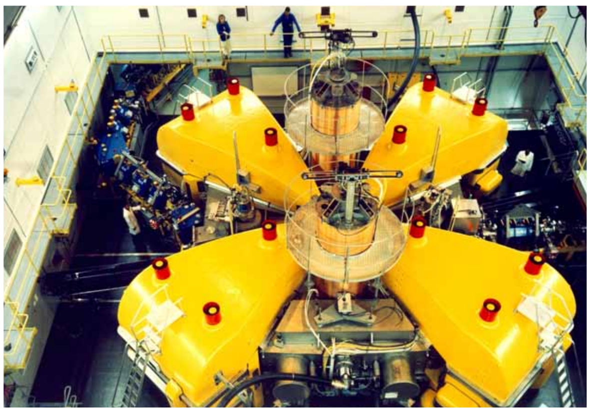
Three universities are utilised:
University of Pretoria
University of the Witwatersrand
University of Stellenbosch



Every minute of every day nuclear medicine is being used on some patient somewhere in the world. This marvel of modern science is destined to expand even further, as the passage of time rolls on.

CYCLOTRON SPECS

iThemba LABS is a research facility based in the Western Cape that houses a Separated Sector Cyclotron (SSC) capable of accelerating protons to an energy of 200MeV. Protons with this energy are capable of travelling a distance comparable to four times around the Earth in one second. Apart from providing nuclear physicists with a probe to study the structure of the atomic nucleus, as well as the reaction mechanisms that govern nuclear interactions, the accelerated protons are also used for the production of radionuclide's and particle therapy. The SSC has four separate magnet sectors with a diameter of 13m, and a consolidated weight of 1200 tons. These magnets provide a circular confinement field which enables the positively charged particles to be accelerated, using high voltages. The SSC magnets are housed in a negative pressure vault that is able to hold three double-decker busses. The cyclotron was South African designed, with some collaboration from French experts.



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