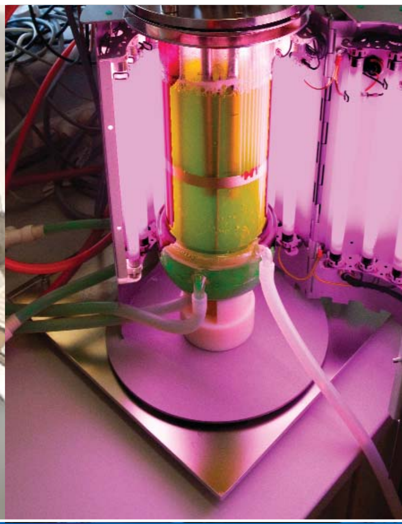
Australian Government

Nuclear-based science benefiting all Australians

Scientific facilities and equipment



The Australian Nuclear Science and Technology Organisation (ANSTO) is the home of Australia's nuclear science expertise. This unique expertise is applied to radiopharmaceutical production and research into areas such as climate change, water resource management, materials engineering, applications of radiopharmaceuticals and use of neutrons in understanding atomic and molecular processes, as well as a range of other scientific research disciplines.

ANSTO is a Federal Government agency and operates a range of nuclear and non-nuclear facilities and equipment for research and commercial purposes including Australia's only operating nuclear reactor, OPAL.

ANSTO applies nuclear science in a wide range of areas for the benefit of all Australians.

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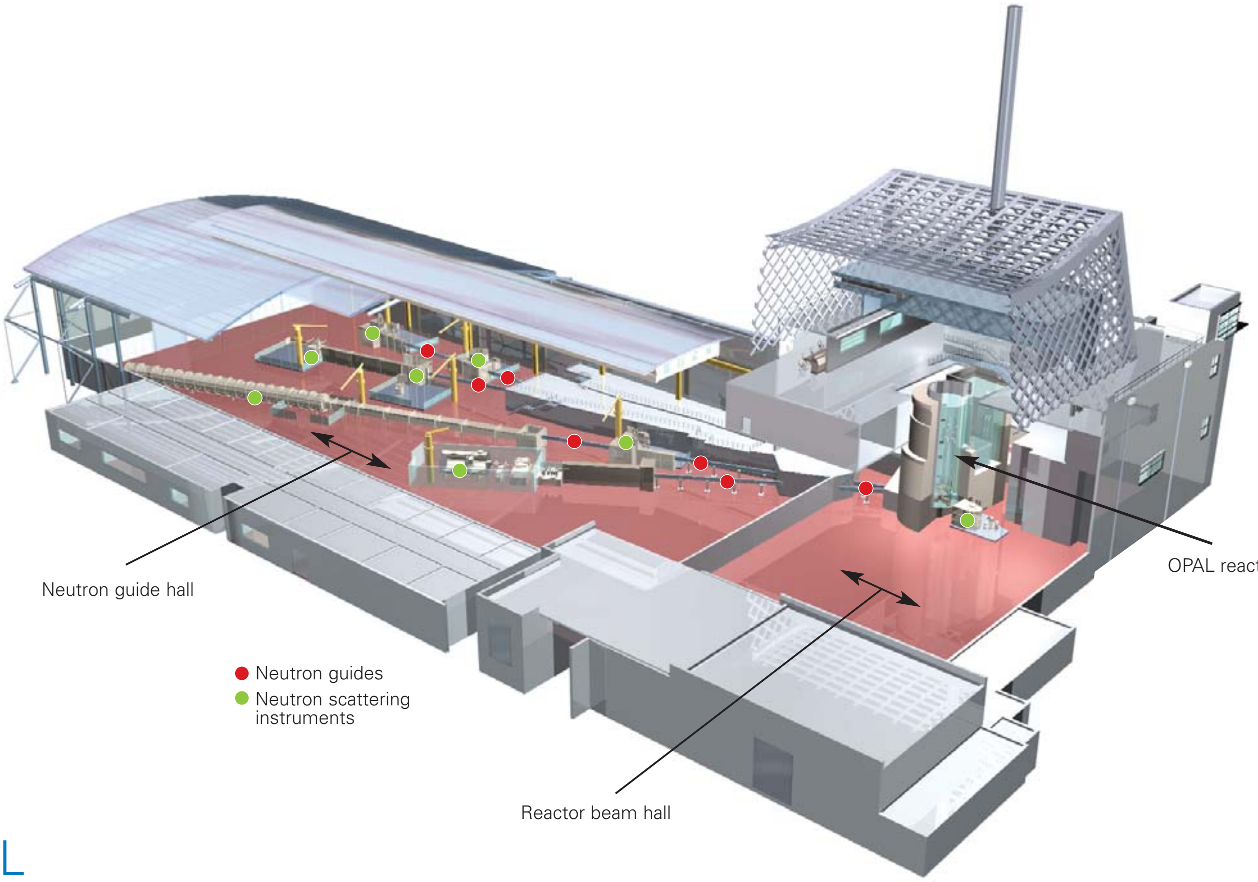


OPAL

OPAL (the Open Pool Australian Light water reactor) is ANSTO's world-class nuclear research reactor, customised to Australia's needs, which was opened in 2007.

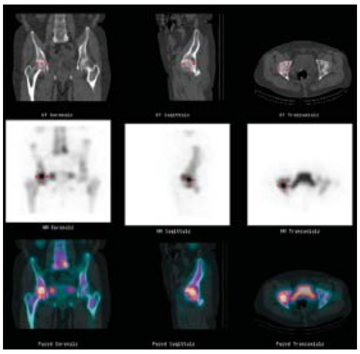
OPAL is a multi-purpose facility that generates neutrons which are used to produce radiopharmaceuticals, world-class scientific research and irradiations for researchers and industry.

The high quality radiopharmaceuticals produced in the reactor are used in nuclear medicine facilities to diagnose and treat cancer and other serious diseases.

At OPAL a range of irradiation services are provided, including the irradiation of silicon ingots, which after processing and electronics manufacturing may be used in many household products like digital cameras, computers and mp3 players.

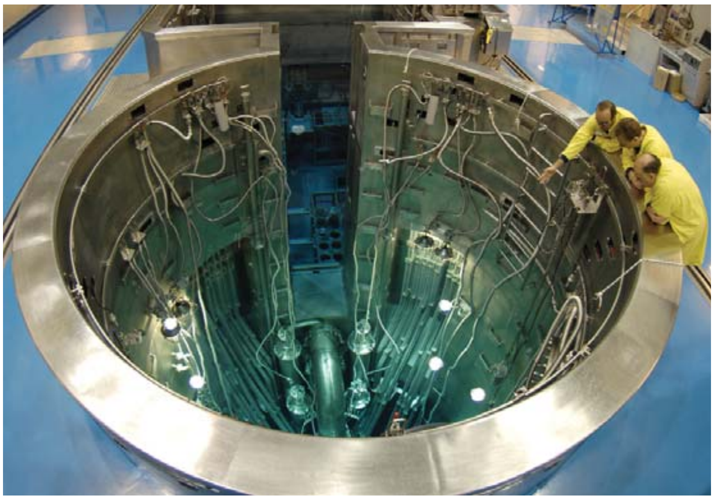
Silicon irradiated in OPAL is used in digital cameras.

OPAL is used to produce life-saving nuclear medicine for treating and diagnosing disease.

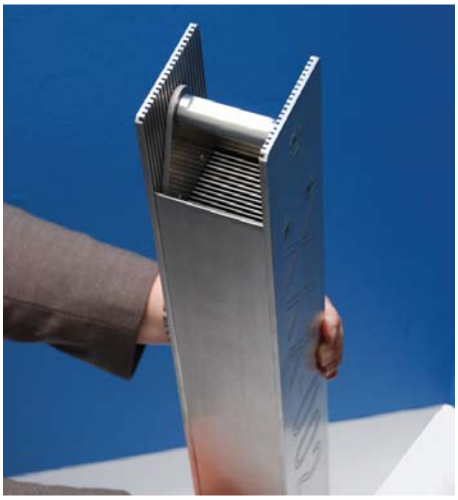


Nuclear medicine imaging is different to X-rays, as the actual chemical functioning of the body is seen.

OPAL



The open pool design makes it easy to see and manipulate items inside the reactor.



The reactor core consists of 16 fuel assemblies, which contain low-enriched uranium.

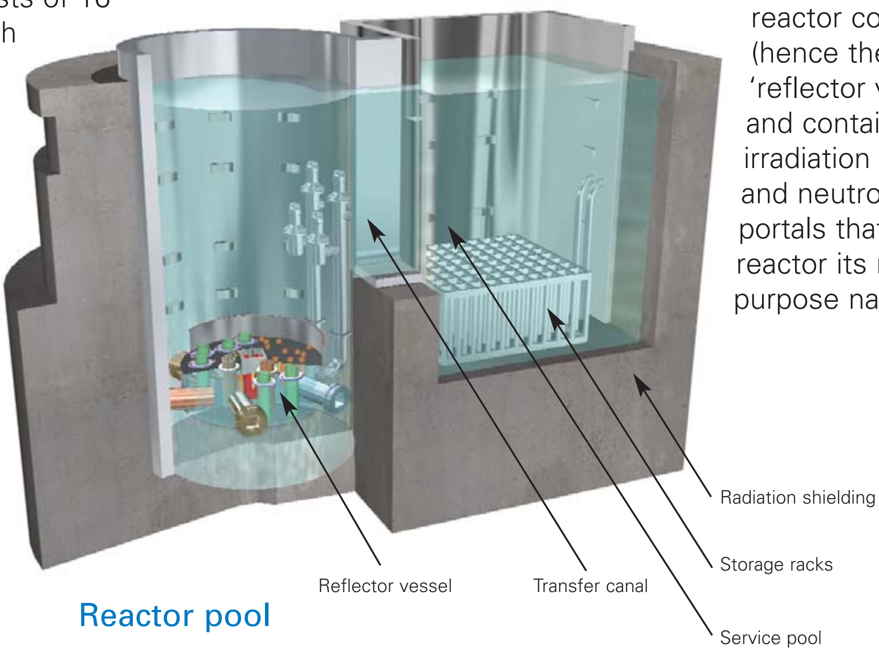
OPAL is also designed to provide neutron beams for neutron scattering research that investigates atomic and molecular structures for both research and commercial purposes.

The reactor core is located in a 13 metre deep open pool filled with demineralised light water (ordinary water).

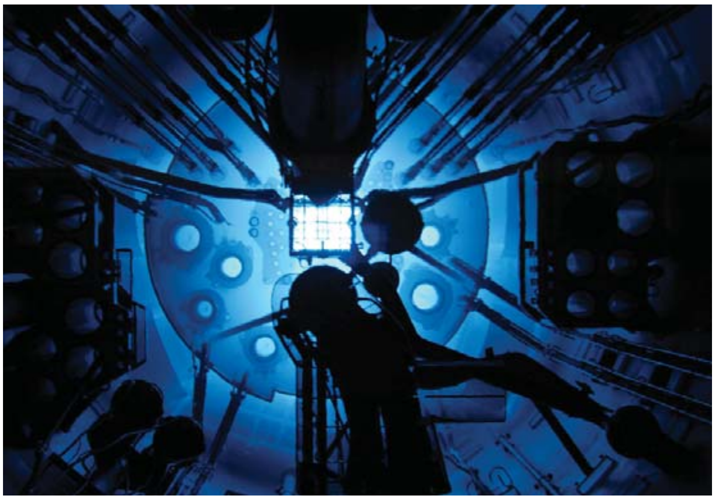
The core is about the size of a two-drawer filing cabinet. It consists of 16 fuel assemblies, which contain low-enriched uranium and five control rods made from hafnium, a material that strongly absorbs neutrons.

The control rods maintain the reactor in a safe state while the reactor is operating and also act as the first shutdown system when required.

The water in the open pool is used as a coolant for the reactor core. There is a vessel surrounding the reactor core which is filled with heavy water (deuterium oxide), which both sustains the chain reaction by reflecting neutrons back into the reactor core (hence the name 'reflector vessel') and contains the irradiation facilities and neutron beam portals that give the reactor its multi-purpose nature.



Reactor pool



The high energy beta particles from spent nuclear fuel immersed in water gives rise to a blue glow known at Cerenkov radiation.

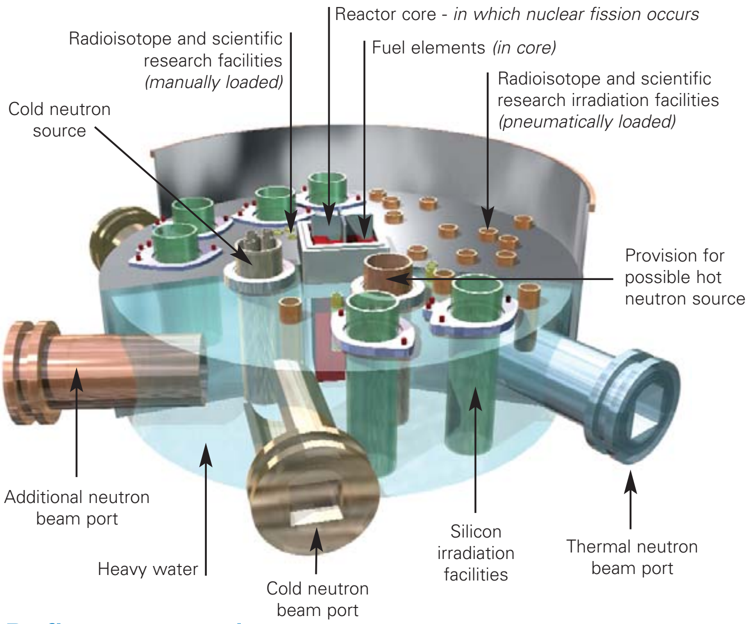
The open pool design makes it easy to see and manipulate items inside the reactor and the reflector vessel. The depth of the water ensures staff working in the area above are shielded from radiation. The pool itself is constructed from stainless steel and is surrounded by a concrete block which also absorbs radiation.

Items to be irradiated in the reactor facilities are inserted into the reflector vessel, either manually using special tools located on the end of long poles made from carbon-fibre, or with pneumatic equipment using compressed nitrogen.

Following irradiation, the items are extracted from the irradiation facilities. A variety of methods are used to transport the radioactive items safely to nearby buildings for further processing or packaging.

The reactor operates on a monthly cycle, with a shutdown for a few days each month for a fuel change. Typically three of the sixteen fuel assemblies are changed and others moved within the core.

Research reactors like OPAL are not used for producing electricity. Unlike nuclear power reactors which may operate at an energy output of around 3,000 megawatts (thermal) and use around 100,000 kilograms (kg) of uranium per year, OPAL produces just 20 megawatts of energy using around 30kg of uranium per year. This output is only enough to warm the water within the reactor pool to about 40 degrees Celsius.



Reflector vessel

Radioactive material is handled inside ‘hot cells’. Operators are protected by the hot cell’s lead casing and reinforced glass.

The OPAL control room is where operators monitor the reactor system.

The reactor building is made from reinforced concrete and has a steel mesh cover which together protect the reactor from external events (including earthquakes and aircraft collisions) and also provides the physical boundary to contain radiation emissions that may result in the very unlikely event of release of radioactivity inside.

The reactor's security design was developed in accordance with current international best practice and is integrated into the overall ANSTO site system, which includes 24 hour protection by the Australian Federal Police.

The reactor safety and protection systems allow for the reactor to be manually or automatically shut down, cooled and containment systems enabled.

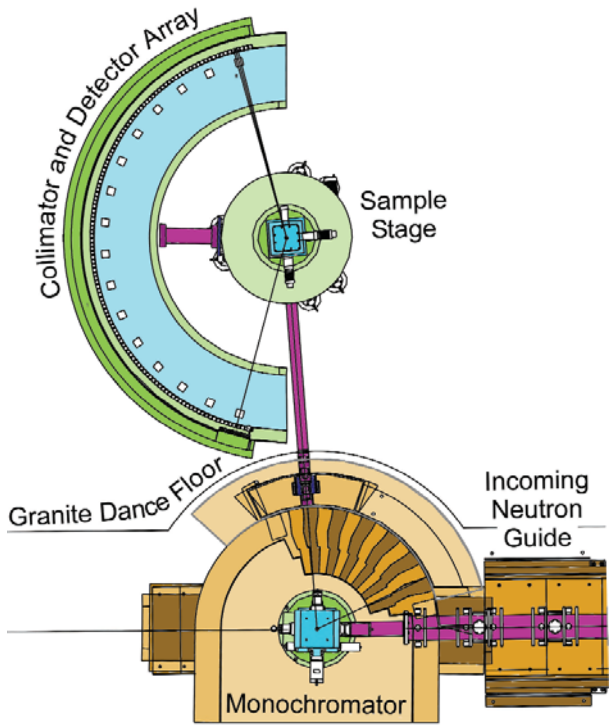
Reactor shutdown – OPAL’s first shutdown system quickly inserts (by gravity and assisted with compressed air) the five control rods into the reactor core. The second shutdown system partially drains the reflector vessel of its heavy water. Both shutdown systems can function in a general power failure and in the unlikely event OPAL’s backup generators also fail.

Core cooling – during operation, the core is cooled by two pumps of the primary cooling system. When the reactor is shut down, residual heat from the reactor core is dissipated by water that circulates naturally upwards through the core.

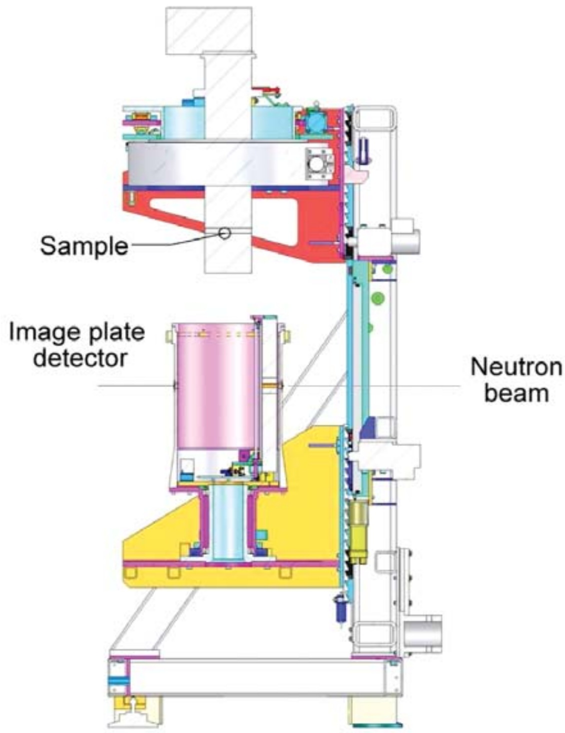
Containment – if necessary, the reactor building can be isolated from the external environment.

The reactor building is made from reinforced concrete and has a steel mesh cover which together protect the reactor from external events including earthquakes and aircraft collisions

Echidna



Koala



Neutron beam instruments

ANSTO's OPAL research reactor is adjacent to research facilities containing neutron beam instruments used for solving complex research and industrial problems in many important fields.

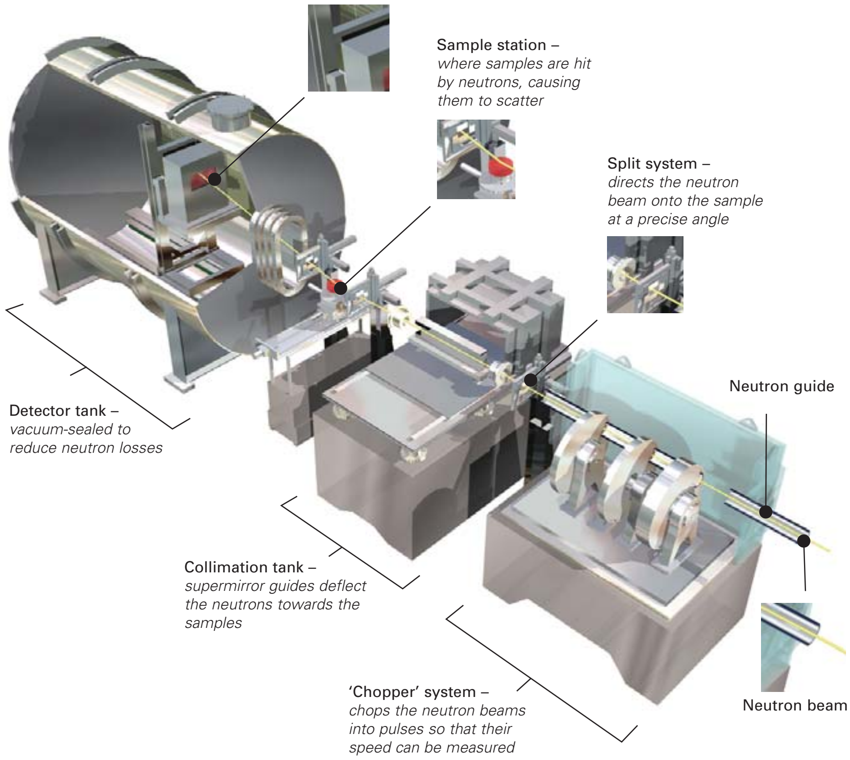
Neutron scattering allows scientists to see what X-rays cannot. They look at materials from the inside out, understanding their atomic structure and how materials respond to various stimuli, such as high magnetic fields and extreme temperatures.

As our bodies and surroundings are made up of atoms, understanding how atoms and molecules move and change during various processes is crucial to understanding how things work and ultimately how to improve energy systems, drug design or manufacturing processes.

Atoms are mostly made up of empty space. When a beam of neutrons is directed at a sample object, most of the neutrons therefore pass straight through. The neutrons that hit the nucleus of atoms in the sample object are scattered, creating a diffraction pattern that can be studied.

There are two types of neutron scattering: elastic and inelastic scattering. When a neutron scatters elastically it changes direction but does not change speed. When a neutron scatters inelastically it changes speed as well as direction. Elastic neutron scattering is used to study atomic and molecular structures, and inelastic scattering is used to study the motion of atoms inside materials.

Platypus



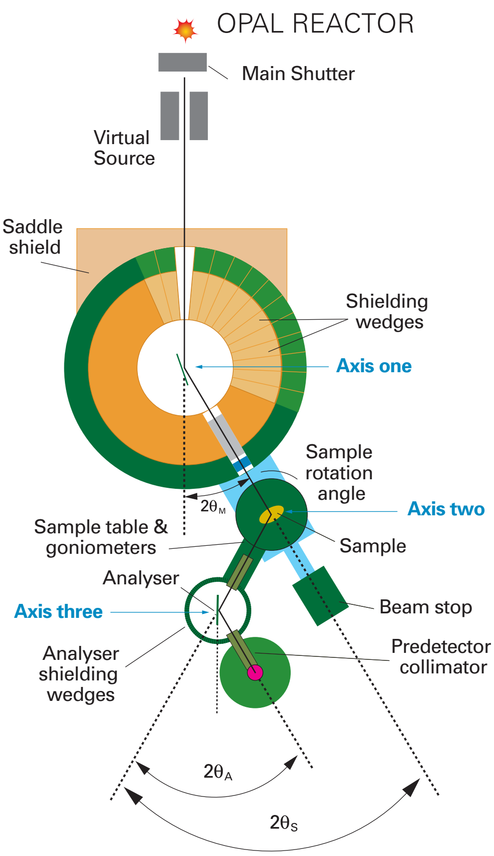
The neutrons produced in the OPAL research reactor flow into neutron guides attached to the portals in the reflector vessel and travel down the guides, forming beams which are directed to the neutron beam instruments. The samples on the instruments scatter the neutrons onto a detector, and the resulting patterns are then interpreted by researchers.

ANSTO's neutron beam instruments are:

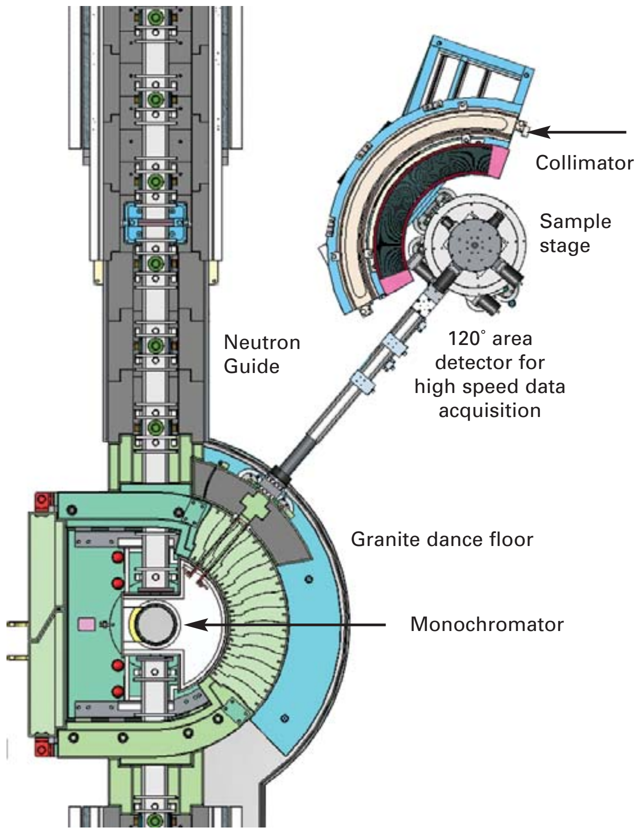
- Echidna – a high-resolution powder diffractometer that can accurately resolve complex atomic and magnetic structures of powders and is used, amongst other things, for research into batteries and creating better building products
- Koala – a laüe diffractometer that can look at crystal structures. Koala's capability to precisely locate individual hydrogen atoms plays an important role in the understanding and development of catalysts, pharmaceuticals and energy materials
- Kowari – a residual-stress diffractometer that looks at stresses in materials such as jet engines or gas pipes or investigating failures of wheels and rails
- Platypus – a reflectometer that can study surfaces and interfaces of thin films, membranes and surfaces that interact with air or liquid. It is not only useful for studying biological materials such as membranes or polymers, but also for studies of thin-film magnetic devices such as data-storage films in hard drives.

Neutron beam instruments

Taipan

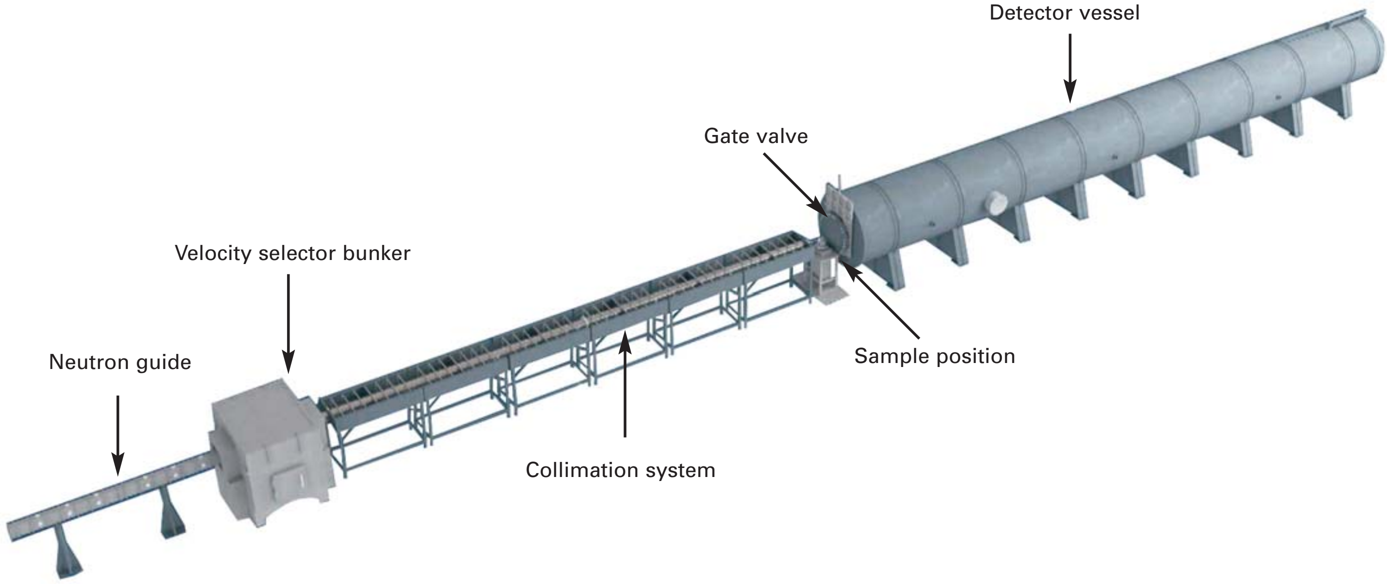


Wombat



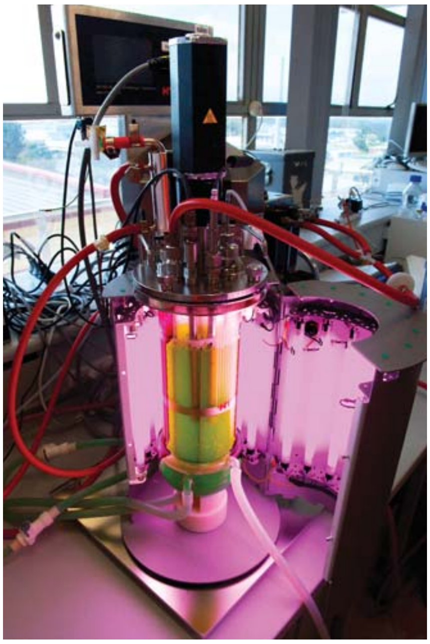
- Quokka – a small-angle neutron scattering instrument that investigates the structure of materials on the nanoscale. Quokka is used for studying materials such as polymers, superconductors, porous materials, geological samples, alloys, ceramics and biological molecules such as proteins and membranes.
- Taipan - a thermal triple-axis spectrometer used to measure neutron inelastic scattering, which is a key technique for the measurement of excitations in materials. These measurements provide information on the forces between atoms, or interactions between magnetic moments.
- Wombat – one of the most powerful powder diffractometers in the world. It can detect millions of neutrons to produce data on the structure of material in a matter of milliseconds: we can watch chemical reactions as they happen. Its focus includes studying novel energy-storage materials and molecules for drug-delivery.
- Sika (under construction) - a cold-neutron three-axis spectrometer suited to study problems in low-temperature physics, like understanding novel materials such as superconductors, magnets and strange metallic states.

Quokka



- Pelican (under construction) - a time-of-flight spectrometer and part of the inelastic neutron-scattering suite for the study of molecular dynamics and diffusions in hydrogen-bonding and storage systems, catalytic materials, cement, soils and rocks, looking at hydration process and ion diffusion.

There are plans to extend the instrument menagerie further over the next few years; for example an ultra-small-angle scattering instrument investigating structure on the microscale level, and a beryllium-filter instrument for the study of hydrogen's behaviour in hydrogen-storage material.



ANSTO's National Deuteration Facility is the first of its kind in Australia.

National Deuteration Facility

The National Deuteration Facility offers the capability to produce molecules where all or part of the molecular hydrogen is in the form of the stable (non-radioactive) isotope of hydrogen called deuterium.

This important technique enables scientists to more effectively investigate the relationship between the structure and function of proteins, DNA, synthetic polymers and other materials known as 'soft matter'.

Molecular deuteration assists in making it possible to observe the arrangement of subunits of an enzyme, or changes in shape when molecules interact or become active or inactive. This can be done with molecules in solution under relevant real life conditions.

Hydrogen and deuterium atoms scatter neutrons quite differently when placed in front of a neutron beam. Molecular deuteration of parts of a molecule creates contrast between those parts containing deuterium and those with normal hydrogen, thus providing more information about the molecular structure.

Deuteration may also be used to obtain information about the position of key hydrogen atoms within a molecule, for example in the region responsible for catalysis by an enzyme.

It can also be used to obtain information about the behaviour of lipid molecules when disrupted by toxins or attacked by enzymes, as well as the position and shape of proteins in membranes.

Scientific facilities and equipment

Scientists are using ANSTO's National Deuteration Facility to study the structure and behaviour of molecules by labelling critical parts of a molecule or complex.

On average, every Australian will use a nuclear medicine product sometime in their lifetime.

Radiopharmaceutical production facilities

ANSTO supplies nuclear medicine to over 225 nuclear medicine centres across Australia and exports to New Zealand and South East Asia.

An average of 3,000 medical isotope shipments are dispatched per month. On average, every Australian will use a nuclear medicine product sometime in their life.

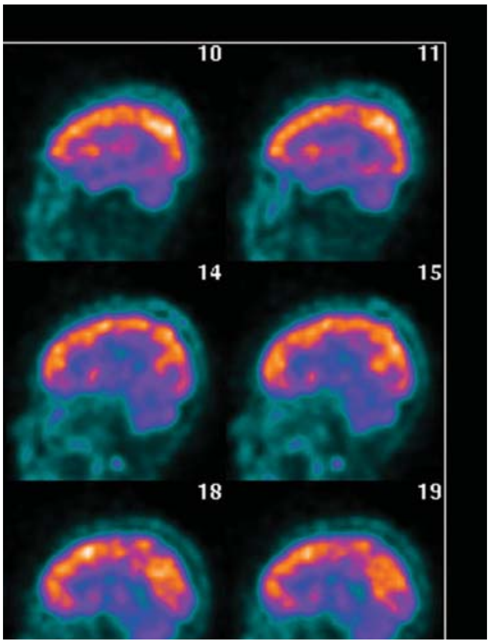
ANSTO simultaneously produces large quantities of different isotopes, such as molybdenum-99 and iodine-131, used for the diagnosis and treatment of serious illnesses such as cancer.

ANSTO's molybdenum-99 manufacturing facility which uses low enriched uranium irradiated targets is used to meet the huge demand for this important radiopharmaceutical, which is the basis of 80 per cent of nuclear medicine procedures performed around the world.

The molybdenum-99 is placed in a container called a technetium-99m Generator and sent to hospitals and nuclear medicine centres. The molybdenum-99 decays to technetium-99m and is extracted by washing a saline solution through the generator.

Molybdenum-99 is placed in a container called a technetium-99m Generator which is sent to hospitals and nuclear medicine centres.

Radioisotope tracers are injected into patients, gamma cameras are then used to take images of the radioisotopes inside the body.



A computer enhanced image is generated by a gamma camera. The image provides information about the patient's body and organs.

ANSTO radiopharmaceuticals are used in over 225 nuclear medicine centres across Australia and overseas.

Technetium-99m can be chemically reacted with a range of biochemicals. It is then injected into the patient as a tracer for imaging to show a wide range of diseases associated with the brain, heart, liver, lungs, salivary glands, and bone. The images are projected and seen using a device called a gamma camera, revealing the physiology and functions of organs and thereby allowing physicians to accurately diagnose the problem.

A computer-enhanced image can then be generated which will provide information about the patient's body and organs and in turn diagnose various heart, kidney, lung, liver and thyroid conditions and some bone cancers.

The other two main radiopharmaceuticals produced are iodine-131, which is used to treat hyperthyroidism and in the diagnosis and treatment of thyroid cancer, and thallium-201, which is used to detect the location of damaged heart muscle.

Radiopharmaceuticals can be used for both diagnosis and treatment. When used diagnostically, the information obtained is usually different to that obtained from scans like X-rays, in that the actual chemical functioning of the body is seen as the radiopharmaceutical is metabolised. The radioactive component is often specially chosen to minimise the radiation received by the patient.

ANSTO produces the important radiopharmaceutical molybdenum-99, which decays into technetium-99m. Technetium-99m is the basis of 80 per cent of all nuclear medicine procedures.

Radiopharmaceutical production facilities

Numerous measures are taken to protect staff working in radioactive areas including safety shielding and protective clothing. Staff also wear personal radiation monitoring devices.

Due to the short half-life of radiopharmaceuticals, they must be dispatched urgently to hospital around Australia and overseas.

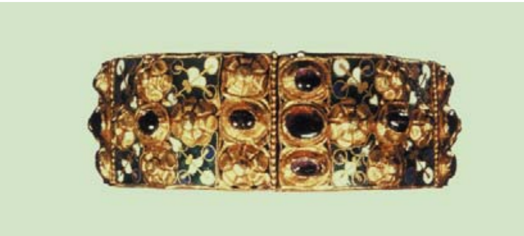
An average of 3,000 medical isotope shipments are dispatched from ANSTO each month.

When used for treatment, the radioactive component of the radiopharmaceutical is chosen for its ability to give a dose of radiation to the organ being treated.

ANSTO produces more than 80 per cent of the annual diagnostic nuclear medicine for procedures in Australia. All products are manufactured in 'clean rooms' and in ‘hot cells’ using remote handling techniques. All the processes in manufacturing the radiophamarmaceuticals comply with strict quality assurance programs.

A trolley of urgent medical supplies is taken to dispatch.

Scientific facilities and equipment



ANTARES, was used to date Charlemagne's crown to between 700 and 780 AD.

ANTARES is used for ion beam analysis and accelerator mass spectrometry.

Accelerators

Accelerators are used to analyse materials - often using extremely small samples - to determine their elemental composition and age.

ANSTO has two accelerators, ANTARES and STAR, both of which are used in ion beam analysis and accelerator mass spectrometry.

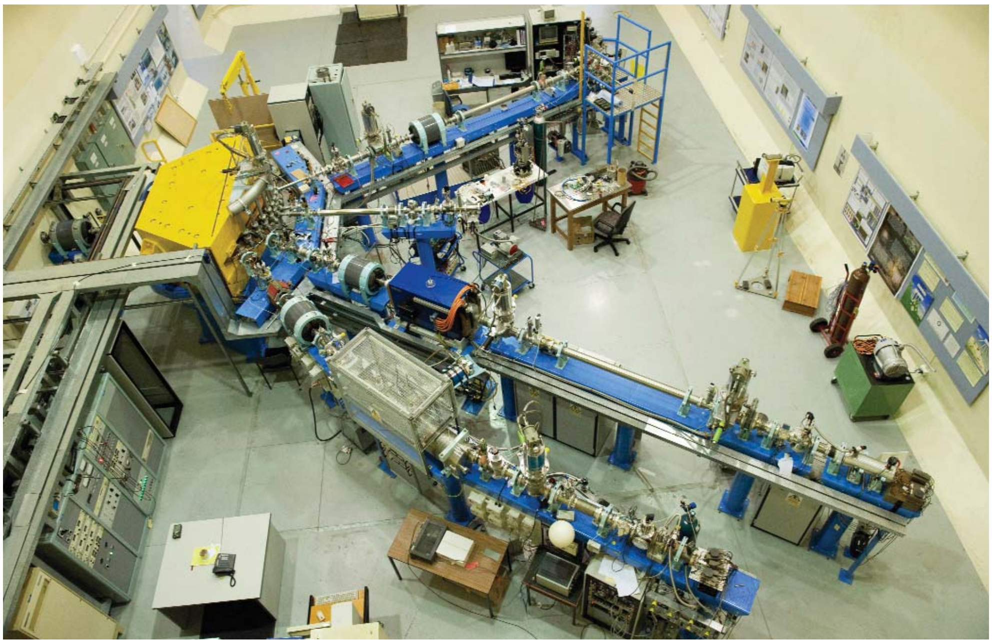
Tandem particle accelerators have three main parts: an 'ion source', where particles are given a negative charge, the 'accelerator', where high voltages are used to accelerate the charged ions and an experimental chamber, at the end of the 'beam line'. The negatively charged particles produced in the ion source are accelerated towards the central terminal in the accelerator, which is at a very high positive voltage. Here they are made to pass through an 'electron stripper', where the charge is changed from negative to positive: this is why it is called a 'tandem accelerator'. The positive ions are then accelerated away from the terminal towards the end of the beam line.

ANTARES

ANTARES (The Australian National Tandem Accelerator for Applied Research) is used by ANSTO scientists in dating and identification of elements such as radiocarbon dating.

ANTARES can be used in beam analysis where the objective is to determine what type of elements the sample is made from and how atoms are distributed throughout the sample. It is a very fast, sensitive and non destructive method. Ion beam analysis fires a fast moving beam of positively charged ions at a sample to find out what elements are present in a range of biological, geological and man-made materials. When a high energy ion beam hits the sample, it interacts with the sample's atoms and provides the basis for analysis.

ANTARES is also used for accelerator mass spectrometry, which is a technique used to detect minute quantities of radioisotopes in



ANTARES has carried out thousands of radiocarbon dating projects, on objects up to 50,000 years old.

ANTARES dated the Venetian lagoon to 1300 years old.

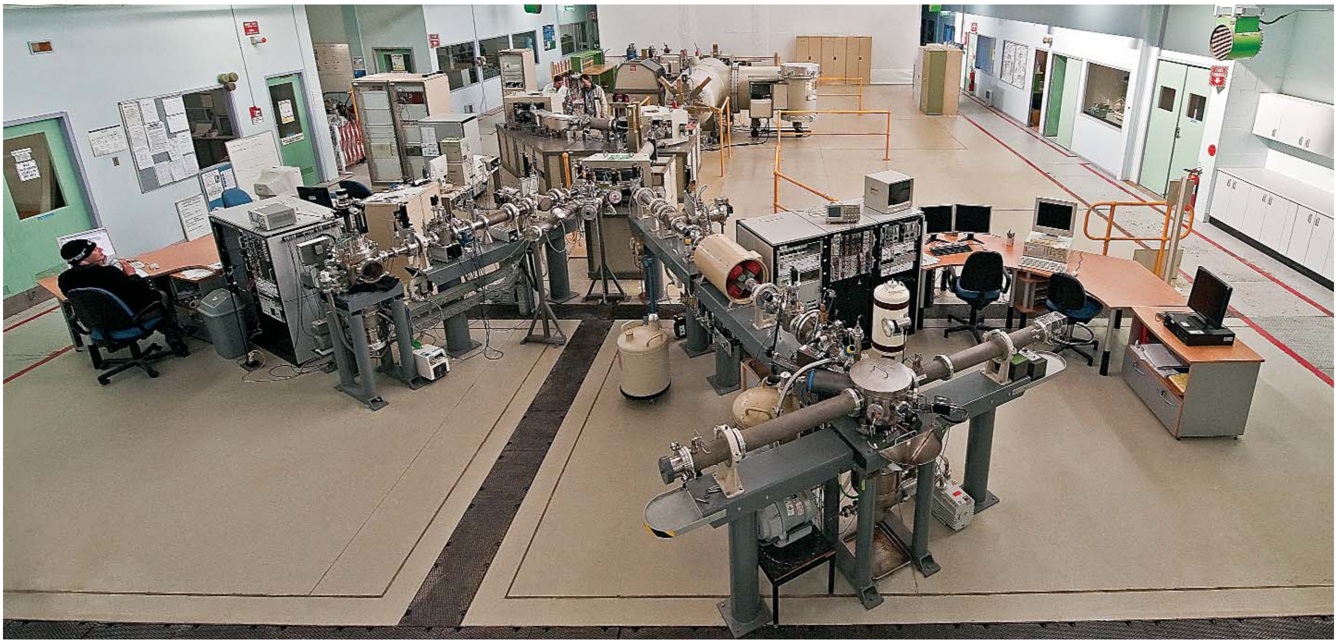
samples. Most of these radioisotopes are naturally produced in the atmosphere and the surface of the Earth by cosmic radiation. Their measurement gives insight into many natural processes such as the carbon cycle, climate and geological processes. Some are produced through the use of nuclear technologies and may be used to determine the safe operation of nuclear facilities or to reveal the clandestine production of nuclear weapons. ANSTO scientists also use ANTARES to radiocarbon date objects for climatologists, anthropologists and archaeologists.

Radiocarbon dating is based on the decay rate of the naturally occurring unstable radioisotope carbon-14, which is a natural radioactive form of carbon. Radiocarbon enters the food chain as radiocarbon dioxide when it is absorbed by living plants during photosynthesis, just like normal carbon dioxide. After plants die or they are consumed by other organisms, the carbon exchange stops and the residual carbon-14 concentration in the organic samples can be calculated to establish the likely age of the sample. ANTARES has carried out thousands of radiocarbon dating projects on objects up to 50,000 years old.

For example, ANTARES has been used to investigate the age of microscopic sea creatures found in sediment in Venice's lagoon. The results suggested the reservoir age of the lagoon was 1300 years.

In another project, ANTARES was used to authenticate and age the Crown of the Holy Roman Emperor, Charlemagne. The high precision analysis performed at ANSTO dated the Crown to between 700 and 780 AD, close to the time Charlemagne lived.

ANTARES is an extremely valuable scientific tool.



STAR is a compact accelerator designed for ion beam analysis and accelerator mass spectrometry.

STAR

STAR (Small Tandem for Applied Research) is a tandem particle accelerator used for the analysis of a diverse range of materials.

A compact accelerator, STAR has been designed specifically for dual functionality providing both ion beam analysis and accelerator mass spectrometry.

Ion beam analysis is used to find out about the nature of the sample – what type of atomic elements make it up and how those atoms are distributed throughout it.

Accelerator mass spectrometry uses the accelerator as a sensitive mass spectrometer, allowing the detection of as little as one atom amongst 10 trillion other less-interesting atoms.

When conducting ion beam analysis, STAR directs a fast moving beam of ions at the sample being studied. When the high energy ion beam hits the sample, it interacts with the atom's electrons and nucleus. This causes the atom to emit X-rays and gamma rays, which reveals which elements are in the sample. The ions fired at the sample also bounce off the sample atom's nucleus, providing information on the location and mass of atoms in the sample.

STAR can analyse less than a picogram (a trillionth of a gram) of material in a few minutes for up to 30 different elements. The technique also allows the surface layers of samples to be depth profiled. This allows scientists to see what elements are present at different depths within the sample.

When conducting accelerator mass spectrometry, STAR accelerates charged atoms from the sample which are separated by mass, energy and charge using electrostatic and magnetic analysers. Finally, nuclear particle detection techniques allow individual atoms to be counted as they enter the ionisation detector. This permits precise measurement of the amount of a radioisotope in a sample, at very low levels.

Each isotope has a specific mass, for example carbon-14 has a mass of 14 atomic mass units and therefore separating atoms from the sample by mass indicates what isotopes are present in it. Isotopes with the same mass from different elements ('isobars') are differentiated by their atomic number. ANSTO scientists use this capability on STAR to carbon date objects, as well as analyse samples in climatology research, nuclear safeguards studies and geological dating.

Being located at Lucas Heights allows quick access to the airport for transport to hospitals and nuclear medicine centres.

The two mini-cyclotrons will produce a short-lived glucose radiopharmaceutical used in positron emission tomography (PET) scanning.

Twin mini-cyclotrons

ANSTO's wholly owned subsidiary PETNET Solutions has two mini cyclotrons at Lucas Heights which are specifically used to produce a short-lived glucose radiopharmaceutical used in positron emission tomography (PET) scanning. These state-of-the-art facilities produce and distribute radiopharmaceuticals to hospitals, clinics, and research facilities for PET imaging.

PET is a nuclear medicine diagnostic technique which has produced significant advances in the diagnosis of cancer and other major medical conditions as it allows doctors to see disease at its earliest stage and precisely determine and monitor treatment.

Rapid and reliable delivery of high quality PET imaging radioisotopes is essential for the successful operation of a PET practice. The half-life of the radiopharmaceutical is 110 minutes, meaning that it loses half of its activity every two hours. The twin cyclotron facility ensures that supplies of this essential product can be reliably maintained.

Close proximity to the airport enables quick air transport to hospitals and nuclear medicine clinics across NSW.

Items are irradiated inside a room with thick concrete walls and door.

GATRI's operator controls the movement of the radioactive source from outside the facility's concrete walls.

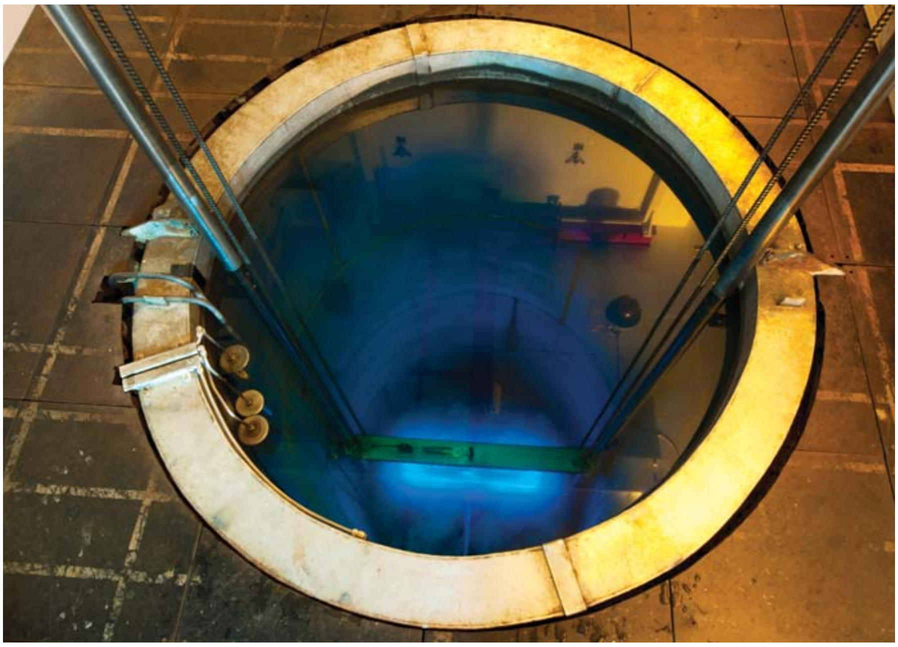
Irradiation facility

ANSTO has an irradiation facility which is used to treat items for medical, health, industry, agriculture and research purposes.

The facility, known as GATRI (Gamma Technology Research Irradiator), provides a comprehensive range of irradiation services including:

- Treatment of frozen human bone and tendons for transplants and grafting in surgery - bones can be processed to ensure they are completely sterile before the transplant takes place so they do not transmit infections. Irradiation is the best method for destroying any residual bacteria without damaging the bone
- Irradiation of the Queensland fruit fly - to help control infestations in commercial growing areas in NSW, Victoria and South Australia. Irradiation is an alternative to spraying toxic pesticides. Laboratory-reared fruit flies are sterilised in GATRI and when they are released in the target region and mate with flies of the pest population, they create no offspring, thus reducing the population
- Irradiation of quarantine goods – GATRI is an Australian Quarantine Approved Premises facility for irradiating research samples such as soil and sediment samples from overseas, even ice core samples from Antarctica
- Plant mutation studies – GATRI has been used to produce seedless mandarins, change the colour of flowers and to make commercial crops more resistant to climate extremes
- Irradiation of medical products – including bandages, cotton tips, eye pads, catheters and medical devices such as knee implants are irradiated in GATRI to very precise doses of radiation. ANSTO's expertise includes the accurate and reliable measurement of these high doses of radiation. Manufacturers must then test those products to assure sterility before use in hospitals
- Accelerating long term effects upon irradiation of products such as plastics and electronics.

The radiation dose and temperature can be accurately controlled.



The cobalt-60 radioactive source is kept in a water storage pool. The source is raised out of the pool for irradiation to take place. The blue glow is Cerenkov radiation, generated from the interaction of gamma radiation in water.

The most common source of gamma rays for irradiation is cobalt-60, which is what GATRI uses. Gamma rays are a form of electromagnetic radiation, similar to X-rays but much more energetic.

Gamma irradiation works by creating chemical changes in materials. In living organisms, this can result in damage to cells and in breakdown of DNA. Gamma irradiation is also particularly suited to materials which would normally deteriorate under heat treatment.

Items to be irradiated are placed in a concrete room in which the radioactive source is raised out of a water storage pool normally used to shield gamma radiation. Items are irradiated for several minutes or hours depending on the dose required.

ANSTO is able to accurately control the radiation dose as well as temperature, allowing users to perform irradiations under specific conditions, including temperature irradiations down to –78° Celsius.

The precision irradiation services, dose measurement and controlled temperature capabilities provided by GATRI are unique in Australia.

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Nuclear-based science benefiting all Australians

The Australian Nuclear Science and Technology Organisation (ANSTO) is the home of Australia's nuclear science expertise. This unique expertise is applied to radiopharmaceutical production and research, climate change research, water resource management, materials engineering, neutron scattering and a range of other scientific research disciplines.

ANSTO is a Federal Government agency and operates Australia's only nuclear reactor OPAL - used for research and isotope production. ANSTO applies nuclear science in a wide range of areas for the benefit of all Australians.

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ANSTO produces regular updates on our science and technology, has available a range of publications and conducts free tours of our site for school groups, community groups and members of the public. For bookings or more information, please contact us.

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