EXPLAINER

OPAL

ANSTO operates Australia's most significant landmark and national scientific infrastructure.

Over its 70+ year history, ANSTO has commissioned and operated Australia's only three nuclear research reactors from its Lucas Heights campus in Sydney.

Starting with HIFAR (1958 – 2007) and Moata in (1961 – 1995), ANSTO's current research reactor, the Open Pool Australian Lightwater (OPAL) multi-purpose research reactor formally commenced operations in 2007. It remains one of the world's most modern nuclear research reactors.

OPAL is one of a small number of reactors around the world with the capacity to produce commercial quantities of radioisotopes, and for this reason, it is the centrepiece to some of ANSTO's facilities at Lucas Heights.

Operating as a 'neutron factory', OPAL provides the radioisotopes for life-saving nuclear medicines for cancer detection and treatment, irradiates silicon for use in advanced electronics and green technologies, and produces neutrons for materials research.

About OPAL

OPAL is a state-of-the-art 20 megawatt multi-purpose research reactor that uses low enriched uranium-235 fuel.

This fuel sits at the heart of the reactor in a compact core of 16 fuel assemblies (30 kilograms) arranged in a four-by-four array. The core is interspersed with 5 control rods that regulate the reactor's power and shutdown capabilities.

The reactor's core sits at the bottom of a 13-metre deep open pool of water. Demineralised light water (H2O) cools the fuel assemblies, and these assembles are surrounded by a zirconium alloy 'reflector' vessel that contains a special type of heavy water (deuterium oxide, or D2O). This reflector vessel is also positioned at the bottom of the 13-metre pool of light water.

The depth of the water paired with the lined sides of the pool, acts as a very effective radiation shield to protect staff working at the surface of the pool.

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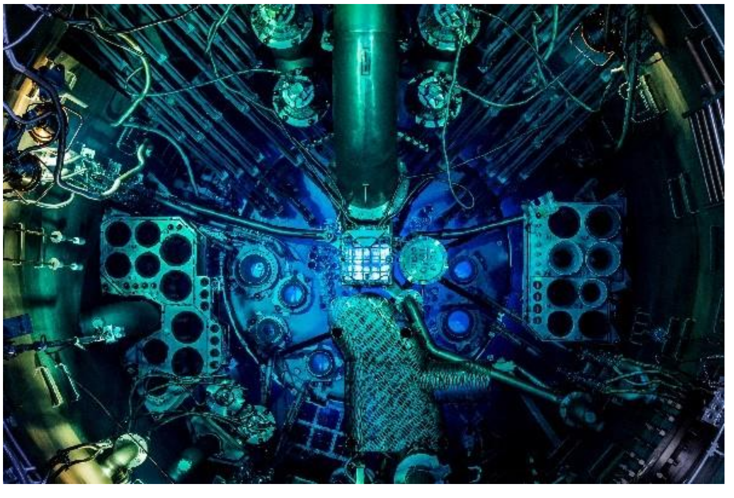
The open pool design also enables workers standing above the pool to easily see and manipulate items inside the reactor.

While OPAL runs for 24 hours a day, ANSTO aims to operate the reactor for 300 days each calendar year.

OPAL typically operates in cycles of 30 – 35 days, followed by a short re-fuelling outage to remove the spent fuel assemblies and replace them with new fuel assemblies. Routine maintenance and inspections are also carried out during these planned shutdowns.



Left: View from the top of the OPAL pool

How OPAL operates

OPAL applies the science of nuclear fission.

Through fission, the nucleus of an atom of uranium-235 (in the fuel) splits into smaller atoms generating new neutrons. These extra neutrons hit other surrounding uranium-235 atoms, which in turn, split and generate additional neutrons. This multiplying effect creates a chain reaction in a fraction of a second.

For fission to support this chain reaction, the neutrons need to be moderated (slowed down) and reflected back into the fuel. These neutrons are what scientists and engineers use for neutron beam research and irradiation of materials such as silicon.

OPAL cannot produce electricity. It was not designed to be capable of producing electricity, nor can it be modified to do so.

Under the basic principles of physics, each time a reaction occurs, there is a natural release of energy in the form of heat and radiation.

In a nuclear power reactor, this energy will heat the water at several hundreds of degrees Celsius, turning it into steam which causes the turbines to spin and generate electricity.

However, the energy output of OPAL is only enough to warm the water within the reactor pool to about 40 degrees Celsius. OPAL can only generate around 20 megawatts of heat, or about 1 per cent of the heat energy compared to a large nuclear power reactor.

The centrepiece of ANSTO's facilities

OPAL is a multi-purpose research reactor, meaning it has variable applications for use in scientific research and industry activities.

The reactor is the centrepiece to some of ANSTO's research and commercial operations at Lucas Heights.

Nuclear medicines

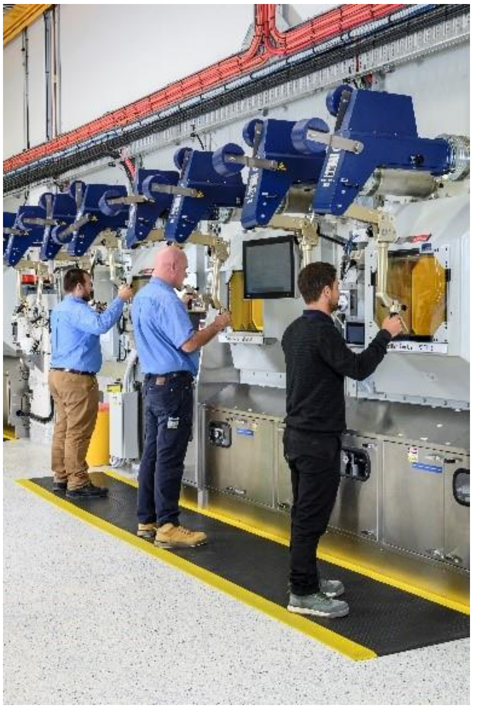
ANSTO's nuclear medicine precinct at Lucas Heights supplies around 75 - 80 per cent of Australia's nuclear medicines, used in the diagnosis, staging, and treatment of diseases like cancer, heart disease, and other medical conditions.

Every Australian is likely to benefit from nuclear medicine, and on average, will require at least two nuclear medicine procedures in their lifetime. The radioisotopes produced at ANSTO enables around 10,000 – 12,000 nuclear medicine procedures each week.

The production of nuclear medicine starts at OPAL. Uranium alloy targets are lowered into the OPAL reactor where fission occurs to irradiate the targets and produce a range of fission products, including the radioisotope molybdenum-99 (Mo-99).

These irradiated uranium targets are then taken to a nearby manufacturing facility where the Mo-99 is separated out and extracted in liquid form to produce the nuclear medicine.

Read more in our Nuclear Medicines explainer.



Above: Producing Mo-99 using hot cells and arm manipulators

Above: Gentech® Generator and vials of Mo-99

Above: Patient undergoing an imaging scan at Royal North Shore Hospital

Silicon irradiation

Through OPAL, ANSTO is the world's largest supplier of irradiated silicon. ANSTO began irradiating silicon in 1985, and supplies high-end, advanced manufacturing industries all over the world, with the greatest demand coming from Europe and Japan.

Silicon irradiation is also known as Neutron Transmutation Doping and is conducted in the OPAL reactor.

Silicon ingots, similar in appearance to mirror-like metal cylinders, are lowered into the OPAL pool where they are targeted with neutrons over a period of time – anywhere from a few hours to several days. During the neutron transmutation doping process, the thermal neutrons react with the silicon atoms, changing some of those atoms to phosphorous, an element which improves its ability to conduct electricity.

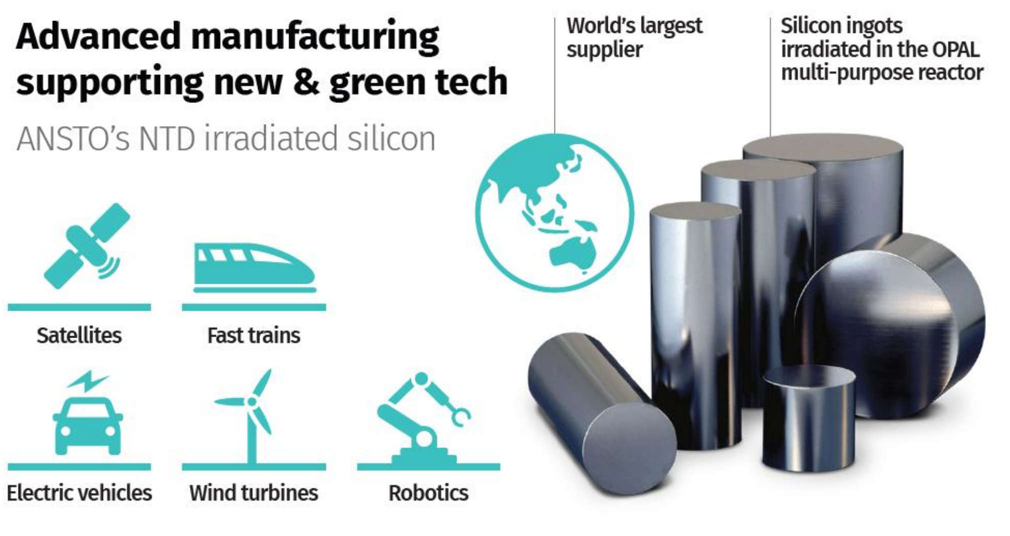
Phosphorus atoms introduce free electrons into the crystal lattice which enhances conductivity. The more phosphorus and the more free electrons, means the more electrically conductive the material becomes.

After the silicon ingots have been removed, they are transferred to the OPAL service pool for 48 hours, where they are cooled to allow radioactivity decay to a level that is safe for handling and transporting. From here, they are cleaned, undergo quality checks, and are packaged for distribution to ANSTO's silicon customers around the world. The silicon is later sliced into wafers for use in a variety of applications by the electronics industry.

ANSTO's silicon business is predominately driven by the demand for power semiconductors. These semiconductor devices use irradiated silicon to control and manipulate the flow of high voltage / high current electrical systems and networks.

There is also demand for irradiated silicon in insulated-gate bipolar transistors, which are power semiconductors that act as electronic switching devices.

These devices are common in a range of high-power semiconductor applications, such as high-speed trains, electric vehicles, power grid infrastructure, and wind turbine systems.



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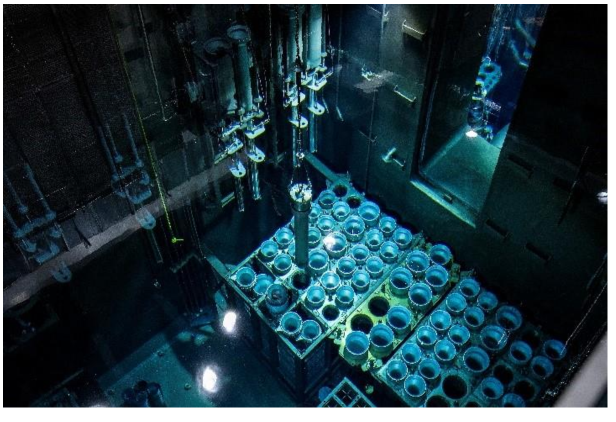

Above Left and Right: Silicon ingots being prepared for irradiation in OPAL and undergoing a quality check

Left: Silicon ingots being irradiated in the OPAL pool

Scientific research

Located adjacent to the OPAL reactor, the Australian Centre for Neutron Scattering (ACNS) harnesses the power of neutrons to deliver research outcomes for science, health, and industry.

The ACNS is the home of neutron science in Australia, and a major research facility in the world and the leading facility in the Asia-Oceanic region. Each year, the ACNS is accessed by hundreds of researchers and industry partners from across Australia and the world.

ACNS is home to 15 neutron instruments to enable scientific investigations in chemistry, medicine, materials science, and environmental science.

The research carried out at the ACNS assists scientists to solve complex problems across a wide range of fields, including energy storage, stresses in metal components, food allergies, and human viruses.

Neutrons produced inside the OPAL reactor pool travel directly through a number of beam tubes and neutron guides to reach this suite of neutron beam instruments in the ACNS facility, enabling researchers and industry partners to study the structure and dynamics of atoms and molecules samples, such as polymers, proteins, and viruses.

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Neutron beam instruments have the potential to reveal much more about the structure of solids and liquids than other investigative methods. These instruments help scientists to understand why materials have the properties they do and tailor new materials, devices, and systems.

The 15 neutron beam instruments are classified into four main groups: diffractometers, small-angle spectrometers, imaging and reflectometry instruments, and inelastic spectrometers.

Right: The Neutron Guide Hall at the Australian Centre for Neutron Scattering, ANSTO

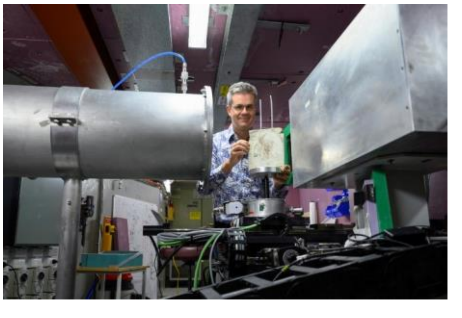
Why do we use neutrons?

Neutrons have no electrical charge and they penetrate materials more effectively than X-rays.

Neutrons can penetrate most materials to depths of several centimetres, compared to X-rays and electrons which can only probe near the surface. Importantly, neutrons are non-invasive so they won't damage the surface or structure of the materials studied, and they don't change the structure of the sample by depositing energy into it.

Neutrons are also scattered by atomic nuclei, whereas X-rays and electrons are scattered by atomic electrons. The point of difference lies in the scattering from light elements. For instance, an electron on a hydrogen atom can be hard to find by X-ray or electron diffraction, but the hydrogen nucleus scatters neutrons much more strongly and is easily found by a neutron diffraction experiment.

This makes them an especially valuable tool in industrial materials analysis. Neutron scattering is a technique used to find answers to fundamental questions about the structure and composition of materials used in medicines, mining, transportation infrastructure, construction, engineering, food processing, and scientific research.



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Australia's earliest nuclear reactors

ANSTO has commissioned and operated Australia's only three nuclear research reactors over its 70+ year history, including HIFAR, Moata, and the current reactor OPAL.

HIFAR

ANSTO's predecessor, the Australian Atomic Energy Commission (AAEC) was established shortly after the implementation of the Atomic Energy Act in 1953.

Construction on Australia's first national research reactor, **HIFAR (High Flux Australian Reactor)** at Lucas Heights commenced in 1955 and the reactor went critical on 26 January 1958. HIFAR was officially unveiled by Australian Prime Minister Sir Robert Menzies on 18 April 1958 in front of 900 staff and invited guests.

HIFAR was central to the research carried out at ANSTO, and operated safely and reliably for almost 50 years until 2007 when it was superseded by the current reactor, OPAL.

As a 10 megawatt research reactor understood to be based on the DIDO reactor at Harwell in the UK, HIFAR was cooled and moderated by heavy water, and 25 fuel elements in its reactor core contained 7 kilograms of enriched uranium.

Around 3,000 tonnes of concrete were poured into the foundations of the reactor, with 10 tonnes of heavy water surrounding the core.

Top: HIFAR, photographed by Max Dupain

Far Right: Inside HIFAR, photographed by Max Dupain

Bottom: Sir Robert Menzies officially opening HIFAR, 1958

HIFAR was originally built for the purpose of testing materials for use in future nuclear power reactors – a reflection of Australia's industrial and economic priorities at the time. In 1972, Australia ceased its pursuit of a nuclear power program, and HIFAR's purpose evolved into producing neutrons for nuclear medicine production, irradiating silicon for the global semiconductor industry, and for scientific use.

Similar to OPAL, neutrons were produced in HIFAR from the fission of uranium atoms.

In 1960, HIFAR reached two milestones: it was taken up to full power, and produced its first medical isotope, Sodium-24, which was used as a radiotracer in pregnant women to measure the transfer of sodium to the fetus.

Following its official operational shutdown in 2007, the HIFAR reactor remains at Lucas Heights. All spent fuel and heavy water have since been removed from within the reactor and is safely managed and stored onsite.

Following the license application approval from the Australian Radiation Protection and Nuclear Safety Agency in December 2024, ANSTO has formally commenced a decommissioning project to remove HIFAR's infrastructure and radioactive components.

Moata

Moata was the second research reactor constructed at Lucas Heights and operated successfully for 34 years from 1961 until 1995. Moata was also officially opened by Prime Minister Sir Robert Menzies in 1962.

In comparison to HIFAR, it was a much smaller research reactor at 100 kilowatts. Moata was used primarily for research and training, and later evolved for use in activation analysis and neutron radiography.

Of particular note, Moata played an important role in aircraft safety. The research reactor was used commercially for approximately 15 per cent of all procedures world-wide involving radiography to check the structural soundness of jet engine turbine blades.

Left: Sir Robert Menzies officially opening Moata, 1962

Moata was also an important tool for Australia's uranium mining industry, providing rapid and accurate measurements or ore.

Following Moata's official shutdown in 1995, it was decommissioned and dismantled in 2009, and is stored safely in shielded containers onsite at ANSTO's waste management stores.

Safety of OPAL

The OPAL multi-purpose reactor is one of the most advanced and safest research reactors in the world today.

OPAL's safety analysis meets the design safety requirements and necessary licensing requirements with ANSTO's regulators, and it has been subject to independent review and approval by the Australian Radiation Protection and Nuclear Safety Agency.

Above: The OPAL building at ANSTO

Physical security and earthquakes

OPAL is situated within ANSTO's large campus, surrounded by an uninhabited 1.6 kilometre radius buffer zone. The campus, including OPAL, is protected 24/7 by the Australian Federal Police.

The design and construction of OPAL ensures effective protection of reactor personnel, ANSTO staff, the general public, and the environment against radiological hazards. The reactor building is constructed out of reinforced concrete which provides a physical boundary in the very unlikely event of any radiation being released inside the reactor, and contains this from being emitted.

The OPAL reactor and the reactor building have been designed to withstand major earthquakes and the physical impact of large aircraft. In fact, OPAL can withstand much greater earthquake loads than other industrial buildings, high rise unit blocks, and dams. Expert geologists have confirmed that the site is geologically stable.

Reactor fuel

OPAL uses low enriched uranium fuel containing just under 20 per cent uranium-235. This offers a distinct advantage over some of the earliest research reactors which required enrichment levels as high as 95 per cent uranium-235.

The reactor core is about the size of a two-drawer filing cabinet, and sits at the bottom of a 13 metre-deep open pool filled with demineralised light water (otherwise considered as ordinary water). The pool itself is constructed from stainless steel and is embedded in a block of high-density concrete that absorbs radiation.

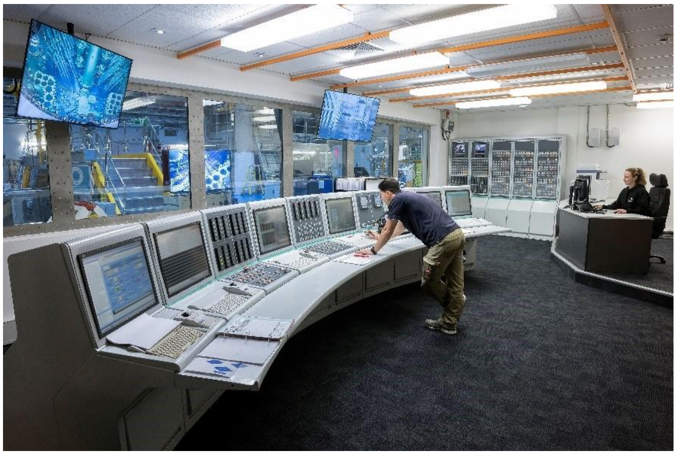
The depth of the water above the reactor core also acts as a very effective radiation shield, meaning most workers on the reactor floor only need to wear light Personal Protection Equipment.

Safety systems

OPAL has two automated safety systems that can quickly and independently shut down the reactor core in the event of an emergency.

In the first shutdown system, five control rods will drop instantly into the reactor core. The control rods contain the element hafnium, which absorbs neutrons and immediately stops their ongoing nuclear chain reaction.

The second shutdown system partially drains the heavy water from the reflector vessel. This allows more neutrons to escape the core, stopping the nuclear chain reaction.



Left: Inside the OPAL control room

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Independent reviews of OPAL

In 2021, ANSTO completed the largest coordinated safety and security review of OPAL, known as the Period Safety and Security Review. The review showed ANSTO continues to be one of the safest and most reliable research reactors in the world.

The review implemented an approach advocated by the International Atomic energy Agency (IAEA) for assessing the safety of research reactors, and Australian regulatory advice on safety and security for nuclear facilities.

It interrogated OPAL's safety and security over the previous 10-year period to provide a view on its future performance. The assessment encompassed 15 safety factors, 19 security factors, and global assessments of safety and security.