Australian Government

ANSTO

Science. Ingenuity. Sustainability.

Introduction to ANSTO

2023

Executive Summary

The Australian Nuclear Science and Technology Organisation (ANSTO) is Australia's civilian nuclear centre of excellence. It has a mandated role to advise the Australian Government on all nuclear and science technology matters. It, along with its predecessor the Australian Atomic Energy Commission (AAEC), has almost 70 years' experience in the application of nuclear science and technology, including the operation of research and multi-purpose reactors, nuclear medicine production, uranium and specialist minerals processing, radioactive waste management, and scientific and engineering support for multi-disciplinary research and operation and maintenance of our nuclear reactors and facilities.

ANSTO has over 1.5 billion AUD worth of assets under management, centred on Australia's only nuclear reactor, the Open Pool Australian Light-water (OPAL) multi-purpose reactor. Based at the main Lucas Heights campus in southern Sydney, OPAL is a 20 MW(t) reactor that produces nuclear medicines and neutrons for research, and irradiation services including neutron transmutation doped silicon for global industry. OPAL is a key part of Australia's national research infrastructure portfolio along with other ANSTO facilities including the Australian Centre for Neutron Scattering (ACNS), the Centre for Accelerator Science (CAS), and the Australian Synchrotron, this last being located at our Clayton campus in Melbourne. This blend of neutrons, particles, and x-rays uniquely positions ANSTO to enable extensive research programs in Australia and overseas servicing more than 5,000 scientists annually. These facilities also enable research at ANSTO across themes of Human Health, Nuclear Fuel Cycle and the Environment, as well as collaboration with domestic and international partners.

In addition to scientific applications, ANSTO has significant capabilities and experience in supporting the operation of reactors and other nuclear facilities. For example, we have dedicated experts in Nuclear Analysis, Nuclear Stewardship, and Nuclear Materials Development and Characterisation that are drawn on for environmental monitoring, preventative maintenance programs for OPAL, study of Generation IV reactor designs and the development of a novel waste form, Synroc®. We have sophisticated and robust nuclear safety and security processes that would be expected of a mature nuclear operator. ANSTO routinely manages, threats and stores solid, liquid, low and intermediate level wastes.

The extensive engineering experience at ANSTO is continually engaged in the design, construction and commissioning of major nuclear projects and facilities both nationally and internationally. These skills and experience also extend to decommissioning facilities and reactors. At the present time ANSTO is providing the design and consultancy services to the Australian Government in support of the establishment of the National Radioactive Waste Management Facility.

While ANSTO has significant nuclear facilities, much of our capability lies in its 1350 staff. Of this workforce, over 400 have PhDs and a significant majority are directly involved with operation or support of our nuclear facilities. Our staff are highly networked internationally and ANSTO is a member of or provides the Leadership of a range of IAEA committees and working groups. ANSTO maintains a Counsellor in Vienna in support of the Australian Permanent Mission to the IAEA

A national naval nuclear power program would undoubtedly require a very significant scale up in Australia's nuclear work force and science capabilities, in terms of scale, complexity, infrastructure, and human capacity. ANSTO has the foundational elements on which to build and sustain the nuclear industry required.

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1 Introduction

The Australian Nuclear Science and Technology Organisation (ANSTO) is home to Australia's nuclear operations, science and technology capabilities. We put science to work, delivering solutions that benefit the Australian economy and shape the industries of the future. Through our expertise and involvement in global initiatives, we maintain and develop Australia's world-class nuclear capabilities, maintain international best practice, provide trusted advice to Government and educate the community.

ANSTO provides a collaborative research environment in Australia, bringing together scientists, engineers and graduates from across industry and academia to work with and through ANSTO to solve complex problems and deliver outcomes and benefits for Australia.

We manufacture and produce nuclear medicines for Australia and the world, investigate the origins of disease, and develop new diagnostic and therapeutic nuclear medicines. Through this work, we improve human health and deliver life-saving outcomes.

We use multidisciplinary nuclear and isotopic techniques to address the world's most challenging environmental problems. Focusing on water sustainability, climate change, air quality, and the impact of contaminants, we are working together to create a more sustainable world.

As the operator of Australia's only nuclear reactor – the Open Pool Australian Light-water (OPAL) multi-purpose Reactor – we address key scientific questions in the nuclear fuel cycle and are Australia's knowledge centre for current and emerging nuclear technologies.

As an industry partner, some of our business capabilities include detection and imaging, minerals and radiation protection consulting, irradiation services, environmental monitoring and training. The ANSTO Innovation Precinct in Southern Sydney is the home of ANSTO's *nandin* Innovation Centre where over 22 start-ups are connected to ANSTO's leading research talent, including over 100 graduates, to develop the next generation of thinking that will support our industries into the future.

1.1 History

The organisation was established in 1987, replacing the then Australian Atomic Energy Commission (AAEC). The AAEC had been in operation since 1953 and oversaw the early decades of Australian nuclear science and technology, including with a focus on research for nuclear power and uranium mining and processing. Based at Lucas Heights in southern Sydney, the AAEC constructed and operated Australia's first two reactors, the High-Flux Australia Reactor (HIFAR) and the Moata reactor.

The main reactor was HIFAR, a 10 MW(t) DIDO-class reactor, operating from 1958 to 2007. It was utilised for a range of activities including radioisotope production for health and industry, and neutron scattering. The reactor was D_2O moderated and cooled, and started using fuel enriched at 93%, which was reduced in stages to low enriched uranium (LEU) in 2006. HIFAR has been defueled and is under care and maintenance awaiting decommissioning which will not occur until a national pathway for resultant waste can be confirmed.

The Moata reactor was 100 kW Argonaut-class operating from 1961 to 1995. It was initially used for research and training, and later included activation analysis and neutron radiography. The reactor was also an important tool for Australia's uranium mining industry, providing rapid and accurate measurements of ore. The reactor was successfully decommissioned in 2009.

The OPAL Reactor was constructed to replace HIFAR and achieved first criticality in 2006. OPAL is a 20 MW(t) INVAP-designed pool-type reactor that utilises low enriched uranium (LEU) for both fuel and nuclear medicine targets. OPAL is a complex, multi-purpose reactor that was designed bespoke for its purpose. It produces a range of medical radioisotopes, produces cold and thermal neutrons for a suite of 15 neutron scattering instruments, can undertake neutron activation analysis and other scientific irradiations, and produces silicon neutron transmutation doping for industry. Despite this complex operating environment, the OPAL Reactor operates on a 24/7 cycle operating at 300+ days per year, making it the leading reactor in its class globally.

In 2013, ANSTO became the operator of the Australian Synchrotron in Clayton, Melbourne. A 3 GeV facility, it is the largest of its kind in the southern hemisphere with ten beamlines supporting Australian and global research into disciplines including advanced materials, agriculture biomedicine, defence science, environmental sustainability, food and food technology, forensic science, energy industry, mining, cultural heritage, planetary science, and electronics. The Australian Synchrotron has played a key role in the characterisation of the SARS-CoV-2 virus and its interaction in the human body. It is currently undergoing expansion with an additional eight beamlines (BRIGHT project).

1.2 Governance and structure

The change from AAEC to ANSTO was facilitated with the establishing *Australian Nuclear Science and Technology Organisation Act 1987* ('the ANSTO Act'). The change broadened the organisation's activities towards non-nuclear power activities in line with Australian Government policy on nuclear power (although research is still conducted on energy systems) and the application of nuclear science techniques to a broad range of research domains.

The key functions established by the ANSTO Act include:

- undertake research and development in relation to nuclear science and nuclear technology;
- condition, manage and store radioactive materials and radioactive waste, arising from the Organisation's activities, or on request of the Commonwealth or a law enforcement agency;
- produce, acquire, provide and sell goods, and to provide services;
- liaise with other countries on nuclear science and technology;
- advise Government on nuclear science and technology; and
- engage with universities and research institutions for research.

It is noted that the ANSTO Act explicitly excludes the organisation from disposing of radioactive waste.

The Act establishes ANSTO as a Corporate Commonwealth Entity within the Department of Industry, Science, Energy and Resources (DISER), reporting to the Minister for Science and Technology, the Hon Melissa Price MP. ANSTO is led by a Board of Directors appointed by the Government and a Chief Executive Officer appointed by the Board. The Board of Directors consists of 5 to 8 members, including the CEO. The current Board Chair is the Hon Dr Annabelle Bennet AC SC, and the CEO is Mr Shaun Jenkinson.

The Hon Dr Annabelle
Bennett AC SC
Board Chair

Penelope J
Dobson
Deputy Chair

Shaun
Jenkinson
Chief Executive Officer

Emeritus Professor
Stephen
Buckman AM

Professor Brigid
Heywood

Andrea
Sutton

Gordon John
de Brouwer PSM

Greg
Storr

ANSTO's Board of Directors.

ANSTO is funded through a mix of Commonwealth budgetary appropriations and revenue from the sale of commercial products and services such as nuclear medicines, silicon neutron irradiations. ANSTO's income in FY2020-21 was $390 million AUD, with just over 70% from Government appropriations.

ANSTO outlines how it achieves its functions through a Corporate Plan. This Plan outlines three Strategic Imperatives for the organisation:

1. **Research and research infrastructure –**
   To conduct research and enable external use of our research capability and infrastructure for the national benefit
2. **Commercial products and services –**
   To provide nuclear medicines and commercial services for the benefit of Australia and the world
3. **Expert and trusted advisor –**
   To be an expert and trusted advisor to government, industry, international partners, and the Australian public

ANSTO employs approximately 1,350 staff

ANSTO employs approximately 1350 staff, with most of those based at the Lucas Heights campus. Approximately 400 staff have PhDs. Staff are attributed across seven operational areas as outlined in Table 1.

TABLE 1 –
ANSTO operational areas and staffing levels

Operational area	Staff
Nuclear Science and Technology Delivers ANSTO's research programs in Nuclear Fuel Cycle, Human Health, and Environment, as well as operation of and access to research infrastructure.	**475**
Commercial Products and Services Delivery of commercial products and services including silicon irradiations, radiation protection training and consultancy services and ANSTO Minerals.	**41**
Nuclear Operations and Nuclear Medicine Responsible for operation of the OPAL Reactor, nuclear medicine production, and waste operations.	**400**
Asset Management and Engineering Oversees maintenance and engineering activities across site, including delivery and implementation of major nuclear engineering projects.	**179**
Chief Operating Officer Group Includes Legal Services, Finance and Operational Services, Risk and Audit, Government and International Affairs, People, Performance and Capability, Communications and Stakeholder Engagement, Governance and Compliance.	**131**
Information Technology Provision of IT services, capabilities, advice, and security for the organisation.	**62**
Office of the CEO Oversee Safety (including radiation safety) and security management, interactions with the Board of Directions, the Chief Nuclear Officer and engagement with the Generation IV International Forum.	**64**
Total	**1,352**

2 Description of major facilities

ANSTO operates over 1.5 Billion AUD in infrastructure and assets to support its functions including science and research, nuclear medicine production, waste operations and other activities. The following section describes some of these facilities in detail that may be of interest to support in developing a naval propulsion program.

2.1 OPAL

The OPAL Reactor is a complex, state of the art 20 MW(t) multi-purpose reactor designed and constructed to meet Australia's current and future needs for a neutron source. Its current uses include:

a. Operating as a high reliability production reactor for 300 days-a-year as part of the global supply chain for nuclear medicine production.

b. Providing thermal and cold spectrum neutron beams for the scientific community and a regional centre of excellence in neutron science.

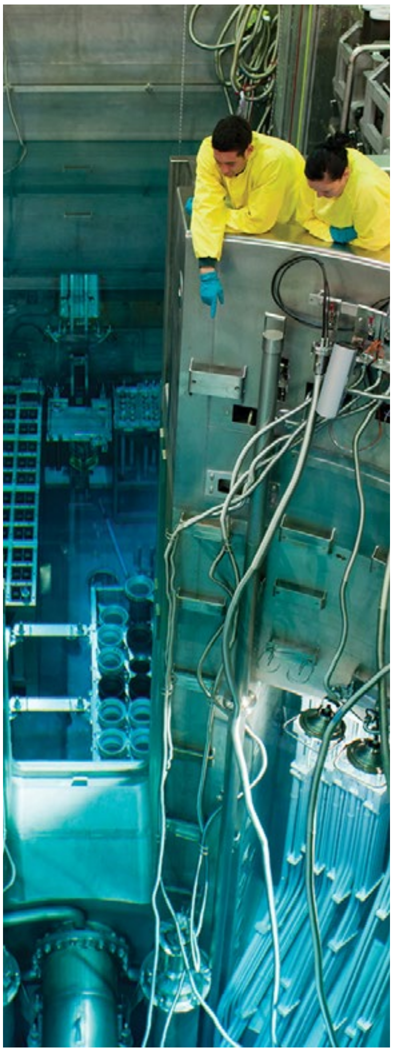
c. Industrial applications for neutrons via Neutron Transmutation Doping (NTD) of silicon for the electronics industry, Neutron Activation Analysis (NAA), and Delayed Neutron Activation Analysis (DNAA) for mining applications.

d. As a research and training facility to enhance and promote educational opportunities in Science Technology Engineering and Mathematics (STEM) for students from primary education through to post-doctorate studies.

e. To maintain Australia's technical expertise in nuclear science and technology, enabling the provision of sound advice to Government in support of the strategic national interest and honour international obligations.

OPAL is a licenced nuclear installation from the Australian regulatory body, the Australian Radiation Protection and Nuclear Safety Agency (ARPANSA). It achieved first criticality on 12 August 2006 replacing HIFAR, which was subsequently shut down on 30 January 2007. The reactor is a pool-type design with a rated thermal power from the core of 20 MW operating on low-enriched uranium (LEU) fuel. It includes operational and safety characteristics consistent with international best practice based upon the principle of "defence-in-depth". The reactor core located near the bottom of the pool is cooled and moderated by demineralised light water (H_2O), with a separate heavy water (D_2O) reflector contained in a cylindrical zircalloy Reflector Vessel that surrounds the core.

ANSTO assumed Design Authority for the OPAL Reactor following practical completion of the contract, taking over from INVAP and reflecting our deep understanding of the reactor and its operation. Indeed, ANSTO's success in operating OPAL is now highly sought after globally by vendors tendering for other multi-purpose reactor projects.



The OPAL reactor pool.

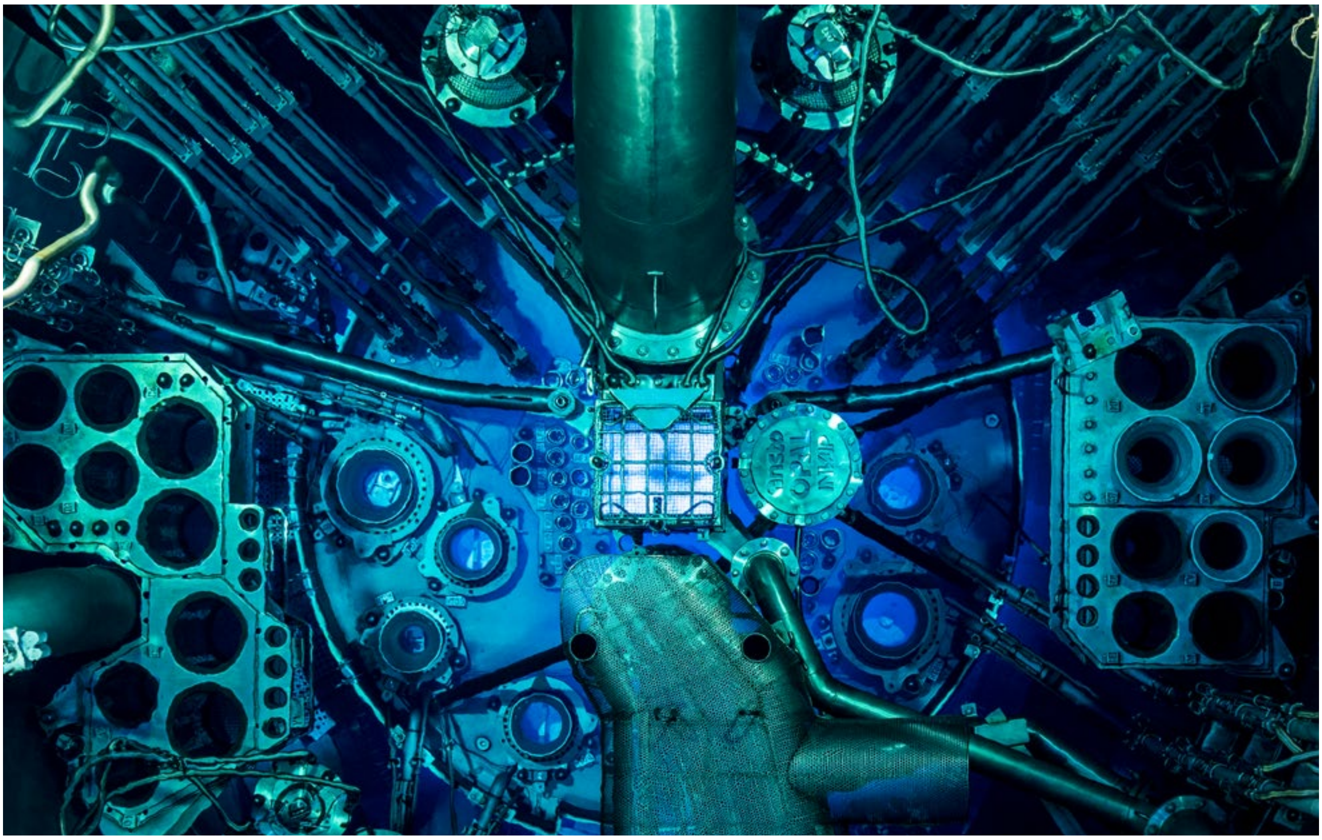
2.1.1 Reactor design

2.1.1.1 Reactor core


Replica OPAL fuel rod.

The reactor has a compact core to maximise the flux of neutrons available for radioisotope production and scientific research. The core consists of 16 box type fuel assemblies (FA) with 19.75% LEU arranged in a 4x4 array. Each FA is made from 21 fuel plates of uranium silicide (U3Si2) dispersed in an aluminium matrix at a density of 4.8 g/cm^3 sandwiched between aluminium cladding to contain the fission products. Fission heat is removed by water circulating through coolant channels between the fuel assemblies. Reactivity is controlled by five hafnium control rod plates, four of which have neutron-absorber plates inserted into the core in a cross-shaped array and the fifth has a central cruciform shaped absorber plate. The core is thus divided into four portions of four fuel assemblies each.

Reactor shutdown is guaranteed under all design conditions via two diverse, independent, and redundant shutdown system. The First Shutdown System (FSS) operates to rapidly insert the five-control rod plate adsorbers in under 900 ms into the core when requested by the First Reactor Protection System (FRPS). The Second Shutdown System (SSS) provides the alternative means of fast reactor shutdown when requested by the Second Reactor Protection System (SRPS) by increasing the core neutron leakage due to the partial gravity drainage of the 5.4 m^3 of heavy water contained in the Reflector Vessel that surrounds the core.

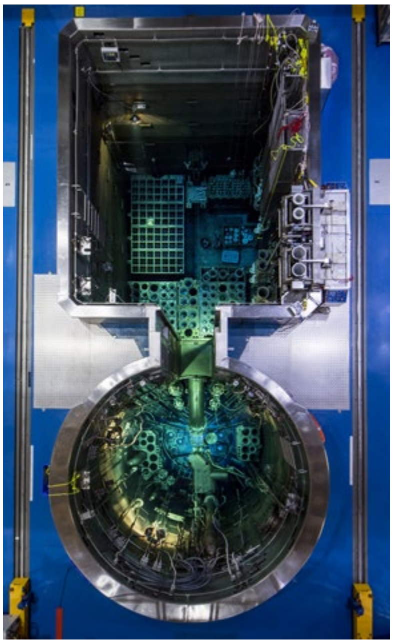

ANSTO's OPAL multi-purpose reactor.

2.1.1.2 Coolant and purification systems

The reactor core is located in a 12.6m deep Reactor Pool (RPO) of demineralised light water which is connected to a Service Pool (SPO) used for the storage of spent fuel and handling of irradiation materials. Heat is removed from the core in either a forced circulation mode whilst operating at power, or natural circulation mode via a series of flap valves within the pool when the reactor is shutdown. In the power state, water is circulated by the Primary Cooling System (PCS) pumps at a flow rate of 1900 m^3/h through the core to remove heat and transfer it to the atmosphere via a series of heat exchangers and cooling towers. In full power operation, the core power density is 250 kW/L. The pool water is continuously purified by passing through filters and nuclear grade mixed bed ion exchange resins to ensure pool water contamination levels are maintained at a minimum in line with ALARP principles.

The Reflector Vessel which contains the heavy water is equipped with its own separate heavy water-cooling systems, ion exchange resin beds, deuterium catalytic recombination system and an isotopic purification system via vacuum distillation technology to maintain the purity of the D_2O.

The reactor also has separate cooling systems for the irradiation facilities, a dedicated pool hot water layer system to minimise pool top dose rates to personnel, a demineralised water system to produce high quality pool water make-up due to evaporative losses and a passive emergency make-up water system to supply water in the event of a loss of coolant accident from the reactor pool.



Top view of the OPAL pool.

2.1.1.3 Instrumentation and electrical systems

The reactor is a highly instrumented modern plant that has continuously updated the separate systems for reactor control, reactor shutdown and post-accident monitoring functions. The main three system are:

a. **Reactor Protection Systems (RPS):** Safety Category 1 systems that includes all electrical and mechanical devices and circuits for the First and Second Reactor Protection Systems that generate signals associated with protective functions. The FRPS is a digital safety system that actuates the FSS (control rod insertion) and the reactor building containment isolation function. At power there are 13 main separate and triplicated signals that can actuate the FSS. The SRPS is an analogue safety system that actuates the SSS. At power there are 8 main separate and triplicated signals that can actuate the SSS.

b. **Post-Accident Monitoring (PAM) System:** A Safety Category 1 system that includes all electrical components required to monitor conditions of the facility during and after an accident. These includes monitoring that the reactor shutdown systems and containment isolation functions have actuated successfully.

c. **Reactor Control and Monitoring System (RCMS):** Includes all the components required for reactor process control and monitoring during normal operation and plant incidents; there are up to 5,000 input/output signals from this system. It is the main interface for plant operations through the main console in the Main Control Room (MCR) and is a Safety Category 2 system.

The reactor is also equipped with its own triplicated Uninterruptable Power Supply (UPS) units for safety critical instrumentation. These are connected to the electrical standby power system which is powered from two dedicated reactor emergency diesel generators with a nameplate rating of 833 kW, in this way the reactor is designed for loss of offsite power events.

2.1.1.4 Irradiation facilities

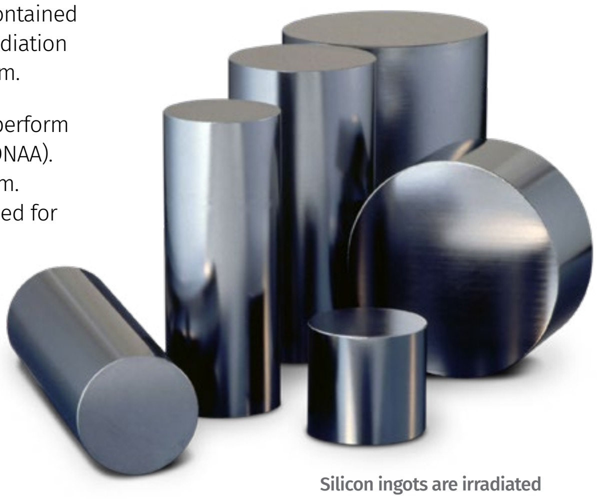
The multi-purpose reactor design incorporates a range of irradiation facilities for production, including:

a. **Bulk Irradiation Facilities (BIF):** For the irradiation of target materials in removable rigs located within irradiation tubes within the Reflector Vessel. There are 12 Low Flux (LF) positions, 3 Medium Flux (MF) positions, and 2 High Flux (HF) positions for the irradiation of medical and industrial isotopes. The rigs are handled remotely by operators standing at the Operations Bridge that runs above the RPO and the SPO before being transferred through the hot cell complex to be further processed at ANSTO prior to customer dispatch. These facilities are primarily used for the production of Molybdenum-99 (Mo-99), Iodine-131 and Lutetium-177.

b. **Long Residence Time (LRT) facilities:** For the irradiation of target materials contained in sealed irradiation cans. These are transferred into/out of one of the 55 irradiation positions in the Reflector Vessel through a nitrogen pneumatic transfer system.

c. **Short Residence Time (SRT) facilities:** Two irradiation positions designed to perform Neutron Activation Analysis (NAA) and Delayed Neutron Activation Analysis (DNAA). The target transfer is performed through a nitrogen pneumatic transfer system. Targets may be irradiated with short exposure periods (>30 sec). These are used for research and commercial mining samples.

d. **Large Volume Facilities (LVF):** are used for the commercial production of NTD silicon used in semiconductor devices. There are six facilities for the irradiation of a range of silicon ingots sized between 4 to 8 inches in diameter. ANSTO irradiates 57% of the global market of NTD silicon with 72 tonnes irradiated in 2021.



Silicon ingots are irradiated in the OPAL reactor.

2.1.1.5 Neutron beam facilities

The reactor is provided with six thermal beamlines, and four cold beamlines from the Cold Neutron Source (CNS) to produce neutrons in specific spectral ranges for research. These neutrons are extracted from their sources by specially designed neutron beams with high-technology, super-mirror inner walls. Neutrons entering the neutron guides can be transported long distances into the guide hall without significant losses.

The CNS consists of a liquid deuterium (D_2) moderator at an operating temperature of 20 K located close to the reactor core and is designed to increase the neutron yield in the “cold” energy range. The CNS is cooled by a Brayton (cryogenic) cycle using a helium cryogenic system that allows reliable and safe operation. A CNS is an advanced piece of nuclear technology operated by very few reactors in the world. It combines the challenges of cryogenic temperature operation close to the core, high radiation damage rates on materials of construction, use of a highly flammable gas close to the core and managing the reactivity impacts of temperature change. At OPAL, the CNS has been reliability running at 98% availability for the last eight years.

2.1.2 Reactor operation

OPAL typically operates for 300 days each calendar year at a reliability of 98% in cycles of 30 to 35 days, followed by a short refuelling outage to remove three spent fuel assemblies and replace them with new fuel assemblies, along with a shuffle of FAs to control reactivity and burn-up. During outages, the OPAL team performs maintenance and undertakes a series of inspections and surveillances. These refuelling outages typically last around four to six days.

OPAL typically operates for 300 days each calendar year

The reactor is one of a number of similar production facilities around the world that produce the global supply of nuclear medicine (in particular Mo-99), including the Safari-1 reactor in South Africa and the HFR reactor at Petten in the Netherlands. ANSTO collaborates with these partner reactors to maintain a 24-month forward calendar of planned reactor power and shutdown days to ensure continuation of nuclear medicine supply.

OPAL is operated on a 24/7 basis by a team of accredited shift operators who perform continuous control and monitoring from the Main Control Room. The Reactor Operations section of ANSTO that runs OPAL is comprised of approximately 127 operators, engineers, technicians, and supporting ancillary staff. The continuous safe and secure operation of the reactor is also supported by the wider ANSTO engineering and scientific expertise available onsite at Lucas Heights.

The OPAL reactor control room.

2.2 Australian Centre for Neutron Scattering

The Australian Centre for Neutron Scattering (ACNS) provides users with neutrons from Australia's multi-purpose reactor, OPAL, to solve complex research and industrial problems. ACNS is currently the leading neutron-scattering centre in the Southern Hemisphere, and amongst the top five reactor-based neutron scattering centres in the world. ACNS is one of three research infrastructure facilities at ANSTO supported by the Government National Collaborative Research Infrastructure Strategy (NCRIS) funding scheme.

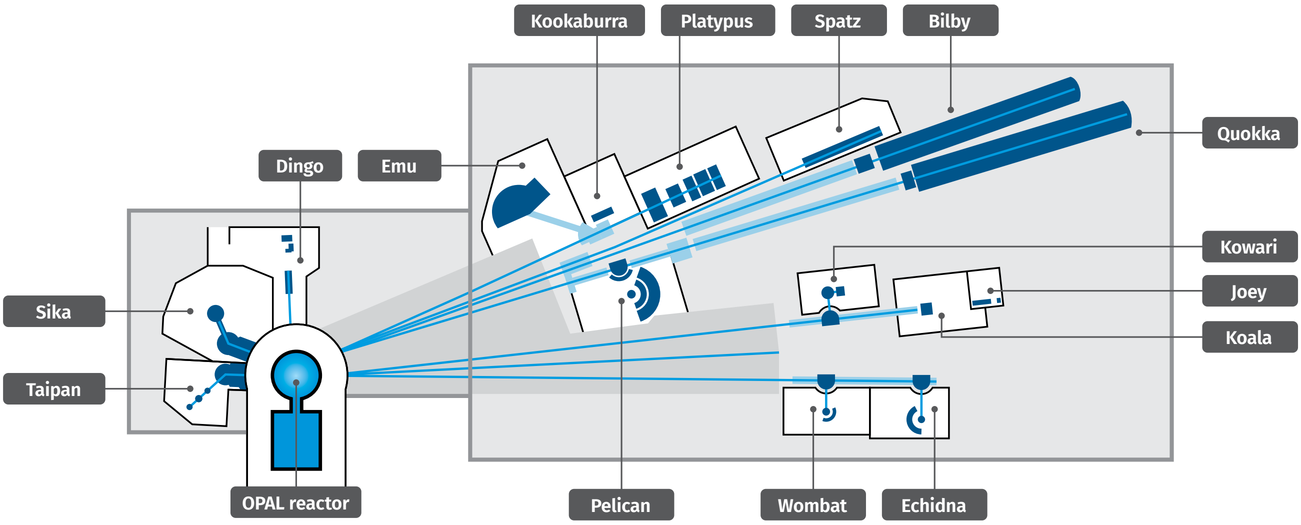
ACNS contributes to Australia's innovation ecosystem through the provision of world-leading neutron scattering techniques that are used to determine and characterise the structure, dynamics, and properties of a range of materials. Fields of research include medicine, minerals, transportation, engineering, food processing, energy, chemistry, physics, electronics, and cultural heritage. The neutron is a unique and irreplaceable probe with advantages for research, including deep penetration into materials and scattering behaviour that is characteristic of the nucleus of constituent atoms.

The ACNS operates a suite of 15 neutron beam instruments with expert instrument scientists across five capability-based teams as outlined in Table 2.

Determine and characterise the structure, dynamics, and properties of a range of materials

TABLE 2 –
ACNS neutron instruments (bold) and selected other major instruments

Technique	Instruments				
Diffraction	**Echidna** High resolution	**Koala** Single crystal	**Wombat** High intensity		
Inelastic Scattering	**Emu** High resolution	**Pelican** Time-of-flight	**Sika** Cold triple axis	**Taipan** Thermal triple axis	**Joey** Laue Camera
Reflectometry	**Platypus**	**Spatz**	X-ray reflectometer	Polarised Helium-3	
Small Angle Scattering	**Bilby** Time-of-flight	**Kookaburra** Ultra SANS	**Quokka** Pinhole SANS	X-ray (SAXS)	
Strain and Imaging	**Dingo** Radiography	**Kowari** Strain scanner			



Five specialised, cross-cutting teams support ACNS instrument scientists and users to enable research using these instruments: Computing and Electronics; Sample Environments; Electrical and Control Systems Engineering; Scientific Operations; and Laboratories and Compliance.

ACNS is a significant international collaborator with approximately 250 researchers visiting the facility to use its instruments each year. Significant national/international partners or networks include:

Australian Neutron Beam Users Group
(ANBUG)

Australian Institute of Nuclear Science and Engineering
(AINSE)

Asia-Oceania Neutron Scattering Association
(AONSA)

International Atomic Energy Agency
(IAEA)

National Synchrotron Radiation Research Center
(NSRRC)
Taiwan

Paul Scherrer Institute
(PSI)
Switzerland

Japan Proton Accelerator Research Complex
(J-PARC)
Japan

Helmholtz-Zentrum Berlin
(HZB)
Germany

ARC Centre of Excellence in **Functional Low Energy Electronics Technologies**
(FLEET)

2.3 Centre for Accelerator Science

The Centre for Accelerator Science (CAS) is ANSTO's platform for ion beam accelerator instrumentation and applications. The CAS supports research and industry user communities to explore the past, understand the present, and design for the future with a suite of accelerator science capabilities that can help answer complex questions. CAS is one of three research infrastructure facilities at ANSTO supported by the NCRIS funding scheme.

> *Explore the past, understand the present, and design for the future*

Capabilities at CAS include a range of radioisotope dating techniques, trace element and actinide identification, surface engineering and characterisation, and radiation exposure and damage, all at ultra-high sensitivity. The facility informs policy, provides critical services in nuclear forensics and air pollution monitoring, and enables discovery and innovation in areas such as environment, climate and health sciences, space technologies, advanced materials for biotech, energy, nuclear and quantum, and cultural heritage.

The staff of the CAS comprise a multi-disciplinary team of scientists and engineers supporting academic and industry users across Australia and the world.

CAS capabilities deliver:

- ultra-sensitive analysis via accelerator mass spectrometry (AMS) and ion beam analysis (IBA) techniques; and
- precision irradiation via a suite of ion beam implantation and irradiation modalities covering material doping and defect engineering, nanostructure fabrication, bulk or surface material modification, or radiation testing

CAS operates four megavolt accelerators delivering to 12 beamlines, 12 chemistry laboratories, and multiple workshops for accelerator systems maintenance and development as outlined in Table 3.

TABLE 3 –
CAS instruments and applications

Capability	Accelerator and techniques			
	VEGA (1 MV)	**STAR** (2 MV)	**SIRIUS** (6 MV)	**ANTARES** (10 MV)
Radioisotope dating	**AMS** $^{14}\mathrm{C}$		**AMS** $^{36}\mathrm{Cl}$ $^{26}\mathrm{Al}$ $^{10}\mathrm{Be}$	**AMS** mg - $^{14}\mathrm{C}$
Actinide counting	**AMS** $^{233}\mathrm{U}$ - $^{236}\mathrm{U}$ $^{238}\mathrm{U}$ $^{239}\mathrm{Pu}$ - $^{242}\mathrm{Pu}$ $^{244}\mathrm{Pu}$ $^{129}\mathrm{I}$ $^{210}\mathrm{Pb}$			
Trace element analysis and surface characterisation		Bulk sample **IBA**	Microprobe **IBA**	
Irradiation		Long-exposure protons, alphas	Microprobe implantation and irradiation, protons and heavy ions	Fast neutrons, microprobe protons and heavy ions, in vacuum or air

CAS is a significant international collaborator with approximately 50 researchers visiting the facility to use its instruments each year. Significant national/international partners or networks include:

International Atomic Energy Agency
(IAEA)

Australian Collaboration for Accelerator Science

National Space Qualification Network
Australian Space Agency Space Infrastructure Funded partnership

ARC Centre of Excellence in
Dark Matter Particle Physics

ANSTO's STAR accelerator.

2.4 Australian Synchrotron

The Australian Synchrotron (AS) is a 3 GeV, 216 m circumference, electron synchrotron light source facility that provides world-class synchrotron tools and expertise for researchers and clients to deliver scientific advances and industrial innovations with medical, social, and economic benefits. The AS operates multiple beamlines and associated ancillary laboratories to support a large user program.

The AS capabilities provide an array of non-destructive, high-resolution, in-situ, real-time imaging and analysis techniques. These generate elemental, structural and chemical information from diverse sample types ranging from living cells to advanced materials, industrial components, and mineral processes. AS beamlines support a broad range of high-quality research with applications in sectors from medicine and nanotechnology to manufacturing and mineral exploration

The AS has 10 beamlines which operate in parallel providing key synchrotron capabilities across multiple techniques, with a further eight beamlines currently under construction as part of the Project BRIGHT Beamline Program.

The Australian Synchrotron is a 3 GeV, 216 m circumference, electron synchrotron light source facility

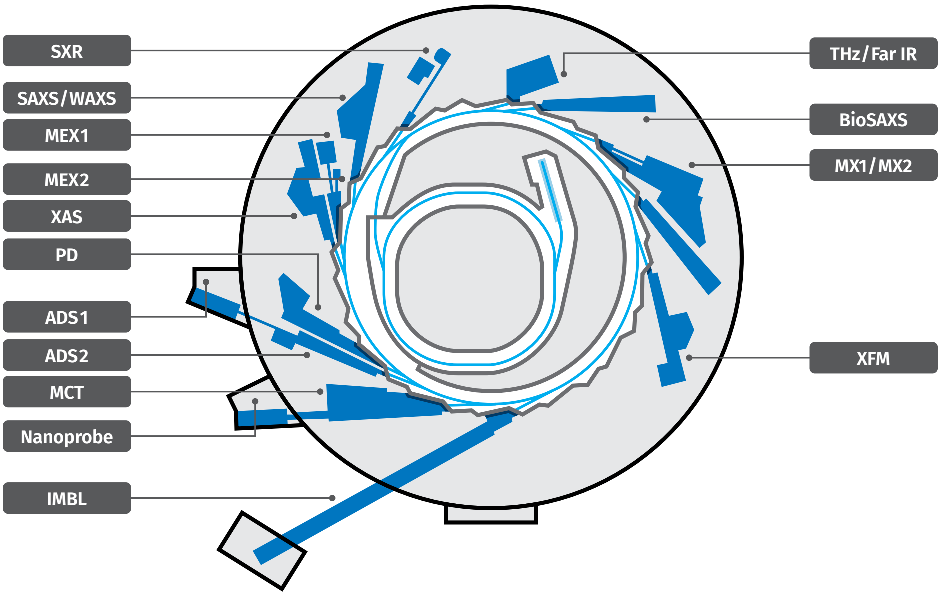
TABLE 4 –
Australian Synchrotron beamlines (operating and under construction)

Technique	Instruments			
Diffraction	**MX1** Macromolecular crystallography	**MX2** Microfocus crystallography	**PD** Powder diffraction	
Imaging/ Microscopy	**IMBL** Imaging and medical	**SXRi*** Soft X-ray imaging	**IRM** Infra-red microscopy	**XFM** Fluorescence microprobe
Spectroscopy	**XAS** X-ray absorption spectroscopy	**SXR*** Soft X-ray spectroscopy	**THz/Far IR** spectroscopy	
Small Angle Scattering	**SAXS/WAXS** Small angle scattering			
BRIGHT† Beamlines	**MEX 1 & 2** medium-energy XAS	**MCT** Micro computed tomography	**BioSAXS** Biological small angle scattering	**Nanoprobe** High-resolution microscopy
	ADS 1 & 2 Advanced diffraction and scattering	**MX3** High-performance macromol. crystallography		

***** Branch line – not operated in parallel
† Under construction or commissioning

The Australian Synchrotron is located in Clayton, Victoria.

The AS operates with six departments which collectively provide the expertise and tools to support high impact research: Science; Accelerator Science and Operations; Operations; Engineering; Controls and Computing; and a Project Management Office.



The AS works with a number of domestic and international partners including:

NZ Synchrotron Group

New Zealand Synchrotron Group
(ANBUG)

AOFSSR

Asia Oceania Forum for Synchrotron Radiation Research
(AOFSRR)

BR—GHT

BRIGHT Funders
31 Universities, PFRAs and MRIs

AINSE

Australian Institute of Nuclear Science and Engineering
(AINSE)

FLEET

ARC Centre of Excellence in **Functional Low Energy Electronics Technologies**
(FLEET)

Aerostructures Innovation Research Hub

AIR Hub
Aerostructures Innovation Research Hub

Medicines Manufacturing Innovation Centre

Medicines Manufacturing Innovation Centre
(MMIC)

2.5 Advanced manufacturing of nuclear medicine

ANSTO produces a range of nuclear medicines for both diagnosis and treatment of serious disease, delivering over 12,000 patient doses per week to over 250 hospitals and clinics in Australia alone. ANSTO also exports nuclear medicine to as far as the East Coast of the US.

Technetium-99m (Tc-99m) is the most widely used diagnostic nuclear medicine world-wide, accounting for approximately 80% of procedures. Applications include diagnosis of cancer and heart disease, neurological conditions, and bone imaging.

Whilst Tc-99m can be produced directly by Cyclotrons, the 6 hour half-life of the isotope means that it cannot transported outside the locality of production. This limits the population that can benefit from the final product. Reactor based production of Tc-99m is the most common, as it produces the precursor isotope, Molybdenum-99 (Mo-99). Mo-99 has a 66-hour half-life, allowing it to be incorporated into a Tc-99m generator, with the Tc-99m 'growing in' over the transport period and continuing to be generated over the week of use. This allows transport of generators and bulk Mo-99 over large distances, with eventual use being at the population of need.

The manufacturing process is complex and is deeply integrated with supply chain and logistics to ensure maximum utilisation and global supply. The key factor in the production is to work backwards from the customer requirements. If, for example, a nuclear medicine facility requires receipt of a Tc-99m Generator or bulk Mo-99 sample by 8am on a Monday Morning, the following steps are all planned precisely to meet that schedule requirement.

Mo-99 production includes three major, time-depend steps: target irradiation, target processing and generator manufacture. ANSTO is involved at all stages of the Mo-99 production process.

This extraction process is functionally similar to, but more complex than the reprocessing of spent nuclear fuel. Nuclear medicine is focussed on extraction of a single isotope of 6% concentration rather than uranium isotopes which constitute 80% of spent nuclear fuel.

ANSTO produces a range of nuclear medicines for both diagnosis and treatment of serious disease

2.5.1 Irradiation

Within OPAL, twelve U-235 LEU targets plates are irradiated in a reactor rig between two and thirteen days depending on requirements. The target plates are a sandwich of U-235 within aluminium cladding and are similar to the OPAL fuel plates. The targets plates are then transferred to ANM via a lead 7.55 T flask and lowered into a heavily shield concrete hot cell.

2.5.2 ANSTO's Mo-99 Manufacturing Facility

The twelve target plates are digested using an alkaline solution within a dissolver to extract the 6% Mo-99 available and the solution is filtered. Once the filtering is completed the solution is loaded onto an Ion exchange column to selectively separated the Mo-99 from the many other isotopes. Volatile radio-Iodine isotopes are also separated and captured on ion exchange columns.

The filtration process utilises a Spent Uranium Filter Cup to capture uranium and other non-soluble particulate. Other soluble radioisotopes are transferred to the Intermediate Level Liquid Waste stream and storage in below ground decay storage tanks.

The Mo-99 solution is eluted from the Ion exchange column and pumped into the purification hot cell. In the purification hot cell there are two different ion exchange columns that the Mo-99 solution passes through to further purify the product for use. After the last purification column is eluted, the solution is transferred to a header tank where evaporation commences.

The Mo-99 solution goes through a slow boil down to evaporate the chemicals used in the purification and extraction steps. The product is boiled down to complete dryness leaving only a dry powder of Mo-99. The powder is then reconstituted with water to produce the final product which is sampled and analysed within our Quality Control laboratory to test for impurities and ensure the product is manufactured to the strict specifications of the Australian Therapeutic goods Administration (TGA), Federal Drugs Administration (FDA) and other regulatory bodies in customer states. As the final product will be classified as a 'sterile injectable product' a very high degree of purity is required.

The ANSTO Mo-99 Manufacturing Facility.

Once the testing is completed, the operations team transfer varying amounts of product based on customer orders into heavily shielded transport containers so the product can be dispensed onto another ion exchange column held within Tc-99m Generators used at nuclear diagnostic imaging centres. This involves the transfer of the bulk product to a separate facility for processing and distribution, where generator production is conducted within an area that is simultaneously classified for radiological and medical clean room requirements.

The production process produces a range of solid, liquid and airborne wastes. The solid waste includes ILW in the form of SUF cups. These are transferred to a waste cell in the Mo-99 Manufacturing Facility for decay heat management and interim storage. Following a decay period of 12 weeks, the SUF Cups are transferred in a highly shielded flask to waste management for processing and storage.

Other solid ILW includes sacrificial production items designated as single use by the TGA.

There are two liquid waste streams from the initial dissolution and purification steps. These are held in below ground storage tanks and following appropriate decay these streams will be immobilised through the Synroc® process.

The airborne streams mainly constitute volatile isotopes of Iodine and Xenon. These are abated prior to discharge through gas capture and storage and use of high-volume carbon columns. As part of the design of the facility, there was a requirement to minimise discharges to the extant level at the time of construction of the facility. The mitigation of Xenon-133 was a specific requirement as this is a key isotope used for detection of nuclear weapons tests under the Comprehensive Test Ban Treaty.

Inside the ANSTO Mo-99 Manufacturing Facility.

2.6 Waste management facilities

Having operated research reactors since the 1950's, ANSTO has significant experience in the management, treatment and storage of radioactive wastes arising from a civilian nuclear industry.

ANSTO has a multi-faceted radioactive waste management regime supported by dedicated waste management facilities and expertise. ANSTO's radioactive waste management facilities deal with the diverse wastes generated from operation of the OPAL reactor, nuclear medicine production, research programs on nuclear fuels, waste-forms for intractable nuclear wastes, and new radionuclide and radiopharmaceutical syntheses for clinical trials. In addition to spent fuel from OPAL, ANSTO manages liquid, solid, and gas waste streams, with low- and intermediate-levels of radioactivity.

Apart from low-level active effluent, all waste generated at ANSTO is tracked through a bar-coding system which records date of generation, contact dose rate, waste constituents and other key information about the waste that aids downstream management. Categorisation of contact-handled wastes includes:

- waste above 0.5 mSv/h;
- waste having other hazardous materials (asbestos, beryllium, toxins, etc);
- waste which is non-compactable (powder, wood, metal, etc);
- waste which is non-shreddable (alpha waste, large plastic components, bolts / tools, etc); and
- waste which is shreddable and compactable.

Low-level waste management at ANSTO.

2.6.1 Management of spent fuel

ANSTO and the former AAEC has operated three research reactors sited at Lucas Heights including HIFAR, Moata, and the current OPAL reactor.

HIFAR's initial fuel load was highly enriched uranium (93% U-235), but over the years the enrichment level of new fuel was steadily reduced, in line with international trends. HIFAR completed conversion to low enriched uranium fuel (LEU) in 2006 in alignment with agreements under the United States Foreign Research Reactor Spent Nuclear Fuel (FRRSNF) program.

HIFAR's fuel was fabricated in the USA and the UK. In line with recommendations from several government inquiries, the used fuel was sent overseas for either disposal (to US under the FRRSNF program) or reprocessing (UK and France), depending on the country of origin of the fuel.

No spent HIFAR or Moata fuel remains at Lucas Heights. ANSTO is one of the few multi-purpose reactor sites in the world not to have legacy spent nuclear fuel accumulated, awaiting disposition. OPAL was designed with approximately 10 years of spent fuel storage in the adjoining reactor service pool. Approximately every 7 years, depending on accumulation rate, spent fuel will be sent to France for reprocessing with ultimate return of intermediate level wastes (vitrified) to Australia. The first OPAL spent fuel shipment was in 2018 and occurred without incident.

ANSTO received wastes equivalent to the reprocessing of 1288 spent HIFAR fuel assemblies from France in December 2015. The vitrified intermediate level wastes (ILW) are temporarily stored in a purpose-built Interim Waste Store (IWS) at Lucas Heights, a steel frame building equipped with a 140-tonne overhead crane, natural convection ventilation and appropriate radiation and other monitoring. The vitrified ILW canisters (20) are contained in a Type B(U) TN-81 dual purpose storage and transport cask. ANSTO is expecting a second return shipment in 2022 of vitrified wastes equivalent to the 114 spent fuel assemblies sent for reprocessing to the UK in 1996. These will be contained in a second TN-81 cask.

Transporting the TN-81 cask to ANSTO in 2015.

2.6.2 Solid waste

The majority of radioactive solid waste generated at ANSTO is classified as Low-Level Solid Waste (LLSW) and arises mainly from nuclear medicine production, research, and routine decontamination processes. LLSW is classified at ANSTO as having a contact gamma dose of less than 2 millisieverts per hour (mSv/h) and/or a contact beta dose of less than 8 mSv/h. ANSTO generates approximately 40 m^3 of LLSW per year.

Intermediate Level Solid Waste (ILSW) is generated chiefly from radiopharmaceutical production, reactor and hot cell operations, and has a surface gamma dose of more than 2 mSv/h. The volume generated each year is approximately 3.5 m^3 and represents approximately 8% of active solid waste generated by ANSTO's operations.

In addition to the IWS, ANSTO Waste Management Services has a number of facilities to pre-disposition and store radioactive wastes produced from ANSTO's operations. ANSTO's main waste storage facilities date back to the 1970's for Low Level Solid Waste (LLSW) storage and 1980's for Intermediate Level Solid Waste (ILSW) storage. A waste conditioning building for LLSW was constructed in 2004 and extended in 2014 to provide capacity for LLSW storage, both conditioned and unconditioned. ANSTO's existing ILSW storage facility was extended in 2017 to provide capacity for storage of materials directly related to nuclear medicine production. ANSTO's current ILSW storage capacity is again due to reach capacity by 2028. Accordingly, ANSTO is currently planning to build a new ILSW storage facility.

ANSTO uses dedicated hot cells facilities for a variety of waste management functions including:

- waste volume reduction of intermediate level solid wastes and packaging in preparation for interim storage in an in-ground storage facility;
- encapsulation of intermediate level solid waste filters from Mo-99 production;
- support for HIFAR decommissioning;
- research support involving radioactive materials;
- radioactive source preparation for ANSTO customers; and
- inspection and packaging of spent radioactive sources.

Low-level waste storage at ANSTO.

2.6.3 Liquid waste

ANSTO generates, treats, and safely discharges approximately 100,000 m^3 of trade waste effluent and sewage and 5,500 m^3 of low-level active effluent a year. The waste effluent is received and processed at the site effluent treatment plant. The waste waters at ANSTO are segregated into three categories for processing: low-level waste waters, trade waste waters, and sewage.

Liquid wastes having greater than 2 mSv/h dose rate on contact (item and or package) are classified as Intermediate Level Liquid Waste (ILLW). They are kept separate from the effluent system.

Effluent treatment operations receive, store, and treat when necessary, effluent generated on site, to minimise the release of radioactive contaminants in ANSTO's effluent discharge and comply with the Consent to Discharge with Sydney Water. Effluent treatment operations consist of the effluent treatment plant and the reticulation system from the buildings across the Lucas Heights campus. The effluent treatment plant consists of tank storage and treatment facilities and solar drying ponds.

The secondary treatment of low-level radioactive waste waters is based on an alum (aluminium sulphate) treatment process where, after solids precipitation and removal of liquids, the solids are transferred to a centrifuge form compaction. The treatment process removes 25% of the radioactivity (accounting for decay) on average. The centrifuged solids are transferred to storage tanks and then to a drum dryer or solar evaporation ponds. After drying, the precipitated solids are transferred to steel drums for interim storage on site. These form part of the ANSTO LLSW inventory of which the majority is stored in the LLSW Storage building

Another facility houses the super-compaction plant with an extension providing storage of contact handled wastes using an Automated Storage Retrieval System. This facility is also used for waste inspection, drum repacking, drum drying of low-level Molybdenum-99 liquid waste, radio-analytical characterisation, special decontamination work and cement conditioning of contact handled waste.

2.6.4 Synroc®

ANSTO has developed a new waste treatment technology, Synroc® which is the first new waste treatment technology to be implemented globally in the last 20 years. The first-of-a-kind fully engineered production facility for Synroc® is currently being constructed at Lucas Heights.

Synroc® relies on the application of Hot Isostatic Pressing (HIP) of a conditioned waste form to produce a low volume, highly durable waste, in which the radioactive isotopes are effectively encapsulated in the material matrix. The matrix can be a glass, glass-ceramic or full ceramic depending on the characteristics of the initial waste. ANSTO plans to deploy this first-of-a-kind technology to treat the liquid by products of our Mo-99 production. As the waste is dominated by fission products, the optimum host material is a glass waste form. The process involves the drying of the liquid waste with simultaneous injection of glass forming materials, leading to a free-flowing powder. The powder is transferred to a bespoke canister, sealed and then subjected to HIP.

ANSTO Synroc® has developed the technology from a Technology Readiness Level (TRL) of TRL 3 to TRL 6, based on the use of a demonstration plant used to define the limiting operational parameters and to optimise the design. Cold Commissioning (TRL 7) and full technology deployment at (Hot Commissioning) is scheduled for the next 2 years.

Synroc® HIP cans.

2.6.5 Preparation for final disposal

ANSTO does not currently dispose of long-lived radioactive wastes, however AAEC did dispose of a range of wastes during the 1960's and 1970's in a near surface trench repository; the Little Forest Legacy Site (LFLS). The LFLS has been environmentally monitored for many years and a plan is being developed for the long-term management of the site, predicated on regulatory approval.

Longer-term, Australia is planning a dedicated National Radioactive Waste Management Facility (NRWMF) for the disposal of LLW and storage of ILW arising from ANSTO's operations, as well as radioactive wastes from other facilities such as hospitals around the nation. The NRWMF will be constructed and operated by a newly formed body, the Australian Radioactive Waste Agency (ARWA). ANSTO has worked with ARWA and the parent Department of Industry, Science, Energy and Resources (DISER) in planning for the NRWMF. In November 2021, the Minister for Resources and Water announced the acquisition of land at Kimba in South Australia as the site for the NRWMF.

Australian policy is to ultimately dispose of ILW. Although no plans for a dedicated facility to this end have been announced, ANSTO, CSIRO and other partners are exploring the potential for utilising an engineered borehole as part of a multi-barrier disposal system.

Artist's impression of the National Radioactive Waste Management Facility.

Science and technology

The Nuclear Science and Technology (NST) group at ANSTO comprises two core elements.

1. **A portfolio of Research Themes and strategic research programs**
2. **A portfolio of national scale research platforms that conduct and enable research**

There are currently 450 people in the NST group which is approximately one-third of the total organisation. NST operations are supported by enabling functions which ensure integration of safety, quality, research services, user office, industry and stakeholder engagement across research themes and research infrastructure as outlined in Figure 1. ANSTO's research and research infrastructure delivers national benefit through research and development activities that have public benefit, maintain sovereign capability and deliver ANSTO business outcomes.

Research themes

Environment

- Environmental change
- Water resources sustainability
- Contaminant impacts

Human health

- Nuclear technology for disease characterisation and treatment
- Radiotherapy and theranostics

Nuclear fuel cycle

- Fuel resources and systems and spent fuel management
- Reactor systems

Strategic program

- ANSTO Synroc®

Research infrastructure

Landmark and national

- **Australian Synchrotron** (AS)
- **Australian Centre for Neutron Scattering** (ACNS)
- **Centre for Accelerator Science** (CAS)
- **National Deuteration Facility** (NDF)
- **Nuclear Stewardship** (NS)

Institutional

- **Biosciences**
- **Isotope Tracing in Natural Systems** (ITNS)
- **Nuclear Materials Development and Characterisation** (NMDC)

Research enablers

- Research office
- Group office
- Industry and stakeholder engagement
- User office

FIGURE 1 –
ANSTO NST Research Themes, Research Infrastructure, and Research Enablers.

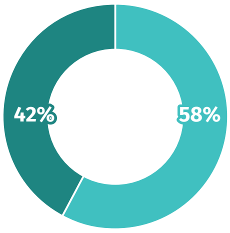
3.1 Research

The ANSTO research portfolio has three core themes: Health, Environment, and the Nuclear Fuel Cycle, as well as a strategic program to deliver research and engineering solutions for the management of nuclear waste forms (Synroc® Technologies). The work undertaken in each of these themes challenges research infrastructure to constantly improve performance and evolve capabilities to meet research demand. Figure 2 shows key facts and figures regarding ANSTO NST's Research Themes.

Research themes

9.3% of NST total expenditure

	Environment	Human health	Nuclear fuel cycle	Synroc®
Staff	27	13	24	17
	Using our unique nuclear science and technology expertise and capabilities to understand and respond to environmental challenges through research focused in the area of water resource sustainability, contaminant impacts and environmental change	Improving the prevention, diagnosis, monitoring and, particularly, treatment of disease, addressing national and international health challenges using our sovereign capability in nuclear science and technology	Building world-class knowledge and skills in nuclear fuel cycle research, informed advisor to the Government on nuclear fuel cycle matters, and contributing to development of sovereign capabilities in the nuclear fuel cycle	Providing integrated technology solutions for the safe and responsible treatment and management of nuclear wastes through scientific underpinning and engineering innovation
Commercial/Govt Reports (FY21)	14	2	9	4
Co-authored journal papers (CY20)	80	22	44	9
Postgraduate students (FY21)	73	19	17	3
IP registrations (FY21)		1	1	1



👤	**Employees and contractors**	81
👤	**'Residential' students**	59

Commercial/Govt Reports (FY21)	**TOTAL**	27
Co-authored journal papers (CY20)	**TOTAL**	155
Postgraduate students (FY21)	**TOTAL**	112

AINSE

The Australian Institute of Nuclear Science and Engineering

45 member organisations comprising of two industry partners, two research institutions and 41 universities from across Australia and New Zealand.

FY22 OPEX	$13.6M
FY22 Revenue *(includes internal offsets)*	$2.8M
FY22 CAPEX	$1.0M

Key partners

Australian Government Department of Defence Defence Science and Technology Organisation

Australian Government Bureau of Meteorology

The University Of Queensland Australia

Sumitomo

QST

Australian National University

University of Wollongong Australia

DMTC

Monash University

UNSW Sydney

+ Many more

FIGURE 2 –
ANSTO NST Research Themes

3.1.1 Human health

This theme investigates biological processes that lead to the development of treatments for disease, strategies to reduce the risk of disease, and the development of more effective treatments. Key areas of focus include:

- advancing the understanding of the effect of radiation on biological systems in a variety of contexts, including in space, in order to improve the prevention, diagnosis, treatment, and monitoring of disease;
- identifying, quantifying, and monitoring the mechanisms which cause, or influence the development and progression of disease, and translating this research into precision diagnostics and evidence-based treatments (‘translational research’); and
- improving nuclear technology-based therapy outcomes, especially for hard-to-treat cancers, through theranostics and the use of proton therapy, heavy ion therapy, and microbeam/mini-beam radiotherapy.

3.1.2 Environment

This theme undertakes interdisciplinary environmental research using nuclear and isotopic techniques to fill data and knowledge gaps, to inform sustainable management strategies, and to increase Australia’s capacity to respond to modern environmental challenges. Key areas of focus include:

- improving and contributing to the sustainable management of water resources in Australia;
- identifying, quantifying, and monitoring the scale and speed of human impacts on the natural environment and climate change; and
- advancing knowledge of the pathways and impacts of contaminants upon animals, plants, and the broader environment.

3.1.3 Nuclear fuel cycle

Nuclear Fuel cycle undertakes research spanning from the mining of uranium to the disposal of radioactive waste. ANSTO has unique capabilities and expertise in radioactive waste management, theoretical predictions of fuel properties, and modelling of the impacts of radiation on materials. Key areas of focus include:

- developing improved fuels for advanced reactor designs;
- investigating materials for use in nuclear applications and the effects of irradiation, corrosion and high temperature on their structural properties;
- advancing understanding of the management of spent fuel and associated waste forms, including ANSTO Synroc® technology; and
- providing support for the lifetime management of the OPAL Reactor.

3.1.4 Synroc® technologies

This group is focused on R&D that drives world class research to create innovative waste form and engineering waste treatment solutions. Key focus areas include:

- demonstrating Synroc® technologies for ANSTO site waste, as part of global best practice in direct disposal and termination of nuclear waste;
- extracting commercial value and delivering impact from the program's intellectual capital; and
- developing a highly skilled and motivated team for the delivery of specialised nuclear projects.

The research portfolio also includes projects within the platforms that are focused on capability development relevant to the platform, for example, the establishment of in-air radiobiological beamlines or novel methods to produce radioisotopes for environmental and nuclear medicine research. In some instances, this also extends to strategic projects within the platforms focused on particular research areas, such as X-ray imaging and therapy, food materials science, cultural heritage, functional materials for energy systems and devices, and magnetic and superconducting materials.

Developing Synroc® technology.

3.2 Research infrastructure and scientific support capabilities

The ANSTO research infrastructure portfolio comprises capital investment in the region of AU $1billion, more than 350 employees and contractors and an extensive array of operating systems and procedures that support more than 8,000 users.

This large portfolio places Australia at the forefront of translational research and innovation for the benefit of public health, industry, and the environment, and is used by universities, researchers, and industry from around Australia and internationally.

ANSTO's landmark facilities (Australian Synchrotron and ACNS) are predominantly focused on external merit users. Among the national facilities, the Centre for Accelerator Science and the National Deuteration Facility share the same external user focus. While not offering merit access to the same extent as the other national facilities, Nuclear Stewardship comprises a range of sovereign capabilities that services the mandated needs of varied Australian Government and ANSTO users. On this basis, it is considered national research infrastructure. The Research infrastructure is outlined in Figure 3. Key infrastructure is discussed in Section 2 and below.

Research infrastructure

85.1% of NST total expenditure

253 72

Australian Centre for Neutron Scattering

The leading neutron scattering facility in the Southern Hemisphere - provides neutrons from Australia's multi-purpose research reactor, OPAL, to solve complex research and industrial problems for external and internal users.

64 38

Centre for Accelerator Science

Improving the prevention, diagnosis, monitoring and, particularly, treatment of disease, addressing national and international health challenges using our sovereign capability in nuclear science and technology.

4 29

Nuclear Stewardship

Supporting Government, industry and scientific users through radionuclide metrology, ionising radiation detection and measurement, radioanalytical chemistry, nuclear forensics and environmental monitoring.

49 22

Nuclear Materials Development and Characterisation

Focussed on materials for nuclear applications in radioactive environments. Enabling the synthesis, processing, engineering and characterisation of nuclear relevant materials

675 194

Australian Synchrotron

World-class operation of Australia's biggest particle accelerator and brightest light source - world-class synchrotron tools and expertise that enable researchers and clients to deliver scientific advances and industrial innovations

18 10

National Deuteration Facility

Only facility of its kind in the Southern Hemisphere - provides isotopic labelling of molecules with stable, non-radioactive isotope deuterium (^2H) using chemical or biological (*in vivo*) processes

22 35

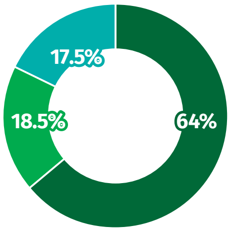
Biosciences

Expertise and capabilities to supply radioisotopes and undertake radiochemistry, radiation biology and preclinical imaging studies to develop and evaluate radiopharmaceuticals

25 16

Isotope Tracing in Natural Systems

Provide a range of radioanalytical, isotopic and elemental analytical techniques, measurements and expertise to support environmental research that quantifies and/or provides a temporal view of environmental processes



Landmark	Employees and contractors	266
National	Employees and contractors	77
Institutional	Employees and contractors	73

ANSTO Co-authored journal papers (CY20)	601
Journal papers acknowledging ANSTO (CY20)	509
All journal papers enabled by ANSTO infrastructure (CY20)	1,110

NCRIS National Research Infrastructure for Australia

ANSTO has received $15.4M of NCRIS funding in FY22 to support operations and development in ACNS, NDF, CAS and Biosciences.

BR—GHT

ANSTO has received $94.1M of capital funding from 31 contributors.

The eight BRIGHT beamlines will expand the beamline infrastructure of the Australian Synchrtron to increase both its capacity and capabilities.

FY22 OPEX	**$64.0**M
FY22 Revenue *(includes internal offsets)*	**$49.7**M
FY22 CAPEX	**$69.0**M

Key partners

Australian Government Department of Defence
Australian Government Bureau of Meteorology
HZB Helmholtz Zentrum Berlin
NSRRC
National Imaging Facility
Australian National University
University of Wollongong Australia
AFP
Monash University
UNSW Sydney
+ Many more

FIGURE 3 –
ANSTO NST Research Infrastructure.

3.2.1 Nuclear focussed scientific support

3.2.1.1 Nuclear Materials, Development and Characterisation

The Nuclear Materials Development and Characterisation (NMDC) platform supports ANSTO's core functions and maintains a sovereign capability in nuclear materials processing and characterisation for Australia.

NMDC enables the synthesis, processing, engineering, and characterisation of structure-property relationships of nuclear relevant materials. Both radioactive and non-radioactive work can be conducted within its large suite of material processing and characterisation infrastructure. Engineering of materials up to the pilot plant scale is a unique feature, which involves expert skills, specialised instrumentation, and facilities to ensure safety.

The platform is predominantly directed to fulfilling ANSTO thematic research and waste form development projects, business, and operational needs. It provides a small number of services directly to commercial clients, other national laboratories and international agencies.

NMDC has a broad set of capabilities focused upon synthesis, processing, characterisation, modelling, and theoretical aspects that underpin research and the development of advanced materials. The platform is the only licenced and permitted infrastructure in Australia with expertise to handle a wide range of complex radioisotopic, physical and chemical forms of materials. Specific capabilities include:

- Actinide Suite – actinide materials handling facility
- Materials Fabrication Bay (MFB) – for active materials handling and characterisation including X-ray diffraction and scanning electron microscopy (SEM) with microanalysis capability;
- non-active sample X-ray diffraction;
- post-irradiation examination infrastructure including hot cells and materials testing;
- non-active materials and chemical processing and characterisation;
- non-active materials testing including tensile, creep, fatigue and hardness;
- Electron Microscopy Facility – Transmission Electron Microscopy (TEM) and focused ion beam-scanning electron microscopy (FIB-SEM); and
- metallography and sample preparation capability.

3.2.1.2 Nuclear Stewardship

The Nuclear Stewardship platform is a cohesive set of nuclear science and technology capabilities and functions that are either mandated by Government, by regulators, or otherwise considered essential to ongoing ANSTO operations. The Platform comprises four groups: Radionuclide Metrology, Nuclear Forensics, Radioanalytical Chemistry, and Environmental Monitoring.

A mandated function of Radionuclide Metrology is maintenance of the national standard of measurement for radioactivity (the national Becquerel standard). This supports Australia's nuclear medicine industry and patients. Government has recognised that ANSTO's Nuclear Forensics capability is essential to fulfilling its policy objectives in relation to counter terrorism, nuclear security and non-proliferation, including regional considerations in South East Asia. The Environmental Monitoring and Radioanalytical Chemistry capabilities are essential capabilities that support ANSTO's research, business, and nuclear operations by providing expert advice, analysis, and data interpretation services on radioactive stack discharges and environmental monitoring.

A mandated function of Radionuclide Metrology is maintenance of the national standard of measurement for radioactivity

Nuclear Stewardship capabilities are underpinned by analytical measurement processes, which make up the research infrastructure assets of this platform:

Radionuclide Metrology services/capabilities:

- primary standards - 4pi Beta-Gamma coincidence counting, liquid scintillation counting;
- secondary standards - Ionisation chamber measurements, precision gamma spectrometry; and
- source preparation

Nuclear Forensics services/capabilities:

- high precision alpha and gamma spectrometry;
- electron microscopy – SEM, TEM; X-ray fluorescence spectrometry and X-ray diffraction; and
- mass spectrometry – Inductively coupled plasma (ICP-MS); Isotope Dilution (IDMS)

Environmental Monitoring services/capabilities:

- radiological characterisation of stormwater, groundwater, air, soil, and biota for the environmental survey of the Lucas Heights campus and buffer zone;
- stack monitoring and plume dispersion modelling to monitor and characterise airborne releases from ANSTO licenced facilities;
- operation of the Lucas Heights weather station to provide real-time weather data; and
- open loop wind tunnel for instrument calibration and dispersion and re-suspension research

Radioanalytical Chemistry services/capabilities::

- gamma spectrometry (natural and anthropogenic);
- radioanalytical Chemistry/Alpha Spectrometry/Liquid Scintillation Analysis (U, Th, Pu or Am isotopes by alpha spectrometry; Sr-90 by liquid scintillation analysis);
- radioanalytical Chemistry/Liquid Scintillation Analysis (Tritium); and
- radioanalytical chemical method development (alpha and/or beta emitters)

Significant national/international partners or networks include IAEA networks (e.g. the Safeguards Network of Analytical Laboratories (NWAL) and Analytical Laboratories for the Measurement of Environmental Radioactivity, (ALMERA)), Department of Defence, and the Australian Federal Police.

4 Commercial products and services

ANSTO provides the Australian and international community with products and services to improve human health, support industries, and protect the environment. ANSTO is committed to consistently providing products and services that meet or exceed the requirements and expectations of our customers and stakeholders in compliance with all relevant national and international standards, statutory and regulatory requirements. ANSTO's major products and services fall under three categories: Health Products; Minerals Consultancy and Radiation Services.

ANSTO's Lucas Heights campus in Sydney is home to three key facilities that enable Australia's advanced manufacturing and distribution of nuclear medicines: the OPAL multi-purpose reactor; the ANSTO Nuclear Medicine facility for production of Mo-99; and the nuclear medicine processing and distribution facility. About 75-80 per cent of nuclear medicine isotopes used in Australia come from ANSTO. We partner with nuclear medicine professionals to enable 700,000 patient procedures each year.

ANSTO has provided the mining and minerals processing industries with consultancy, process development and research services for more than 40 years. The Minerals unit has highly experienced engineers, metallurgists, chemists, and scientists with access to process development and piloting facilities, separation technologies, mineralogy and radioanalytical capabilities, including NAA and DNAA. Process development has been provided around rare earths, lithium, critical and strategic metals including zirconium, niobium, scandium, titanium, molybdenum, tungsten, gold and silver, and uranium extractions.

ANSTO's minerals unit process development facility.

4.1 Radiation Services

ANSTO has over 35 years' experience radiation consultancy services, radiation safety training, and instrument calibration, all tailored to meet clients' needs. ANSTO is one of the largest, most experienced providers of radiation protection services in Australia. We have practical expertise in all areas of radiation protection, health physics and the control of radioactive substances.

Consultancy services include, but are not limited to:

- Expert advice and assessments for compliance to national and state legislation, development of radiation management plans and operating procedures
- Development of emergency response plans and monitoring programs
- Occupational workplace monitoring of facilities and apparatus
- Source identification, transportation and disposal
- Environmental monitoring
- Decontamination services and waste minimisation and treatment
- Contaminated land characterisation

ANSTO is Australia's leading provider of radiation safety training to meet industry and regulator needs. Our training includes a strong mix of theoretical knowledge and practical application.

Courses are delivered at ANSTO's Lucas Heights facilities or at client's facilities within Australia and around the world. Our main courses that are offered include:

- Advanced, Industrial and General Radiation Safety Officer courses
- Nuclear and Radiological Emergency Preparedness and Response courses
- Safe use of X-rays and Industrial Gauges courses for those who operate the broad range of these devices
- Laboratory Worker course for those who work in laboratory settings
- Mining Industry Specific courses.

Courses can be customised to specific needs and online training material developed. ANSTO is also finalising a comprehensive Nuclear Skills training program to provide a continuous pipeline of skills at all levels.

ANSTO is the largest provider in Australia of reliable and traceable calibration services for radiation monitoring instruments, including survey meters, contamination monitors and electronic personal dosimeters. Our reference sources are traceable to the Australian standard maintained by ARPANSA. ANSTO operates under ISO 9001 Quality Management System accreditation.

5 Engineering capabilities

ANSTO has significant and wide-ranging engineering capabilities developed from almost 70 years of designing and operating civilian nuclear facilities at its Lucas Heights site in Sydney, NSW.

5.1 Facility engineering

The engineering design authority of each of ANSTO's landmark infrastructure is managed under an asset management framework using ISO-55000 Asset Management standards and is focussed on continuously improving its practices. ANSTO requires that each business unit maintains an Asset Management Plan, this includes major facilities such as the:

- OPAL Reactor;
- Australian Centre for Neutron Scattering (ACNS);
- Centre for Accelerator Science (CAS);
- Australian Synchrotron;
- ANSTO Nuclear Medicine (ANM); and
- Waste Operations.

Each of these facilities has its own dedicated engineering support staff who assume ownership of assigned assets and are responsible for defining the maintenance decision making and future capital investment needs for the asset. These engineers are the organisation's nominated resident expert in relation to allocated systems and equipment, with an overall understanding of the drivers and limitations of system reliability and the ability to provide sound technical support and advice to operations and maintenance functions.

At ANSTO, this engineering function includes:

- Provision of technical support for the planning and implementation of maintenance on safety critical equipment and contaminated and/or radioactive plant and equipment.
- Development of maintenance strategies for systems based upon a reliability centred maintenance approach using a knowledge of failure modes and criticality with a focus on applying condition monitoring techniques to predict failures.
- Preparation and review of integrated support provisions for maintenance including maintenance plans, work instructions, specialised equipment/tooling, spare parts, technical data and information.
- Maintaining and updating the configuration management of engineering design documentation.
- Investigating plant failures and safety events to determine root causes of failures and implement action plans and lessons learnt to prevent reoccurrence.
- Supporting the implementation of asset acquisition, redesign and renewal projects in collaboration with capital projects and engineering teams to ensure projects are delivered consistent with safety, reliability and maintainability requirements.

5.2 Centralised engineering

The ANSTO site is also supported by other centralised engineering teams as outlined below.

5.2.1 ANSTO Maintenance & Engineering

A centralised engineering team, ANSTO Maintenance & Engineering (AME) provides comprehensive engineering support in the fields of nuclear, mechanical, electrical, electronics, control systems, civil, construction, chemical/process, project management and detail drafting. Capabilities within AME include:

- Project management for research and development applications: project planning and execution, contract and construction management.
- Design, manufacturing and installation oversight of: active handling equipment; hot cell equipment; radioisotope production processes; radiation shielding; nuclear medical facilities and equipment; pressure and vacuum vessels; and transport packages for radioactive material.
- Design and Approval of: pressure vessels; radioactive transport packages; lifting equipment; Sealed sources; Active ventilation; welding methods; radiation gauges; piped gas and compressed air systems; control systems; electrical installations; and nucleonic systems.
- Software simulation/calculation: finite element analysis (FEA); seismic and structural; Static and dynamic process/chemical modelling; and computer aided design both in 2D and 3D modelling.
- Support for manufacturing, procurement, fabrication and installation.
- Electrical distribution equipment upgrade and expansion, control and monitoring system design and implementation, instrument troubleshooting and repair, instrumentation for scientific research including advice, design & implementation, programming and support for PLCs and SCADA systems.
- Safety assessments: HAZOP of processes; FMECA and FMEA of mechanical equipment; Risk Analysis (Qualitative and Quantitative); Functional safety consultancy (SIL assessment and verification); Safety analysis report preparation; Gap analysis of industrial installation against respective Australian and International standards; Risk Based Inspection Program and compliance for pressure vessels; and Licensing support and advice.

5.2.2 Nuclear Analysis Section

ANSTO's Nuclear Analysis Section (NAS) is a team of nuclear physicists and engineers that specialise in the fields of reactor physics, neutronics, shielding, criticality and thermal hydraulics. The group has experience in both experimental and theoretical aspects of these areas in support of operation, utilisation, and safety analysis of nuclear facilities. This includes fuel management strategies for the OPAL Reactor, support for development of irradiation targets and the development of any related safety analyses and relevant submissions for a variety of engineering, regulatory and other projects.

The group develops computational codes in the areas of neutronics, reactor accident analysis, and thermal hydraulics. It has expertise to run many internationally known and used code systems in the various areas of interest including Monte Carlo and Computational Fluid Dynamics (CFD) based codes. In addition, it performs targeted research and development in an experimental water tunnel facility.

5.2.3 Project Management

ANSTO has a well-developed project management regime which is utilised for the delivery of complex or major engineering projects. The Executive-level Capital Committee provides governance for these projects and is supported by the Capital Program Management Office (CPMO). The CPMO oversights project management policy and reporting, project management development and training, and performs independent prospect and project progress, performance, and process reviews.

ANSTO 's aim is to be an intelligent and well-informed customer, mobilising multi-disciplinary teams to create detailed user requirement specifications and applying a robust project management lifecycle framework.

Project planning at ANSTO.

6 Decommissioning capabilities

ANSTO has experience in the planning and decommissioning of nuclear reactors previously in operation on the Lucas Heights site including HIFAR and Moata.

6.1 HIFAR

HIFAR was a 10 MW heavy water DIDO class reactor originally built as a materials test reactor which was to be used for the establishment of a nuclear power industry. With the transition from AAEC to ANSTO in 1987, its primary use became for neutron scattering experiments and radioisotope production.

Following permanent shutdown of HIFAR in 2007 all spent fuel was removed from the reactor and repatriated to the country of origin and the heavy water, rigs/targets, safety rods and coarse control arms were subsequently removed removing any criticality or nuclear safety risk from the facility.

HIFAR is now a steel building containing the reactor block and shielding, the primary circuit, including the Reactor Aluminium Tank, the core internals, the graphite reflector and the Reactor Steel Tank. The existing Engineered Safety Provisions are also part of the facility, but other than the Active Extract Ventilation, are no longer required. Following the completion of initial post-closure activities, HIFAR is now a “de-fuelled facility” with a significant reduction in hazards. It is currently in a care and maintenance period before its final decommissioning is completed, licensed by ARAPNSA under a Posses or Control Licence.

Characterisation of the HIFAR Facility took place over a period of approximately four years from November 2014 until August 2018. This included drilling into the core to analyse core samples and the deployment of ANSTO’s own first-of-a-kind imaging technology – CORIS360TM – to examine the periphery of the reactor and supporting plant. This delivered world first radiation imaging inside a nuclear reactor vessel to support safe, cost effective reactor decommissioning. The device collected images inside the harsh environment at the top of the reactor vessel, where the dose rate reached 10 Sv/h. The deployed system could remotely image the entire vessel with a hemispherical field of view. This customised device successfully identified and located Co-60 as the dominant radionuclide present inside the HIFAR reactor vessel. A series of quantitative images, capturing the dose rates, were collected from four different locations where the technology was deployed. The imaging results were able to quantitatively determine the level of radioactivity of the identified components, with measured Co-60 activities ranging between 2.0 TBq and 17.2 TBq. The new characterisation data provided invaluable insights to construct a broader reactor dose model.

The HIFAR decommissioning project is currently developing the plans and arrangements and licence submission to ARPANSA for final decommissioning.

ANSTO’s HIFAR reactor.

6.2 Moata

Moata was ANSTO's second reactor and operated successfully for 34 years from 1961 until 1995. It was a small 100 kW Argonaut research reactor and was initially used for research and training, and later included activation analysis and neutron radiography. Commercially, Moata was used for approximately 15 percent of all procedures world-wide involving radiography to check the structural soundness of jet engine turbine blades. The reactor was also an important tool for Australia's uranium mining industry, providing rapid and accurate measurements of ore.

Moata was opened by Robert Menzies.

Following closure of the reactor, a number of major steps were taken to assist with final decommissioning. Fuel was removed in 1995, the primary (light water) coolant was drained in 1997, the reactor control system was removed in 1998, and a decommissioning licence was obtained from ARPANSA, in 2000.

In 2008, planning for dismantlement of the reactor in two phases was initiated. Phase One included removal of internal reactor components, steel core structures, graphite moderator and beamline facilities. Phase Two included biological shield dismantling with cutting and removal of the concrete shielding and floor area below the shielding. Detailed characterisation was undertaken of the two areas, including core samples and radiological surveys of components. This allowed for estimation of individual maximum and collective doses, as well as final waste disposition.

Modelling of the reactor shielding block was generated and a scale model built. This model was used in conjunction with the detailed radiological surveying to practice dismantling protocols, determine order of cuts, and minimise dose to workers. Radiation protection was integrated with management of conventional safety factors including working from heights, wire cutting, dust generation and use of plant and equipment (excavator, mobile crane).

Safety was ensured by oversight and design of operations with input from ANSTO radiation protection and WHS advisors, bespoke safety induction for contractors, daily safety checks, and toolbox talks. Safe work method and environment work statements were generated and included risk assessment and mitigating actions. The radiological doses received were well within regulatory constraints and planned estimates and complied with the as low as reasonably achievable (ALARA) philosophy.

A key consideration for the dismantling operation was the close proximity of sensitive (detection limit $1x10^{-14}$) C-14 accelerator mass spectrometry facilities and the need not to compromise this capability during the removal of 12 tonnes of graphite. A containment tent with HEPA filtering was constructed around the reactor block to address this requirement. Dismantling staff had to work within this confined setting.

Waste management included segregation of radiologically exempt material from contaminated materials. Exempt materials were cleared to public disposal facilities. Contaminated materials were stored in shielded containers on-site, ready for disposition to a national waste facility when available.

The project was awarded the National Best Small Project Award 2010 by the Australian Institute of Project Management.

7 Approach to nuclear safety

ANSTO's approach to nuclear safety is aligned to the IAEA framework, including:

- IAEA Fundamental Safety Principles, SF-1
- IAEA Leadership and Management for Safety, GSR Part 2
- IAEA, Basic Safety Standards, GSR Part 3
- IAEA Management System for Faculties and Activities, GS-R-3
- Safety Assessment for Facilities and Activities, GSR Part 4 (Rev1)

Each Controlled Facility as described under the *Australian Radiation Protection and Nuclear Safety (ARPANS) Act* and Regulations is described in a Safety Analysis Report, with a supporting Safety Assessment developed to comply with GSR Part 4. The SAR and Safety Assessment are developed using ANSTO subject matter experts and owned by the line function responsible for the safe operation of the facility. The SAR, Safety Assessment and supporting documentation are subject to independent assessment through the Safety and Reliability Assurance (SRA) process.

The SRA process provides assurance all hazards associated with ANSTO's activities have been identified and controlled in accordance with the hierarchy of controls. It ensures that all reasonable steps have been taken so that the residual risks to the health and safety of ANSTO staff and the community will be reduced so far as is reasonably practicable and provide a net benefit. The process also ensures ANSTO is meeting its obligations under the Work Health and Safety Act and Regulations and ARPANS Act and Regulations for the activities it undertakes.

The process is supported by and ensures compliance with:

- ISO45001: 2018 Occupational Health and Safety Management Standard: Requirements
- AP-2300 ANSTO Work Health & Safety Management System Overview
- AE-2301 ANSTO WHS Risk Management Standard
- AE-2310 ANSTO Radiation Safety Standard

Activities are assessed for safety related hazards and the effectiveness of the control measures depending on the potential impact of the hazards identified. An assurance process, commensurate with the level of risk is applied to ensure activities are controlled and the residual risk is as low as reasonably practicable and broadly acceptable in line with current occupational risks. The procedure involves the following stages:

- Screening of activities for safety significance
- Safety control evaluation
- Activity acceptance
- Independent review for activities where there is a regulatory impact
- Periodic review of activities

Any new activity or equipment or change to an existing activity or equipment, that involves a potentially significant safety or environmental hazard must be assessed to determine the significance of the hazards present. The inherent and residual risks and consequences are assessed against ANSTO's Risk Matrix and Risk Appetite statements, which have been approved by ANSTO's Board. Where the new or changed activity presents an impact level of moderate or above or an inherent level of risk of medium or above a safety control evaluation according to this procedure must be performed to ensure effective controls are in place to adequately mitigate that risk.

In assessing the proposed activity, the potential impacts of incorrectly conceiving or executing the proposal shall be the guiding principle applied. Activities/areas to be considered are:

- Designated hazardous areas
- Hazardous processes
- Major plant design and operation
- Changes to an ARPANSA licence with significant implications for safety (Section 63 of ARPANS Regulations 2018)
- Significant changes or modification(s) to a facility, including changes to radiological hazards, operating design limits, process equipment specifications, composition or use of chemicals or other substances, process design or facility layout.
- The use of materials or equipment requiring approval from Comcare (the Commonwealth WHS regulator).
- Constructing an item important to safety in an ARPANSA licensed facility (Section 66 of ARPANS Regulations 2018)

Regulatory submissions with a potential safety impact must be endorsed by the Chief Nuclear Officer (CNO). The CNO conducts and independent review of activities conducted under a Controlled Facility Licence and presents a summary report and recommendations to the CEO and Executive annually.

7.1 Radiation protection

At ANSTO exposures from external sources of radiation are controlled using accepted nuclear industry standards based on time, distance and shielding. Examples of the source terms routinely handled include Spent Uranium Filter Cups, with a contact dose rate 1 Gy/hr which are transferred between hot-cells and shielded storage pits in transfer flasks, and the GATRI irradiation facility which has a maximum dose-rate of 1 kGy/hr. ANSTO uses a series of controls and principles, including:

- Use of shielding as a passive engineering control in shielded hot-cells, transfer flasks, transport containers, and storage configurations, and use of water as a shield for the OPAL reactor core and storage of disused sealed radioactive sources;
- Rigorous controls over access to areas with a radiation hazard, including linking area access to appropriate training in radiation protection;
- Use of engineered controls, interlocks, and key capture measures;
- Installed area monitoring, backed up with radiation surveys by both operators and Health Physics Surveyors (HPS); and
- Use of active and passive dosimetry to measure effective and equivalent doses (to extremities and the eye).

ANSTO has also undertaken significant non-routine activities involving significant radiation hazards such as the dismantling of the Moata reactor, replacement of in-pile components in the OPAL Reactor, shipment of spent reactor fuels from both the HIFAR and OPAL reactors and receipt of vitrified, reprocessed waste residues from France. All these activities have been carefully planned and carried out within the approved collective and individual dose-budgets.

The ANSTO Radiation Safety Standard explains the system of radiological classification of areas used to control, prevent, limit, and review occupational exposure (actual or potential) to ionising radiation. This system of radiological classification ensures that occupational dose limits and dose constraints are not exceeded and kept as low as reasonably achievable (ALARA).

Radiological monitoring provides the basis for operational radiation safety assessment. Monitoring programs for workplace radiological conditions surveys and individual exposures using personal dosimeters such as Thermo-luminescent Dosimeters (TLDs) and Electronic Personal Dosimeters (EPDs) are in place.

Routine, task-related, and special monitoring is undertaken as required. Routine monitoring is the foundation of the operational monitoring program and consists of planned monitoring that confirms the radiological conditions and levels of individual dose to meet radiation protection requirements and objectives. Task-related monitoring applies to a specific activity and can be used to provide data on the safe management of the activity and decisions on protection techniques (and their optimisation).
Task specific radiological surveys are performed before and during tasks as required by a Safe Work Method and Environmental Statement (SWMES) or other risk assessment.
Special monitoring is mainly undertaken as part of investigations to provide detailed information to assess or define facilities or procedures, possibly during abnormal conditions.

The control of contamination and potential exposures to staff, visitors, the pubic and the environment are all carefully controlled, following the hierarchy of controls. Wherever practicable, radioactive material is contained to prevent a release of contamination. The engineered controls for this are:

- Ventilated hot-cells which provide a physical containment boundary by operating the cells at a negative pressure relative to the external environment.
- Facilities using unsealed radioactive materials will have an active ventilation system, which maintains the facility at a negative pressure to the surrounding environment. Within these facilities there will be a cascade to lower ambient pressures, with extracts being directed to a dedicated ventilation stack fitted to appropriate abatement technologies (e.g. HEPA filters or carbon columns).

Areas in which unsealed radioactive sources are handled or may be present are designated as Contamination Controlled areas, with access via a change barrier. All activities on the active side of the barrier are conducted using the PPE required for the area. On leaving the area and at specified intervals whilst working in the area, staff undertake personal monitoring to ensure that they are free from contamination. If contamination is detected, staff are trained to assist each other in removing contaminated PPE, self-washing and notification of facility managers, Health Physics personnel and Emergency Response Teams as required.

Areas are monitored for contamination by both operational staff and Health Physics and any contamination detected is reported through ANSTO’s event reporting system. ANSTO has established criteria for classifying contamination events, with the investigation required being driven by the classification.

Where the potential for localised airborne contamination exists, appropriate respiratory protective equipment is used by trained staff and airborne monitoring for particulate or volatile isotopes is carried out.

ANSTO has facilities for both in-vivo (Whole Body Monitoring) and in-vitro (urine sampling for tritium) for measuring internal exposures. Whilst these are routinely carried out for assurance purposes, they can also be deployed as part of incident investigation.

7.2 Environmental monitoring

ANSTO applies appropriate abatement of airborne discharges through established international techniques. Buildings which have the potential for airborne releases are identified and active ventilation systems are installed. These systems maintain the facility under a negative pressure relative to the external environment, with further increasing negative pressure cascading airflow to a dedicated extract system. The extract system is fitted with appropriate abatement technologies for particulate and gaseous systems and discharges to the environment are monitored and assessed.

ANSTO monitors defined sources of airborne emissions from specified discharge stacks. The dispersion of the assessed discharges form inputs into environmental models developed by ANSTO to match the specific topography surrounding ANSTO. Other inputs include meteorological data from the dedicated meteorological station situated in the centre of the Lucas Heights facility.

The output from the dispersion modelling is inputted into a standard dose modelling package (PC-CREAM) to identify doses at specific receptor sites around Lucas Heights from all exposure pathways. ANSTO uses a hypothetical "Critical Group" – members of the public who reside on the 1.6km boundary of the exclusion zone. Members of the critical group are assumed to reside on their property for 23 hours a day and grow 25% of the food they consume. If the dose estimated to this hypothetical critical group are acceptable, the actual dose to a real member of the public would be significantly lower.

The IAEA sets an annual dose constraint of 300 µSv for a member of the public from a single site. ANSTO imposes a target maximum dose to the critical group of 20 µSv per annum. Actual estimated doses from the ANSTO Lucas Heights site are less than 5 µSv per annum from airborne discharges.

The release of radioactive liquid is done in line with ANSTO's trade waste agreement with Sydney Water and is released with other liquid wastes from site. ANSTO's agreement requires that the radioactive content in the waste is below the World Health Organisation standard for radioactivity in drinking water on receipt at the Cronulla Water Treatment Plant. Measurement by ANSTO's Environmental Monitoring Group has shown that the levels of dilution between discharge from ANSTO and receipt at Cronulla demonstrates that ANSTO is orders of magnitude below the criteria in the trade waste agreement.

Additionally, ANSTO's Environmental Monitoring Team undertake a program of analysis of flora and fauna in the natural buffer zone adjacent to both ANSTO and the outflow from the Cronulla Water Treatment Plant to confirm that environmental discharges are not accumulated in the local ecology.

ANSTO's environmental discharges are submitted to the regulator, ARPANSA, and published to the public.

7.3 Radiation monitoring in support for the Visiting Ships Program (Nuclear)

ANSTO is a member of the Australian Government interdepartmental Visiting Ships Panel (Nuclear) – VSP(N) – to control arrangements for visits to Australia by nuclear powered warships (NPW) and other nuclear-powered vessels.

ANSTO is responsible for the development of strategic and operational plans and the coordination and implementation of the Nuclear-Powered Warship (NPW) Radiation Monitoring Program as required by the Defence Operations Manual (OPSMAN1). These plans are formulated in accordance with ARPANSA's Guide for Radiation Protection in Emergency Exposure Situations (Radiation Protection Series G-3 Part 1) and Guide for Radiation Protection in Emergency Exposure Situations – Planning, Preparedness, Response and Transition (Radiation Protection Series G-3 Part 2).

ANSTO has been providing support to the Australian Defence Force for visits of nuclear-powered vessels in Australian ports since 1976. This support encompasses provision of on-ground assets and personnel, conduct of exercises, and validation of ports for hosting the vessel.

Under the VSP(N), ANSTO provides additional support in the event of an incident. The immediate response to a NPW accident is provided by local radiation monitoring groups, comprising State radiation health, emergency services personnel or navy reservists under the direction of an ANSTO health physicist. This would be augmented during the early response phase by additional ANSTO resources.

The average number of visits have been around 2-3 per year for approximately 10-20 days in total. There has been a rolling biennial program of port validations mainly for Brisbane, Fremantle, and Darwin. Melbourne and Hobart have historically been done on a desktop review basis.

8 Approach to nuclear security

ANSTO has a dedicated Nuclear Security and Nuclear Safeguards (NSNS) Division of 16 staff led by the Chief Security Officer (CSO) responsible for general organisation security and nuclear security and safeguards responsibilities including:

- Protection against unauthorised the removal (theft) of nuclear and other radioactive materials and sabotage to facilities.
- Recovery of missing, lost or stolen nuclear and other radioactive materials.
- Mitigation and minimisation of the effects of sabotage.

The NSNS Division is responsible for the ANSTO Security Plan. Facilities within the Organisation that hold nuclear material and radioactive sources manage individual, facility-specific security sub-plans with the NSNS Division providing technical and other second-line support to each facility.

The NSNS Division is also responsible for maintenance of the ANSTO Security Manual (SECMAN). The SECMAN is modelled on the Commonwealth's Protective Security Policy Framework (PSPF). As a Corporate Commonwealth Entity, ANSTO is not required by Government policy to implement the PSPF but does observe the requirements, recognising the good practice standards.

The ANSTO Security Plan and SECMAN both draw on IAEA Nuclear Security Series guidance. The general guidance of the IAEA is adapted to the Australian context through ANSTO's 'Permit to Possess Nuclear Material and Associated Items', which is issued by our primary nuclear security regulator, the Australian Safeguards and Non-proliferation Office (ASNO).

Processes are in place for the recording and follow up of security incidents. The electronic security system is continuously monitored, recorded, and is reviewed daily to identify and action system faults. Security incidents and performance deviations are well recorded through the Organisation's event reporting platform.

The development of a nation-specific Design Basis Threat (DBT) is an IAEA suggestion to theorise the plausible capabilities of potential insiders and external adversaries who might attempt unauthorized removal of nuclear and other radioactive material or sabotage. Australian Government agencies collaborate to maintain a national nuclear security threat assessment and to identify potential adversaries, their attributes and characteristics, and the possible adversary actions that inform periodic updates to the Australian DBT. ANSTO's protection systems are required by regulation to be designed and evaluated relative to the DBT.

The full Australian-defined DBT is classified while a less detailed, unclassified version is available as open-source information. In summary, the Australian-defined DBT is a small assault group of well resourced, determined and dedicated individuals seeking to sabotage a nuclear reactor or steal nuclear material. The adversaries are willing to kill and risk death. They are armed with firearms and explosives, have hand tools and some specialist equipment, drones, land vehicles (motorbikes, cars or trucks) and may use a combination of tactics and diversions. The DBT may be supported by an informed insider(s) and/or an advanced, persistent cyber-attack. The DBT also includes the potential for sabotage attack by aircraft impact.

The Australian Security Intelligence Organisation (ASIO) has assessed vulnerabilities in the layered ANSTO (Lucas Heights) and OPAL physical protection systems. Periodic, independent vulnerability assessment is an acknowledged good practice to monitor the effectiveness of the physical protection systems and to identify improvements on a risk-based priority. That is particularly the case when high confidence is attributed to the effectiveness of the original facility design security features. Another recognised benefit of updating some of the core security risk tools is to review multi-agency interoperability for emergency and contingency response.

The NSNS Division is developing a partnership with the US Department of Energy, National Nuclear Security Administration (NNSA) – through the Office of International Nuclear Security – for information exchange and potentially the secondment of an NNSA employee to Lucas Heights. This partnership has potential to enhance the NSNS Division's engagement with good practice research and our adoption of operating improvements. Benefits for the NNSA lie in having a 'footprint' in South-East Asia and a local partner through which to conduct regional engagement and training.

8.1 Personnel security

Through the NSNS Division’s Personnel Security Section, ANSTO adopts the PSPF good practice policy for assessing the eligibility and suitability of personnel. Pre-employment screening is conducted for employees, business contractors and most non-business (construction and other trades) contractors. A small percentage of ANSTO staff hold a national security clearance due to the information access and responsibility of the role; national security clearances are vetted and provided by the Australian Government Security Vetting Agency (AGSVA) within the Department of Defence. Pre-employment screening in combination with access control provides the foundation measures for securing ANSTO’s information, assets and material from insider threats. Insider threat monitoring is anchored in general security awareness and a pro-reporting culture, along with information technology system surveillance.

The ANSTO personnel security assessment vets the eligibility and suitability of individuals seeking access ANSTO to sites, information or resources. The assessment process reviews individual integrity, honesty and potential risks associated with foreign contacts. Two in-house (i.e. non-national security) vetting and clearance levels are applied, depending on the requirements of each role - General (limited) Area Clearance or Protected Area Clearance. ANSTO clearances include third-party checks, such as a national police records check and counter-terrorism intelligence check. Both categories of clearance require an individual to be an Australian citizen or to have a CEO’s citizenship waiver.

A General Area clearance allows physical access to ANSTO sites, access to the ANSTO IT network, general administration/office buildings and some research facilities. A Protected Area clearance allows access to selected protected areas on a “need to access” basis for their role. A Protected area clearance is required for access to Vital Areas, which have additional access controls such no lone workers, PIN pad and remote authentication.

National Security Clearances are conducted for those needing access to security sensitive areas, national security classified information, and inter-agency coordination, or who hold a specific position of trust that requires a deeper level assurance than in-house vetting affords.

NSNS Division process an average of 1500 clearance and access requests annually, while maintaining approximately 2000 active clearances. Each year there are between 100 to 200 Protected Area clearances, with the balance being General Area clearances. Guest researchers are a separate category of access request, being visitors from other Australian and international research centres who seek access to ANSTO’s research facilities, equipment and instruments. The request for access by Guest Researchers is conducted in two parts. The first is an assessment of the research proposal for the allocation of facility time, the second aspect is basic probity checks to assess security risks. With access granted, Guest researchers are afforded limited facility and IT access that is sufficient to enable their research.

An average of 20 applications (approximately 1.3 per cent) are declined each year. Applications are declined for noncompliance with minimum document requirements, background character assessment (e.g. criminal convictions) or foreign interference concerns.

8.2 Physical protection

The physical protection of nuclear material, radioactive sources and our facilities is the central element of ANSTO's security system. The focus is on controlling access to mitigate the threats and consequences of material or technology theft and sabotage. The NSNS Division applies the theoretical characteristics of the DBT to determine the effective physical protection system from the initial design approval through to daily operation of the detection, delay and response functions.

The Physical Protection System (PPS) is based on a graded approach that considers the current evaluation of plausible threats, the relative attractiveness of targets (including ANSTO and Australian Government reputation), the nature of the nuclear material and potential radiological or other impact consequences. The system is designed and operated to achieve defence in depth, with several layers and methods of protection (structural, other technical, personnel and organisational) that must be overcome or circumvented by an adversary in order to achieve malicious objectives.

In addition to assessing the enterprise level security risks, the controls required to secure a specific facility or target are assessed through the development of plausible attack paths or Adversary Sequence Diagrams (ASD). This approach to individual target analysis along all plausible attack paths assists the identification of the detection and delay measures required to allow for an effective response before the realisation of harm.

Insider threats present an additional challenge to the external adversary due to attributes of: authorised access; knowledge of layouts, targets and routines; and potentially a level of authority to influence the environment. The primary mitigation of insider threat serves a dual safety purpose, with measures such as 'no lone worker' protocols and remote authentication (ie. security control room knowledge) measures applied to sensitive areas.

ANSTO's campuses and facilities feature administrative controls (e.g. land use and airspace restrictions) and physical barriers (e.g. fencing and proximity card door locks). The NSNS Division is responsible for harmonising the requirements of PSPF security zones and IAEA access areas.

Design of the PPS is primarily influenced by the IAEA approach to defining areas, based on the sensitivity or potential for harm associated with categories of material and technologies. Access is controlled to provide a buffer around protected areas (containing Category I or II material and/or sabotage targets) and vital areas (containing material or equipment that, if sabotaged, could lead to unacceptable radiological consequences).

ANSTO sites feature an on-site guard and response capability, graded for the scale and risk profile of the site. The Lucas Heights site features a combined security and safety monitoring control room staffed by a national scale private sector security contractor. ANSTO contracts a guard and response force from the Australian Federal Police (AFP) Protective Service. The AFP operates a station, like those found at many other key installations such as the Federal Parliament and some Defence facilities.

The ANSTO Security Operations Centre (ASOC) is the primary point for the detection function by monitoring sensors, alarms and receiving reports from staff. The AFP provides high visibility (deterrence) patrolling and low-impact response to routine detections in the greenfield area and to alarms (e.g. an unsecured door). The AFP also provides on-site response to threats in accordance with ANSTO's Nuclear Security Contingency Plan, which includes triggers for an escalated response from off-site by State (New South Wales) Police.

8.3 Information security

Commitment to maintain the security of its information is detailed in the Board approved ANSTO Information Management Policy, which directs compliance with Australian legislation, regulations and policies and international codes. Central to ANSTO's information security is the requirements of the Commonwealth's PSPF. ANSTO's information security is based on the identification of information holdings and assessments of sensitivity and security classification, and the implementation of related operational controls, including physical protection, administrative controls, and cyber security controls.

ANSTO has separate CSO and CIO functions. The CSO, as lead of the NSNS Division, has non-technical responsibility that is confined to developing the Organisation's standards for non-digital information security with no enterprise oversight function. The primary information security and cyber defence responsibility rests with the Chief Digital and Information Officer, who leads the Information Technology Division.

ANSTO maintains a nuclear cyber security risk management framework following IAEA and Australian Government guidance. The IAEA provides guidance for a nuclear cyber security risk management framework, which ANSTO has applied to its technology landscape. The Australian Government Information Security Manual (ISM), also adopted by ANSTO, provides detailed definitions of the cyber security controls to be applied to mitigate risks. Figure 4 illustrates ANSTO's cyber security risk management framework.

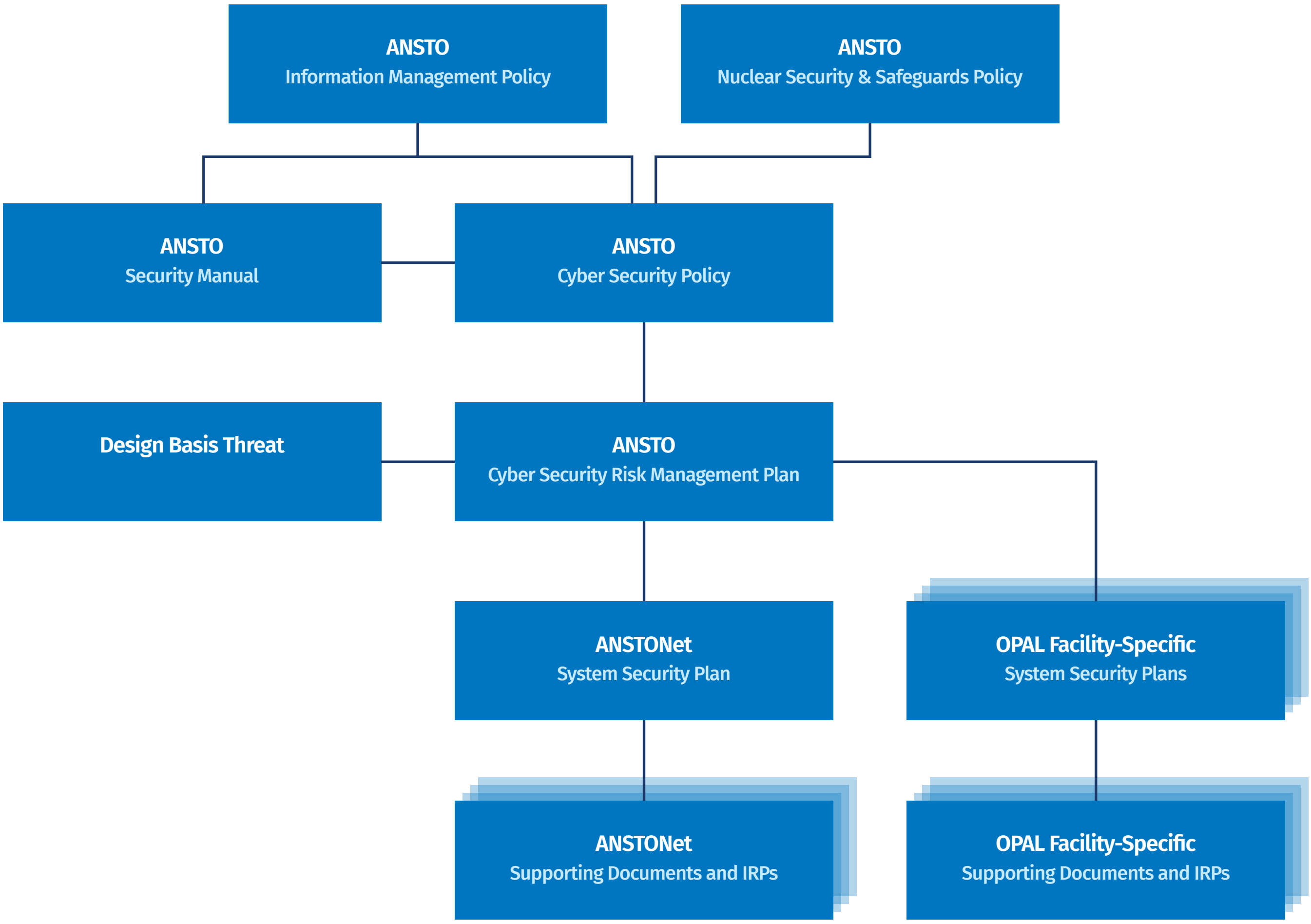


FIGURE 4 –
ANSTO's cyber security risk management framework.

ANSTO applies the Australian Cyber Security Centre supply chain cyber security guidance to significant projects, including assessments of suppliers' physical, cyber and personnel security maturity. For the OPAL Reactor, ANSTO performed supply chain cyber security risk assessments and audits during the most-recent Reactor Control and Monitoring System (RCMS) major upgrade in 2015 and is in the process of conducting supply chain cyber security assessments for the major First Reactor Protection System (FRPS) upgrade project. ANSTO reports overall cyber security maturity status to the Australian Signals Directorate as part of the whole-of-government annual cyber security survey. Survey results are used to gauge ANSTO's cyber security maturity compared with other Australian government agencies and organisations.

As with the PPS, security applied to the IT framework uses a graded approach and achieves defence in depth. The main ANSTO IT network operates in the unclassified domain but is restricted to authorised users. Other systems variously have more restrictive access controls and in some instances segregation from the main network. For example, the OPAL Reactor facility features a range of Operational Technology (OT) systems essential for engineering, operation, maintenance, safety and security. The OPAL Reactor's OT systems are collectively known as "OPALNet" and is defined as a Cyber Security Level 1 Zone – the highest digital risk and control environment adopted within the Organisation.

Asset management responsibility of OPALNet systems, including the engineering and maintenance of cyber security controls is the responsibility of the OPAL Reactor Operational Technology team, through the OPAL Reactor Engineering Manager. Cyber security second-line support is provided through the IT Division's Cyber Security and Operational Technology Manager. The OPALNet systems are physically located within the PPS overlay of the Reactor Building Protected Area. All OPAL Reactor IT systems are physically isolated from other ANSTO computer-based systems using physically separate computer and network infrastructure. OPAL Reactor OT systems are broadly segregated into three systems: First Reactor Protection System, Reactor Control and Monitoring System, and OPALNet engineering and admin system.

The other large-scale isolated IT system is called SecNet, which is used to monitor and control the electronic aspects of the PPS. Those features include closed circuit television cameras, motion detectors, electronic access control and monitoring systems, electronically controlled gates, and vehicle barriers.

ANSTO has well established processes for identifying information and systems to be protected, and for applying controls proportional to their value, importance and sensitivity. Specific requirements for information security within Reactor Operations are documented and interface with the enterprise requirements detailed in ANSTO's Security Manual. These arrangements encompass physical protection, administrative and cyber security controls for information holdings and associated technology systems and are aligned with the PSPF.

9 Regulatory interface

As a nuclear organisation, ANSTO operates within a complex and highly-regulated business environment with varying degrees of accountability to more than 30 regulators across international, federal and state levels. In recognition of this complexity, we have developed a range of strategies, policies and systems that ensure compliance with relevant laws and regulations.

Being a Commonwealth agency, ANSTO's main nuclear safety regulator is the Australian Radiation Protection and Nuclear Safety Agency (ARPANSA). ANSTO holds some 22 licences with ARPANSA covering its nuclear installations (nuclear reactor, waste operations, nuclear medicine production), prescribed radiation facilities (e.g. Centre for Accelerator Science, Materials Fabrication Bay, PIE Hot Cells), and sources.

Licensing requirements are integrated into ANSTO's safety management processes. Each licenced facility or area has a Licensing Officer with knowledge of the specific safety requirements. Regulatory matters are considered in the Safety and Reliability Assurance process of internal approvals and reviews, with independent checks undertaken by subject matter experts for matters with regulatory impact.

In line with ARPANSA regulatory philosophy, ANSTO considers international best practice in preparation of its regulatory submissions and safe operation of its facilities and activities. ANSTO has recently completed a periodic safety and security review which involved international review and benchmarking against other industries.

ANSTO also holds a number of permits with the Australian Safeguards and Non-Proliferation Office (ASNO) for the control of nuclear material and associated technology and equipment. ANSTO has a safeguards team officers, supported by authorised officers in the respective areas of the organisation where nuclear material is held.

In the production of nuclear medicines, ANSTO also has to comply with Therapeutic Goods Administration requirements including Good Manufacturing Practices for safe use in human patients. GMP and TGA requirements are sometimes contradictory to safety and ARPANSA requirements requiring sophisticated technical solutions and regulatory interactions. For example generally GMP would require medicine to be manufactured under positive pressure to protect the product, were as radiation protection requirements would necessitate hot cells to be kept under negative pressure to minimise potential spread of radioactive contamination.

10 Conclusion

ANSTO is a small but sophisticated nuclear organisation based on 70 years of world leading nuclear science and reactor technology. While we (nor Australia) run a nuclear power program, the OPAL reactor is a complex, multi-purpose reactor with daily pool movements – including LEU nuclear medicine targets – that affect core dynamics including reactivity. Importantly, we have scientific facilities and expertise that support effective operation and maintenance of a complex reactor, such as post-irradiation examination hot-cells and advanced nuclear analysis. Our highly effective operational effectiveness has seen us become a class-leading reactor and supplier of nuclear medicines. As an open-pool type reactor, and producer of nuclear medicines, radiation protection mechanisms are robust and sophisticated. We have significant experience and capabilities in management of resultant radioactive waste generated from our operations. We operate in a highly secure environment and apply the highest levels of physical, personnel and information security.

While ANSTO has key nuclear facilities, much of our expertise lies in the capabilities of our staff. Our the small but highly specialised workforce has at least some capabilities in almost every area of nuclear fuel cycle.

A national naval nuclear power program would undoubtedly require a very significant scale up in Australia's nuclear work force, in terms of scale, complexity, infrastructure, and human capacity. ANSTO has the foundational elements on which to build and sustain the nuclear industry required.

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