Submission
No 59

INQUIRY INTO URANIUM MINING AND NUCLEAR FACILITIES (PROHIBITIONS) REPEAL BILL 2019

Organisation:	Australian Nuclear Science and Technology Organisation - ANSTO
Date Received:	18 October 2019

ANSTO Submission

to the New South Wales Legislative Council Standing Committee on State Development Inquiry into the Uranium Mining and Nuclear Facilities (Prohibitions) Repeal Bill 2019

ANSTO

18 October 2019

Introduction and Scope

As the custodian of Australia's nuclear science, technology and engineering capabilities and expertise, ANSTO (the Australian Nuclear Science and Technology Organisation) is pleased to make this submission to the New South Wales Legislative Council Standing Committee on State Development's Inquiry into the Uranium Mining and Nuclear Facilities (Prohibitions) Repeal Bill 2019.

ANSTO's support for, and involvement with, the Australian uranium industry spans multiple decades. ANSTO Minerals, a business unit of the organisation, is Australia's leading minerals process development consultancy. It has expertise in the leaching and processing of uranium ores, and has been active in the development and application of technologies for the uranium industry for more than 35 years. This work has been, and continues to be, instrumental in the minimisation of the environmental impacts of uranium mining and in the maximisation of the efficiency of production.

ANSTO Minerals has conducted studies for the majority of Australia's closed and operating uranium mines—Mary Kathleen, Nabarlek, Olympic Dam, Ranger, Beverley, Honeymoon, and Four Mile—and has undertaken development work for the Jabiluka, Koongarra, Mt Gee, Kintyre, Crocker Well, Westmoreland, Yeelirrie, Lake Way, Wiluna, Valhalla, Anderson's Lode, Samphire, Bigryli, Mulga Rock, and Benett Well deposits.

More recently, ANSTO Minerals has been engaged to support international projects at the Rössing and Langer Heinrich operations and the Trekkopje, Husab, and Marenica deposits in Namibia, the Mkuju River and Likuyu North deposits in Tanzania, the Kayelekera operation in Malawi, the Falea deposit in Mali, the Lumwana project in Zambia, as well as to support the development of projects in Sweden, Spain, Mauritania, and Canada. The work undertaken by ANSTO Minerals has supported numerous preliminary, definitive, and bankable feasibility studies.

ANSTO also is represented in the Organisation for Economic Co-operation and Development – Nuclear Energy Agency's (OECD–NEA) Expert Group on Uranium Mining and Economic Development. That Group is examining the contribution of uranium exploration and mining activities to socio-economic development, and assessing whether the uranium industry is effectively managed to deliver benefits to the local and national communities hosting, or affected by, uranium projects.

While ANSTO is agnostic about whether New South Wales—or Australia—might in future adopt, or consider the adoption of, nuclear power (and other nuclear fuel cycle activities currently prohibited by State and Federal legislation), the organisation is an 'intelligent observer' of international developments in nuclear power and other peaceful uses of nuclear science and nuclear technology. This knowledge and expertise is gained through the organisation's representation of the Australian Government in various International Atomic Energy Agency (IAEA) and OECD–NEA forums, in addition to its engagement with bilateral and multilateral partners.

As mandated by the *Australian Nuclear Science and Technology Organisation Act 1987* (Cth) (ANSTO Act), ANSTO plays a vital role in providing expert and technical advice on all matters relating to nuclear science, technology, and engineering. ANSTO also plays a critical role in informing policy-making in these areas.

In this regard, ANSTO has contributed to—or been the lead agency on—a number of relevant Federal parliamentary processes, including in support of Australia's accession to the Generation IV Framework Agreement for International Collaboration on Research and Development of Generation IV Nuclear Energy Systems and to the IAEA's Regional Cooperative Agreement for Research, Development and Training related to Nuclear Science and Technology for Asia and the Pacific—both of which are important forums for international cooperation on nuclear issues.

In large part through the agency of ANSTO, Australia has developed a strong international role and reputation in nuclear science and technology, including uranium mining, which has resulted in the country's *de facto* permanent membership of the IAEA's Board of Governors as the sole designated representative from the South-East Asia and Pacific Region. This position has given Australia—and ANSTO—important global responsibilities; it also has given the country a strong voice in ongoing discussions about the various peaceful applications of nuclear science and technology.

ANSTO's capabilities and expertise extend across the nuclear fuel cycle

These capabilities, and the extent of ANSTO's expertise through the various stages and focus areas of the fuel cycle, are highlighted in the table below:

Capability / Area of Expertise	Description
Materials science and materials engineering	ANSTO has established significant capability in the development of materials that are able to withstand extreme environments, and has expertise in characterising existing and advanced materials for the energy, defence, and aerospace sectors. Through the use of its landmark research facilities, the organisation is leading the development of renewable/clean energy technologies, battery materials, and the study of the structural integrity of materials. ANSTO's researchers have delivered numerous innovations in materials, including the ANSTO Synroc wasteform technology, particulate membrane technology for water filtration, simulation software for the maintenance and efficiency of power plant components, and an innovative micro-particle encapsulation technology. Conventional facilities are complemented by advanced microscopy, nanoindentation, and specialist laboratories for handling radioactive materials. ANSTO's expertise extends to theoretical calculations and modelling, and all industrial processes of the nuclear fuel cycle, with a focus on fuel resources and systems, reactor systems, and used fuel management.
Provision of expert advice	Section 5 of the ANSTO Act mandates the organisation to provide advice on aspects of nuclear science and nuclear technology, and the application and use of nuclear science and nuclear technology. ANSTO provides such advice to government, parliaments, ministers, departments and agencies, inquiries and investigations, members of the public, and international, multilateral, and bilateral partners—in pursuit of the national interest.
International relations	Section 5 of the ANSTO Act also mandates the organisation to act as a means of liaison between Australia and other countries in matters related to its activities. ANSTO is a member of, or represents Australia in, numerous international and multilateral forums, and maintains an extensive network of bilateral partners.
Silicon irradiation	ANSTO Silicon provides neutron transmutation doping silicon irradiation services for commercial customers for use in microelectronics and other specialised irradiations for research and industry, with 46 per cent of global market share.
Community engagement on nuclear fuel cycle activities	ANSTO's engagement with the Australian public has introduced new ways to discuss and think about nuclear issues, by taking the time to engage and educate non-scientific audiences about the benefits of nuclear science and technology, and about how the application of nuclear technologies relates to daily lives. ANSTO plays a leading role in nuclear education and is helping to grow a more informed generation of Australians about nuclear science and nuclear technology. ANSTO provides expert advisors to the IAEA on global nuclear education and engagement. A senior ANSTO officer also lectures and presents regularly at Australian and international

	conferences and universities on effective communication and community engagement programs about the nuclear fuel cycle.
Minerals processing	ANSTO Minerals provides consultancy and process development services, particularly in the areas of uranium, rare earth, lithium, and base metals processing, as well as radioactivity control and novel flowsheet design.
Development and manufacture of nuclear medicines	ANSTO Health develops, produces, and distributes diagnostic and therapeutic radiopharmaceuticals for hospitals and clinics, and radiochemicals, cold kits, and accessories for application in the health care sector, industry, and research.
Management of radioactive wastes	ANSTO has developed significant capabilities and expertise in the management of radioactive wastes, including the safe processing and storage of used reactor fuel. ANSTO has undertaken extensive research and development of future radioactive waste management techniques, including commercial waste management technologies, and provides expert advisory services to commercial and non-commercial clients.
Human health	ANSTO uses its infrastructure, capabilities, and expertise to: build knowledge and optimise the beneficial impacts of nuclear science on human health; produce nuclear medicines; and enable research into disease prevention and approaches to improve the detection, diagnosis, and treatment of disease.
Environmental applications of nuclear techniques	ANSTO has developed world-leading capability in the areas of water resource sustainability, environmental change management, and the impact of contaminants—employing nuclear techniques, including isotopic tracing analysis, radon measurements, and environmental radioactivity measurements, as well as geochemical and biological techniques and fine particle analysis.
Nuclear stewardship	ANSTO's Nuclear Stewardship capabilities include radionuclide metrology, ionising radiation detection and measurement, radioanalytical chemistry, nuclear forensics, and environmental monitoring.
Facilitation of research through the provision of landmark infrastructure	ANSTO is responsible for the operation and management of Australia's nuclear infrastructure and research facilities, including the Open Pool Australian Light-water Reactor, the Australian Centre for Neutron Scattering, the Centre for Accelerator Science, the National Deuteration Facility, the National Research Cyclotron, and the Australian Synchrotron; and is mandated under its Act to facilitate their use for or by academic, research, and scientific communities, government agencies, and commercial clients.
Nuclear decommissioning	ANSTO is the custodian of significant nuclear decommissioning expertise, having successfully decommissioned one of two shut down research reactors at its Lucas Heights campus. A serving ANSTO executive is Chair of the IAEA's Decommissioning Network.
Nuclear liability	Through the agency of ANSTO, Australia has developed significant capability in the development and maintenance of nuclear liability regimes. A senior ANSTO officer is Chair of the IAEA's International Expert Group on Nuclear Liability.
Reactor operations	ANSTO has overseen the design and construction, commissioning and operation of nuclear research reactors safely and efficiently for over 60 years, providing it with substantial reactor operations capability and knowledge.

Engineering and manufacturing	ANSTO has developed in-house capability to design and manufacture specialised equipment for use in active environments

Submission Outline

In making this submission, ANSTO notes—and draws on—previous submissions by the organisation to Federal and State Government nuclear inquiries and policy processes, which have focused on:

- the pre-requisites for nuclear power in Australia;
- the potential to expand existing, or to establish new, nuclear fuel cycle activities in South Australia;
- approaches to radioactive waste management;
- the benefits that might result from Australia’s membership of the Generation IV Framework Agreement;
- the cost of nuclear power when adapted for Australian circumstances;
- emerging nuclear technologies and international nuclear technology development efforts;
- the steps required for nuclear power to become a viable option in Australia; and
- other potential nuclear fuel cycle opportunities for Australia.

In addition, ANSTO has made submissions to previous Federal and State Government inquiries into energy policy, which have addressed:

- the assurance of Australia’s energy security and the potential role of nuclear power therein, including with regard to economic issues, legislative requirements, and public sentiment:
  - *ANSTO Submission to the Independent Review into the Future Security of the National Electricity Market*, February 2017;
  - *ANSTO Submission to the Energy White Paper – Green Paper*, November 2014;
  - *ANSTO Submission to the Energy White Paper – Issues Paper*, February 2014;
  - *The Role of Nuclear in Enhancing Energy Security in Australia*, Submission to the Select Committee for Fuel and Energy, July 2009; and
  - *The Nuclear Option as Part of a Diverse Energy Mix*, Submission to the Department of Resources, Energy and Tourism, June 2009.
- the need to target base-load generation as one of the most efficient ways to reduce greenhouse gas emissions, and technology considerations for base-load services with the available options:
  - *Relative Economics of Energy Generation for NSW*, Submission to the Public Accounts Committee Inquiry into the Economics of Energy Generation, February 2012; and
  - *The Nuclear Power Alternative for NSW*, Submission to the Owen Inquiry into Electricity Supply in NSW, June 2007.

This submission proceeds as follows:

- Part One – Uranium Mining
    - Technical Matters
    - Economic Matters
    - Environmental Matters
    - Social and Community Matters
- Part Two – Nuclear Facilities
    - Nuclear Power – Status and Developments
    - Other Nuclear Fuel Cycle Activities
    - Applications of Nuclear Science and Technology
    - Financial and Economic Considerations
    - Environmental Considerations
    - Health, Safety, and Security Considerations
    - Social and Community Considerations
    - Legal and Legislative Considerations
- Part Three
    - Useful Reports and Publications
    - Upcoming Meetings and Events.

ANSTO does not make any policy recommendations in this submission.

Part One – Uranium Mining

Technical Matters

Uranium is an important global energy commodity

A single 20 g uranium pellet is equivalent to the energy contained in 400 kg of coal, 410 lt of oil, or 350 m^3 of natural gas. Owing to its enormous inherent energy, uranium as a fuel source for nuclear power reactors accounts for about 10 per cent of global electricity production and 29 per cent of global low-carbon electricity production.[1] While nuclear power continues to be seen by some as a controversial topic, many countries view nuclear power as a significant component of their energy systems, especially as the world transitions to a low-carbon future.[2] Because of this, the World Nuclear Association predicts that there will be growth in the global production from uranium over the next 20 years.[3]

There are two important concepts to understand: radiation and radioactivity

Uranium is a naturally occurring radioactive material. When uranium decays, it emits low levels of radiation. The rate at which it decays is referred to as ‘radioactivity’, which is measured in the units of Becquerels (Bq). If the radiation, which can be in the form of particles or electromagnetic radiation, interacts with biological material, it will give a dose to that material. The most common unit for the measurement of dose is the Sievert (Sv). Dose limits for the exposure of people are set by regulators based on international standards.

In Australia, the average background radiation dose is approximately 1.5 millisieverts (mSv) per year, with sources of exposure including the sun, rocks, buildings, soils, food, and other humans. Background levels vary significantly across the world. Put in context, a routine X-ray of the abdomen will result in a dose of 13 mSv[4], while a worker at Olympic Dam would receive an average dose of less than 1 mSv in a year.[5] Dose limits are set at 1 mSv per year for members of the public and 20 mSv per year averaged over five years for radiation workers.

There are different techniques used for uranium extraction

Uranium has been extracted economically from ore bodies since the 1950s in Australia. Different techniques can be used to extract uranium, with the preferred method generally dependent on the nature of the ore body. Most processes involve a series of chemical process, including: leaching the ore with either acid or alkali solution, separating the leach solution from the un-leached solids (the tails – wastes), purifying and concentrating the uranium from the leach solution, and, finally, precipitating and then drying to produce a uranium oxide compound known as ‘yellowcake’. The leaching step can be conducted in a series of tanks, and then crushing/grinding the ore. This is the current practice at the Ranger Mine in the Northern Territory and the Olympic Dam Mine in South Australia.

Another method is to place the coarsely crushed ore into plastic-lined piles known as ‘heaps’, and then to irrigate the heaps with the leaching solution and to collect the uranium laden run-off. This is known as ‘heap-leaching’, and has been proposed for Olympic Dam. Finally, the leaching solution

---

[1] International Energy Agency (IEA), *Global Energy & CO_2 Status Report 2018*, IEA, 2019, https://webstore.iea.org/global-energy-co2-status-report-2018.

[2] IEA, *Nuclear Power in a Clean Energy System,* IEA, May 2019, https://www.iea.org/publications/nuclear/.

[3] World Nuclear Association (WNA), *The Nuclear Fuel Report: Global Scenarios for Demand and Supply Availability 2019-2040 (Summary)*, WNA, London, 2019, https://www.world-nuclear.org/our-association/publications/publications-for-sale/nuclear-fuel-report.aspx.

[4] ANSTO, *What is Radiation?*, ANSTO, Lucas Heights, November 2018, p. 9.

[5] WNA, *Occupational Safety in Uranium Mining*, WNA, March 2018, https://www.world-nuclear.org/information-library/safety-and-security/radiation-and-health/occupational-safety-in-uranium-mining.aspx.

can be injected underground directly into the unmined orebody, and then pumped back to the surface to recover the uranium that was leached (known as ‘in-situ recovery’). This is current practice at the Beverley and Four Mile uranium mines. The technologies used to purify and concentrate the uranium from the leach solution, principally ion exchange and/or solvent extraction, are well established and have not changed significantly in the last 30 to 40 years.

The risks are well understood

Uranium mining is a well-established activity that has been undertaken for more than 60 years. There are operating mines in every continent except Antarctica. Generally, the major occupational risks to mine workers are similar to those of other mining operations, and include hazards associated with heavy equipment and machinery, hazardous chemicals, and working at heights or in confined spaces. These risks are managed within the safe work legislation of the respective jurisdictions. The additional radiological hazards associated with mining uranium must also be addressed. The most significant radiological hazard is usually the inhalation or ingestion of radioactive dusts or the inhalation of radon gas, which typically is managed through the use of ventilation and breathing protection apparatuses, where necessary. The same is true of workers involved in drilling programs for exploration projects.

Aside from risks to the mine workers, the potential for harm to the environment must also be carefully considered. While these risks are explored in further details below, tank and heap leaching operations produce ‘tailings’, which consist of the un-leached solids. The tailings management plan for any proposed plant must include a consideration for the safe accumulation of these solids during a mine’s operation, as well as the plan and funding for the area’s remediation post-operation. In the case of in-situ recovery, no tailings are expected to be produced; however, this method can only be used where there is sufficient geological containment to prevent the escape of the leaching solution into the surrounding areas. This usually is managed by continually drawing out more water than is pumped underground, and by continuous monitoring of the waters surrounding the area being leached.

Economic Matters

Uranium production and demand is relatively steady, but there are fluctuations

According to the 2018 Uranium ‘Red Book’, a collaboration between the OECD–NEA and the IAEA, total identified global uranium resources (both reasonably assured and inferred) amount to 6,142,200 tonnes—recoverable at up to US$130 per kilogram.[6]

Available figures for worldwide exploration and uranium mine development expenditure are current at 1 January 2017. These figures show that expenditure totalled US$663,678 million in the reporting period, which was a 59 per cent decrease on figures reported in 2014. For 2016 to 2017, Canada had the highest uranium exploration and development expenditures, followed by China and India. Australia’s figures are current as of 2016, and show that AU$23.4 million was spent on exploration and mine development in the same year—a decrease from the AU$44 million expended in 2015.[7]

Australian recoverable resources of uranium account for about 30 per cent of the total known global resource, with approximately 80 per cent of this resource located in South Australia. Five mines are licensed to operate in Australia (Beverley/Beverley North, Four Mile, Honey Moon, Olympic Dam, and Ranger), though only three of these are operating due to market forces. Australia is the only producing country in the Pacific region.

Despite the aforementioned fall in exploration and development expenditure, Australia was the world’s third largest producer of uranium in 2018 (6385 tonnes uranium [tU] – 12 per cent), behind Kazakhstan (21,540 tU – 41 per cent) and Canada (7000 – 13 per cent), respectively.[8] Namibia (11 per cent), Niger (six per cent), and Russia (five per cent) rounded out the top six producing countries, which together accounted for 88 per cent of uranium production. This represented a 12 per cent decrease on production in 2017.[9] In situ recovery is now the dominant method of extraction, accounting for 50 per cent of uranium production, up from 15 per cent in 2000.

The world’s supply of uranium is believed to be more than adequate to meet projected requirements for the next 130 years, regardless of the role that nuclear power plays in meeting future electricity demand and global climate change mitigation objectives. Demand for uranium is a function of the number of reactors operating, which itself is a function of electricity demand. The role that nuclear energy will play in helping to meet projected global electricity demand, therefore, will depend on government policy decisions, with attendant impacts on uranium demand.

The global uranium market is fairly stable

According to the OECD–NEA, citing data produced by TradeTech, banks and hedge funds are displaying more interest and engagement in the global uranium market. As evidence of this, a new market fund, ‘Yellow Cake’, has been established to facilitate the acquisition and delivery of uranium oxide. Moreover, while intermediaries dominate in the spot market, producer buying has steadily

---

[6] OECD–NEA and IAEA, *Uranium 2018: Resources, Production and Demand*, A Joint Report by the Nuclear Energy Agency and the International Atomic Energy Agency, OECD–NEA and IAEA, Paris and Vienna, 13 December 2018, http://www.oecd-nea.org/ndd/pubs/2018/7413-uranium-2018.pdf.

[7] OECD–NEA and IAEA, *Uranium 2018: Resources, Production and Demand*.

[8] Grancea, L., ‘Global Context of Uranium Mining’, Uranium Mining and Economic Development Expert Group Meeting, OECD–NEA, Paris, June 2019.

[9] Grancea, ‘Global Context of Uranium Mining’.

increased in order to meet contractual terms.[10] Global trade of natural uranium amounted to about US$4 billion in 2018.[11]

Between 2011 and 2017, both spot and long-term contract prices declined. However, since 2017, prices have made somewhat of a small recovery, and on 7 October 2019, the spot price stood at US$25.30 per pound.[12] It is unlikely that uranium prices will increase substantially in the near-to-medium future, which means there is little impetus to identify and develop new uranium deposits at present.

Uranium mining contributes to socio-economic development, but the potential contribution to New South Wales is unclear

Uranium exploration and mining activities can deliver substantial developmental benefits for the communities and localities in which those activities occur. The South Australian Nuclear Fuel Cycle Royal Commission, for example, found that that State's uranium industry had 'produced substantial benefits to the South Australian economy, and will continue to do so.'[13] In the decade to 2016, uranium contributed more than AU$3.5 billion to the State's export revenue and delivered AU$141 million in royalties.[14]

Operations at Ranger have resulted in the payment of more than AU$500 million in royalties over the lifetime of the mine.[15] Since 2013, royalty payments have been calculated on 5.5 per cent of net sales revenue from mine production. The equivalent of 4.25 per cent of Ranger sales revenue is paid to Northern Territory-based Aboriginal organisations. The remaining 1.25 per cent of royalties are paid to the Australian Government, and are then distributed to the Northern Territory Government. Royalties paid by Energy Resources of Australia, which operates Ranger, amounted to AU$10.7 million in 2018. The company also contributes more than AU$100 million in salaries and local spend in the Jabiru region annually.[16]

It is important to acknowledge that not all experiences of uranium projects have been reported by stakeholders to have been positive and beneficial. The public statements of Mirrar Traditional Owners of the Ranger mine in this regard are instructive[17].

In the absence of reliable data about the uranium resource in New South Wales due to limited historical and contemporary exploration activities, it is difficult to postulate the potential value and scale of the socio-economic benefits that might accrue to the State were prohibitions to be lifted and new uranium mines were to become economic.

---

[10] Grancea, 'Global Context of Uranium Mining'.

[11] Kozak, D., 'Main findings', European Commission, EURATOM Supply Agency, Meeting of the Expert Group on Uranium Mining and Economic Development, Paris, 17-19 June 2019.

[12] Cameco, *Uranium Price*, Cameco Corp., 2019, https://www.cameco.com/invest/markets/uranium-price.

[13] *Nuclear Fuel Cycle Royal Commission Report*, p. 23.

[14] Department for Energy and Mining, *Uranium*, Department for Energy and Mining, 2019, http://energymining.sa.gov.au/minerals/mineral_commodities/uranium.

[15] Energy Resources of Australia, *Sustainability Report*.

[16] Energy Resources of Australia, *Sustainability Report*.

[17] See, for example: Margarula, Y., 'Jabiluka: Traditional Owner Statement', in *Mirarr fighting for country, protect our living tradition*, Information Kit Module 3: Statements & Map, Gundjeihmi Aboriginal Corporation, 1999.

Environmental Matters

Environmental impacts of uranium mining

The mining of all minerals and metals presents environmental impacts, including land clearance, land disturbance resulting from the removal of overburden, changes to the water table, and the potential unplanned discharge of hazardous chemicals.[18] However, adverse impacts to the environment are less likely to occur today as responsible mining practices seek to identify risks and to implement strategies to prevent, mitigate, and/or manage those risks across the life-cycle of a mine.

Significant attention has been given to the environmental impacts associated with the development of uranium mines, in particular. Those impacts, for the most past, are the same as for any other mineral or metal extraction process. However, certain impacts are attributable to the unique chemistry and radioactivity of uranium and its decay progeny. For example, some aquatic species can concentrate these radioisotopes, with further accumulation in the food chain. Indeed, studies from Canada have shown that uranium can accumulate in freshwater plants in high concentrations.[19] The majority of radiological effects, though, are negligible, particularly in Australian uranium mines, which are well-regulated, and the environmental risks posed are similar to other extractive operations.[20]

Environmental exposure

The principal environmental exposure pathway for all mining operations is via surface water, because of its ability to provide a transport mechanism for contaminants, for example, through the discharge of process or waste water into streams or groundwater. Wastewater can contain chemicals, metals, and, in the case of uranium mining, radionuclides of a higher-than-background level, which may present environmental risks if containment systems fail. Environmental exposures also may occur through the air (dust or radon gas are common pathways), contaminated soil, sediments, or via gamma radiation emitted by radionuclides in contaminated materials.

The disturbance of land, the temporary storage of ores and waste on site, the dewatering of mine pits, and a variety of other activities undertaken for all mining operations, regardless of the commodity being mined, have the potential to contaminate soil, produce dust, and affect surface water quality.[21] As such, despite uranium mining presenting additional radiological risks, the environmental exposure pathways remain the same for uranium and other mines.

Acid mine drainage

Acid mine drainage, commonly referred to as ‘AMD’, is formed through the oxidation of metal sulphides present in uranium ore or in mining waste material by micro-organisms. These micro-organisms thrive under acidic conditions. As uranium processing typically involves acid leaching, any inability to manage acidic liquids, including wastewater, presents a risk of AMD occurring.

---

[18] Heard, B., *Environmental impacts of uranium mining in Australia: History, progress and current practice*, A policy paper commissioned by the Minerals Council of Australia, Forrest, May 2017.

[19] Kay, P., *Australia’s Uranium Mines – Past and Present*, Science, Technology, Environment and Resource Group, Parliamentary Library, Parliament of Australia.

[20] Kay, *Australia’s Uranium Mines – Past and Present*.

[21] Committee on Uranium Mining in Virginia, Committee on Earth Resources, National Research Council, ‘Potential Environmental Effects of Uranium Mining, Processing, and Reclamation’, in *Uranium Mining in Virginia: Scientific, Technical, Environmental, Human Health and Safety, and Regulatory Aspects of Uranium Mining and Processing in Virginia*, National Academies Press, Washington (DC), 19 December 2011, https://www.ncbi.nlm.nih.gov/books/NBK201052/.

If appropriate steps are not taken to prevent the occurrence of AMD, it can result in damage to the ecological system and the contamination of water resources through the discharge of sulphuric acid, heavy metals (including iron, manganese, aluminium, copper, chromium, zinc, lead, vanadium, cobalt, and nickel), metalloids (for example, selenium or arsenic), and radionuclides (uranium, radium, radon, and thorium).

Importantly, other heavy metals and metalloids have been found to be significantly more detrimental to the environment than the release of uranium or its daughter products.[22] Heavy metals also are by-products of many other mineral/metal extraction processes, particularly those associated with gold mining.[23] Acid mine drainage, therefore, is not specific to the mining of uranium.[24] As such, uranium mining presents no additional risk of AMD when compared with other mining operations.

Modern mining practices

Many of the documented environmental impacts associated with uranium mines are attributable to the period during which those mines operated, as environmental impacts were not an important consideration for companies, regulators, and members of the public, and mitigations were not widely deployed.

The Rum Jungle uranium mine (1954–1964) is a case in point. The mine was poorly regulated, leading to legacy environmental impacts that have been difficult and costly to remediate. During its operation, environmental protection was a low priority, inadequate pollution controls were established, and the quality of critical environmental risk management infrastructure was poor. This resulted in AMD, which led to the leaching of heavy metals and other chemicals (zinc, copper, manganese, sulphides) into the environment.[25] The other heavy metals have been, for reasons stated above, of greater environmental impact than the failure to contain the uranium and its daughter products.[26]

The failure to effectively manage environmental impacts in the past has resulted in changes to Australia's regulatory and environmental protection frameworks. Improving environmental stewardship was demonstrated at the Nabarlek (1979–1995) and Mary Kathleen (1956–1982) mines, though, of course, further improvements have been made in the years since those mines closed.[27]

In the case of the Ranger uranium mine (which commenced operation in 1980), the number of studies undertaken prior to—and during—operation, and the continuous disclosure of environmental performance, with independent oversight by the Supervising Scientist Branch of the Commonwealth Department of the Environment and Energy (and its predecessors), is indicative of the significant progress in the Australian uranium industry's environmental performance and in the development of robust regulatory frameworks that mandate the effective and safe operation of uranium mines.[28]

---

[22] Committee on Uranium Mining in Virginia, Committee on Earth Resources, National Research Council, 'Potential Environmental Effects of Uranium Mining, Processing, and Reclamation'.

[23] Fashola, M.O., Ngole-Jeme, V.M., and Babalola, O.O. 'Heavy Metal Pollution from Gold Mines: Environmental Effects and Bacterial Strategies for Resistance', *International Journal of Environmental Research and Public Health*, vol. 13, no. 11, 2016.

[24] INAP: The International Network for Acid Prevention, *Global Acid Rock Drainage Guide*, Revision 1, 21 October 2014, http://www.gardguide.com/images/5/5f/TheGlobalAcidRockDrainageGuide.pdf.

[25] Heard, *Environmental impacts of uranium mining in Australia*.

[26] Harries, J., Levins, D., Ring, B., and Zuk, W., 'Management of waste from uranium mining and milling in Australia', *Nuclear Engineering and Design*, vol. 176, 1997, pp. 15-21.

[27] Mining operation dates include rehabilitation and remediation works.

[28] Heard, *Environmental impacts of uranium mining in Australia*; Read, J.L. and Tyler, M.J., 'Natural Levels of Abnormalities in the Trilling Frog (Neobactrachus centralis) at the Olympic Dam Mine', *Bulletin of*

The Olympic Dam polymetallic mine[29] similarly shows evidence of the uranium industry's evolving environmental performance. Commencing operations in 1988, Olympic Dam is one of the largest mines in the world and, moreover, is the second largest producing uranium mine. Water use at Olympic Dam has been the subject of public scrutiny. However, issues of water consumption are not specific to the mining of uranium and are of concern across all mine operations.

The environmental impacts associated with all mining activities are dependent on the conditions at the respective mine sites, the rigour of the monitoring programs to provide early warning of contaminant migration, and the efforts to mitigate and control potential impacts. Environmental consequences share the same cause across all mining operations, including uranium mining. The standard and type of mining practice, not the mineral or metal being mined, is the major distinguishing characteristic between good, satisfactory, and poor environmental outcomes.[30]

ANSTO's role in helping to reduce the environmental impacts of uranium mines

ANSTO Minerals, a minerals processing unit within the organisation, provides consultancy services to uranium companies and to companies engaged in the exploration for, and mining of, other ores. For over 35 years, ANSTO Minerals has provided practical solutions and innovative technologies to improve the environmental performance of uranium mining and processing activities. The unit has been effective in assisting uranium companies to minimise their environmental footprint, recover waste streams, and become more efficient.

Assessments and approvals process

The legislative and regulatory frameworks governing uranium mining in Australia are complex and vary between state, territory, and Commonwealth jurisdictions. These frameworks exist primarily to ensure the safety of humans and the protection of the environment.

National regulatory requirements and laws

The *Nuclear Non-Proliferation (Safeguards) Act 1987* (Cth) ensures the physical security of nuclear materials within Australia. Under this Act, the possession of nuclear material (including uranium) requires a permit and approvals from the Australian Safeguards and Non-proliferation Office (ASNO).

The *Customs (Prohibited Exports) Regulations 1958* (under the *Customs Act 1901*) (Cth) is an additional instrument mandating that an export licence is required for the exportation of radioactive material (including refined uranium, plutonium, and thorium). Export applications are assessed by the Commonwealth department with responsibility for the Resources portfolio (presently, the Department of Industry, Innovation and Science) and ASNO to ensure that Australian uranium only is exported to countries for peaceful uses and under bilateral safeguards agreements.

State-based laws and regulations

While exploration for uranium is permitted in New South Wales, its mining is prohibited, as it is in Victoria.[31] In Queensland, while there are no restrictions under the *Mineral Resources Act 1989*

Environmental Contamination and Toxicology, vol. 53, 1994, pp. 25-31; Leach, V.A. and Chandler, W.P., 'Atmospheric dispersion of radon gas and its decay products under stable conditions in arid regions of Australia', *Environmental Monitoring and Assessment*, vol. 20, 1992, pp. 1-17; Read, J.L., 'Use of ants to monitor environmental impacts of salt spray from a mine in arid Australia', *Biodiversity and Conservation*, vol. 5, 1996, pp. 1533-1543.

[29] Olympic Dam principally is a copper mine; gold and silver also are extracted, and uranium is mined as a by-product.

[30] Heard, *Environmental impacts of uranium mining in Australia*.

[31] *Nuclear Activities (Prohibitions) Act 1983* (Vic).

(Qld), the incumbent State Government has adopted a policy stance that prevents the development of uranium mines.[32] In the Northern Territory, the Commonwealth controls decisions pertaining to uranium mining; joint agreements between the Commonwealth and Northern Territory Governments can also allow for uranium to be mined. There are no legislative restrictions in Tasmania.[33] Uranium exploration and mining is permitted in South Australia and, with some policy irregularity, in Western Australia, with two of five licensed mines currently operating in South Australia. In those jurisdictions where uranium mining is permitted, the operations are subject to the normal regulations that are applicable to all mineral or metal extraction activities, in addition to those that are specific to the extraction of uranium.

Environmental assessments and approvals

The licensing process for new mines requires comprehensive environmental impact statements and assessments to be undertaken in accordance with state and territory government requirements in respect of:

- the minimisation of the impacts on flora, fauna, and habitats;
- the contamination and pollution of land; and
- the management and use of water resources, including both surface water and groundwater.

These assessments are published and usually are open for public consultation and/or comment. Following this, a determination as to whether to approve the development of a mine is made.

In addition to the necessary State and Territory approvals, assessment and approval under the Commonwealth *Environmental Protection and Biodiversity Conservation Act* 1999 is a specific requirement for uranium mines.

South Australia

In South Australia, to avoid environmental legacy issues and associated costs, a Program for Environment Protection and Rehabilitation is approved prior to a mine's operation and is regularly updated during the life of that mine.[34] The current regulatory framework also requires a plan for the remediation of mine sites to be established at the outset of operations in order to minimise ongoing risks to the environment.[35] In addition, physical separation of mines and mineral processing facilities from sensitive environments is required. An independent regulator monitors and enforces compliance with regulatory requirements. These requirements are aligned with internationally accepted standards. A mine at which radioactive ores are mined, or a facility at which those ores are processed, specifically requires a licence from the State's Environment Protection Authority, which requires compliance with national radiation safety measures and provides for enforceable penalties in the event of a breach.[36]

---

[32] *Mineral Resources Act 1989* (Qld).

[33] *Mineral Resources Development Act 1995* (Tas).

[34] Baldry, K., Palmer, G., Borysenko, A., Marshall, G., and Ward, T., Transcript of Evidence, Nuclear Fuel Cycle Royal Commission, 8 October 2015, p. 563; Department of State Development – Mineral Resources Division (DSD), *Submission to the Nuclear Fuel Cycle Royal Commission in response to Questions regarding lessons learnt from historical uranium extraction, milling and processing activities in South Australia*, Final, 6 October 2015, p. 25.

[35] Baldry, et al., Transcript of Evidence; DSD, *Submission to the Nuclear Fuel Cycle Royal Commission*.

[36] Environment Protection Authority South Australia, 'Response to questions from the Nuclear Fuel Cycle Royal Commission regarding environmental impacts at the former Port Pirie uranium/rare earths element treatment facility and Radium Hill mine site', 2015, pp. 10-12, 14.

Social and Community Matters

Public support and community consent

While the risks of uranium exploration and mining activities arguably are no greater than for the extraction of any other mineral or metal, they remain the subject of considerable community debate and concern. It would be necessary, then, for any potential future uranium industry activities in New South Wales to be preceded by extensive community engagement and public education activities so as to build a basis of knowledge to enable members of the public and potential host communities to feel sufficiently informed of the benefits—and risks—associated with uranium projects. It then would be possible to assess whether there is informed support and consent for these activities.

Pathways for obtaining support

There are numerous tools, frameworks, and principles that can be used in support of engagement between proponents of uranium developments (and governments) and communities / land holders, and that can facilitate or assess support and consent for developments. There also are helpful lessons from corporate practices—historical and contemporary; arising from both positive experiences and those that have been reported by stakeholders to be less than satisfactory.[37] Useful tools include: Impact and Benefit Agreements, Social Impact Assessments, Environmental Impact Assessments / Statements incorporating community consultation/feedback processes, Human Rights Impact Assessments, and Indigenous Land Use Agreements.[38] Prominent frameworks include: Native Title, Social Licence to Operate, Sustainable Development, and Corporate Social Responsibility / Corporate Citizenship. Other proposed frameworks are Citizenship Participation and Extractive Development Partnerships.[39] Free, Prior and Informed Consent is a fundamental principle, while other principles include ‘Enduring Value’ or ‘Shared Value’, the International Council on Mining and Metals’ 10 Guiding Principles, and the Equator Principles, which provide the basis for financial institutions’ assessment and management of the environmental and social risks of extractive projects.[40]

There is also a substantial body of literature regarding optimal approaches and processes to facilitate community engagement generally and with specific regard to exploration and mining activities.[41]

Rights of Aboriginal and Torres Strait islander peoples

The majority of uranium deposits in Australia and around the world are located on the traditional lands of tribal and first peoples.[42] Australian and international legal instruments and principles recognise the rights of these peoples to control access to those lands, the types of activities that

---

[37] Graetz, G. ‘Energy for Whom? Uranium mining, Indigenous people, and navigating risk and rights in Australia’, *Energy Research and Social Science*, vol. 8, July 2015, pp. 113-126; Graetz, G., ‘Uranium mining and First Peoples: The nuclear renaissance confronts historical legacies’, *Journal of Cleaner Production*, vol. 84, 1 December 2014, pp. 339-347.

[38] Graetz, ‘Energy for Whom?’, pp. 113-126.

[39] O’Callaghan, T. and Spagnoletti, B., ‘Mining, Corporate Social Responsibility, and Corporate Reputation’, in O’Callaghan, T. and Graetz, G., eds, *Mining in the Asia-Pacific: Risks, Challenges and Opportunities*, Springer, Cham, Switzerland, 2017, pp. 296-298.

[40] Corder, G., ‘Mining and Sustainable Development’, in O’Callaghan and Graetz, pp. 256-257.

[41] See, for example: Kemp, D., ‘Community Relations in the Global Mining Industry: Exploring the Internal Dimensions of Externally Oriented Work’, *Corporate Social Responsibility and Environmental Management*, vol. 17, 2010, pp. 1-14; Ministerial Council on Mineral and Petroleum Resources (MCMPR), *Principles for Engagement with Communities and Stakeholders*, MCMPR, 2005.

[42] Graetz, ‘Uranium mining and First Peoples’, pp. 339-347.

occur on those lands, and provide for them to derive benefits in return for that use.[43] In the event that prohibitions on uranium mining were removed in New South Wales and uranium developments were proposed on the traditional lands of the State's Aboriginal peoples, including land subject to Native Title claims and determinations, it would be essential that these rights are respected and that developments deliver sustainable benefits to those peoples, host communities, and surrounding regions. The consequences of not meeting community expectations in this regard could result in the withdrawal of public support and community consent for those activities to occur.

---

[43] Graetz, G. and Franks, D.M., 'Incorporating human rights into the corporate domain: due diligence, impact assessment and integrated risk management', *Impact Assessment and Project Appraisal*, vol. 31, no. 2, 2013, pp. 97-106.

Part Two – Nuclear Facilities

Nuclear Power – Status and Developments

As of 31 December 2018, there were 451 nuclear power reactors operating across 30 countries and Taiwan, with a combined generating capacity of about 400 gigawatts electrical (GWe), representing over 10 per cent of the world's electricity supply.[44]

In 2018, nine new reactors were connected to grids, three were permanently shut down, and construction commenced on five.[45] Importantly, growth in the adoption of nuclear power is shifting from the Western Hemisphere to Asia, which is home to 35 of the 55 reactors under construction and to 58 of the 68 reactors that have been connected to grids since 2005.[46]

While the number of reactors under construction is significant, at the end of 2018, nearly half (47 per cent) of the 451 reactors had been in operation for between 30 and 40 years, with a further 17 per cent in operation for more than 40 years.[47] Accordingly, a number of reactors will require retirement and decommissioning over the next few decades; decisions to extend the life of, retire, and replace these reactors will have significant implications for global energy security, energy sector investment, and the achievement of international emissions reduction targets.[48]

The uncertainty regarding the potential replacement of reactors scheduled to be retired around 2030 and beyond—particularly in North America and Europe—means that there also is uncertainly regarding the proportion of global electricity generation that will be derived from nuclear power in the coming decades.[49] The high growth scenario would see global nuclear power capacity rise 30 per cent over current levels by 2030 and almost a doubling of capacity by 2050. In the low growth scenario, capacity would continue to decline for around a decade before returning to forecast 2030 levels by 2050.[50]

Of the 55 reactors under construction, 46 are in countries with existing nuclear power programs, with China (11), India (seven), and the Russian Federation (six) leading.[51] South Korea, the United Arab Emirates, and Bangladesh also are key centres of activity.

While some jurisdictions have reassessed their existing (Germany and Taiwan) or planned (Vietnam and the Philippines) nuclear power programs in the wake of the March 2011 Fukushima Dai-Ichi incident and, on this basis, have decided to bring their programs to a close, other jurisdictions have indicated that they will be introducing nuclear power to their energy supply systems.

Indeed, 28 countries have signalled that they are considering, or actively are planning, the introduction of nuclear power, including Egypt, Kenya, Niger, Nigeria, and Saudi Arabia.[52]

---

[44] International Atomic Energy Agency (IAEA), *Nuclear Power Reactors in the World*, Reference Data Series No. 2, 2019 Edition, IAEA, Vienna, 2019, https://www-pub.iaea.org/MTCD/Publications/PDF/RDS-2-39_web.pdf.

[45] For the purposes of this submission, the term, 'reactor/s', refers to nuclear power reactors and not nuclear research reactors, unless stated otherwise.

[46] IAEA Board of Governors, *Nuclear Technology Review 2019*, GOV/2019/4, 15 January 2019, p. 1.

[47] IAEA Board of Governors, *Nuclear Technology Review 2019*, p. 6.

[48] International Energy Agency (IEA), *World Energy Outlook 2018: Executive Summary*, IEA, 2018, p. 3.

[49] IAEA Board of Governors, *Nuclear Technology Review 2019*, p. 9.

[50] IAEA Board of Governors, *Nuclear Technology Review 2019*, p. 1.

[51] For its part, China is on track to double its installed nuclear capacity from 27 GWe to 54 GWe in the period 2016 to 2020, with a projected growth to 130 GWe by 2030 and, potentially, to around 500 GWe by 2050, which would account for 28 per cent of China's total annual electricity generation. See: Xiao, X. and Jiang, K., 'China's nuclear power under the global 1.5C target: Preliminary feasibility study and prospects', *Advances in Climate Change Research*, vol. 9, no. 2, 2018, pp. 138-143.

[52] IAEA Board of Governors, *Nuclear Technology Review 2019*, p. 9.

Importantly, the centre of nuclear construction expertise, like nuclear power programs more broadly, also is shifting away from the Western Hemisphere. Historically, reactor vendors and service/supply chain providers had their bases of operations in the United States, the United Kingdom, and France; however, Russia, South Korea, and, increasingly, China are emerging as key suppliers. Those supply chains are proving more robust than those in Europe and the United States, resulting in lower plant costs and quicker build times.

Advances in reactor designs

Generation IV reactors

Currently deployable power reactors are of the third generation, and often are referred to as 'Gen III' or 'Gen III+' designs. These reactors are proven to be generally safe and reliable, but advances in materials engineering, among other disciplines, are contributing to the development of the next generation of reactor designs. The Generation IV International Forum (GIF) provides the platform for international cooperation to develop these designs, which promise to be even safer and more sustainable than the current reactor fleet.

Australia was invited to join the GIF—and to accede to the Framework Agreement for International Collaboration on Research and Development of Generation IV Nuclear Energy Systems—in recognition of the unique contribution that the country can make to its work, which largely is attributable to ANSTO's nuclear and materials engineering capabilities. ANSTO was the lead agency for the treaty process for Australia's accession to the Framework Agreement, with that Agreement entering into force for Australia on 13 December 2017.

ANSTO's participation in the GIF is helping Australia to maintain and extend national capabilities in leading-edge nuclear technologies, such as fuel resources and systems. Participation also is providing Australia with improved knowledge and understanding of the next generation of nuclear reactor technologies and their applications; in the process, furthering Australia's nuclear non-proliferation and safety objectives.

Generation IV reactors represent the next iteration in nuclear power technology and promise to use fuel more efficiently, reduce waste production, meet stringent standards for safety and proliferation resistance, and to be more economically competitive against other electricity generation technologies and previous generation reactor designs.

Enhanced features include:

- inherently safe designs that would be considered by nuclear safety regulators to be 'walk-away safe';
- the ability to 'burn' radioactive waste to close the fuel cycle;
- the ability to supply high-temperature process heat to decarbonise industrial activities, including desalination and hydrogen production;
- the reduction in reactor build costs and construction times; and
- strengthened non-proliferation mechanisms.

A leading Generation IV reactor design—that of the high-temperature gas reactor (HTGR)—already is in the commissioning phase in China (the HTR-PM). High-temperature reactors are designed to be air-cooled, and China intends that they will be deployed in the country's interior, where water resources are scarce. The first-of-a-kind HTR-PM will have two reactor pressure vessels supplying heat to one common turbine, generating 210 MWe. It is envisaged that six high-temperature reactor pressure vessels will feed a single turbine in subsequent plant builds, thereby increasing efficiency and maximising economies of scale.

Another Generation IV reactor design, the sodium fast reactor (SFR), is characterised by its high level of neutron generation, which, in addition to power generation, can be used either for actinide (long-lived radioactive waste) burning or fuel 'breeding'. For example, the Russian BN-600 sodium fast reactor, which commenced commercial operation in 1982, has been used to burn and consume weapons-grade plutonium since the 1990s. The newer BN-800 SFR, which was commissioned in 2016, will be used to trial advanced fuel forms for improved utilisation.[53] China and India also are undertaking research and development into SFRs, with India hoping to use these reactors to breed uranium-233 fuel from thorium.

Molten salt reactors (MSRs), a further Generation IV design, have the potential to produce high-temperature industrial heat and the capacity to burn actinides in an inherently safe, yet cost effective, manner. Currently, China is leading investigations into MSRs through the agency of a US$3.3 billion research and development program. The construction of the first-of-a-kind Shanghai Institute of Applied Physics (SINAP) Thorium MSR (TMSR) 2 MWth test reactor is scheduled to be completed within the next five years. Research into MSRs is also active in North America and Europe, as evidenced in the projects being pursued by private companies, including TerraPower[54], Terrestrial Energy[55], Elysium Industries[56], ThorCon[57], Moltex Energy[58], and Kairos Power.[59]

Australia is maintaining its knowledge base in advanced reactors. In addition to its participation in the GIF, ANSTO has completed a joint research centre project with SINAP examining high-performance materials for use in molten salt reactors.

Small modular reactors offer flexibility, enhanced safety, and industrial applications

Small modular reactors (SMRs)—the next wave of reactor designs—are defined as nuclear power plants that generate less than 300 MWe.[60] The initial development of SMRs can be traced back to the IRIS program two decades ago[61], which investigated the use of proven pressurised water reactor (PWR) technology in smaller, simplified, and safer reactor designs that are easier, quicker, and cheaper to manufacture than large 1 GWe PWRs. Since the IRIS program, the term, 'small modular reactor', also has come to encompass non-PWR-based technologies, including HTGRs, SFRs, lead fast reactors (LFRs), and MSRs, which loosely can be termed, 'Advanced SMRs'.

---

[53] Pakhomov, I., *BN-600 and BN-800 Operating Experience*, JSC 'SSCRF–IPPE', Generation IV International Forum, State Scientific Center of the Russian Federation – Institute for Physics and Power Engineering, Russia, 19 December 2018.

[54] TerraPower LLC, *TWR Technology: Preparing Nuclear Energy for Global Growth, TerraPower LLC*, 2019, https://terrapower.com/productservices/twr.

[55] Terrestrial Energy, *Terrestrial's Integral Molten Salt Reactor®: Safe, clean, low-cost and high-impact*, Terrestrial Energy Inc., 2019, https://www.terrestrialenergy.com/technology/.

[56] Elysium Industries, *The Molten Chloride Salt Fast Reactor*, Elysium Industries, 2017, http://www.elysiumindustries.com/technology.

[57] ThorCon, *Powering up our world*, ThorCon¸ 2019, http://thorconpower.com/.

[58] Moltex Energy Ltd, *Stable Salt Reactors*, Moltex Energy Ltd, 2019, https://www.moltexenergy.com/stablesaltreactors/.

[59] Kairos Power, *Technology*, Kairos Power LLC, 2019, https://kairospower.com/technology/.

[60] 300 MWe is enough to power approximately 250,000 homes. In contrast, a large nuclear power plant that produces 1000 MWe (or 1 GWe) powers approximately 750,000 homes. See: STRATA, *The Future of Small Modular Nuclear Reactors in the U.S.*, Strata Policy, 2017, https://www.strata.org/small-modular-nuclear-reactors/.

[61] Petrovic, B., Ricotti, M., Monti, S., Cavalina, N., and Ninokata, H., 'Pioneering Role of IRIS in the Resurgence of Small Modular Reactors', *Nuclear Technology,* vol. 178, iss. 2, 2012.

A sub-class of SMRs generating less than 10 MWe is commonly referred to as 'micro-reactors'; these reactors are designed for remote deployment to service hard-to-reach communities, or for mobile deployment into disaster areas. Also in development are transportable—including floating or truck-mounted—SMRs, which are designed to be returned to their point of origin at the end of their life. Russia is leading research and development activities in this area, with the first such plant set to be deployed before the end of 2019.[62]

Small modular reactors, including Advanced SMRs, have the potential to reduce build costs and timeframes through the employment of various strategies, including:

- the elimination of costly active safety systems through the use of passive safety features or inherently-safe reactor designs;
- shifting the majority of construction off-site to an enclosed factory environment using modular manufacturing techniques and series-production methods;
- increasing learning rates to be in line with those of other industries, such as combined cycle gas turbines, shipbuilding, and aircraft manufacturing, where a high proportion of construction is factory-based;
- the use of next-generation technologies, such as reactor coolants with superior thermal characteristics, high-performance alloys, and accident-tolerant fuels; and
- innovative delivery and construction models.[63]

The smaller size of SMRs and SMR-based plants offers distinct advantages of particular relevance to New South Wales—and Australia more broadly—when considering future grid design and the integration of various low-carbon technologies in the electricity generation and distribution system. These advantages include:

- the potential of most SMR designs to operate in load following regimes in concert with variable renewable energy sources;
- reduced transmission overheads compared with large gigawatt plants;
- their ability to provide for district heating and desalination requirements; and
- their ability to provide for industrial heat requirements.[64]

These last two points are particularly important in the context of the need to decarbonise residential and industrial heating and water purification processes—in addition to the need to decarbonise the electricity system.

---

[62] ROSATOM, *Projects*, The State Atomic Energy Corporation ROSATOM, 2019, https://rosatom.ru/en/investors/projects/; World Nuclear News, *Russia's floating plant reaches final destination*, World Nuclear News, 16 September 2019, http://www.world-nuclear-news.org/Articles/Russias-floating-plant-reaches-final-destination.

[63] Department for Business, Energy and Industrial Strategy (BEIS), *Advanced Nuclear Technologies – a UK framework*, Clean Energy Ministerial, BEIS, 2019, https://www.cleanenergyministerial.org/sites/default/files/2019-06/BEIS_Advanced_Nuclear_Technologies_2019.pdf.

[64] Canadian Nuclear Association, *SMR Roadmap*, 2018, https://smrroadmap.ca/.

Near-term deployable SMRs—those in development by NuScale (United States)[65], CAREM (Argentina)[66], and SMART (South Korea)[67]—predominantly are PWR-based technologies, with the exception of the Chinese HTR-PM, which is an HTGR technology. Westinghouse is developing a demonstration SMR unit in the United States and plans to establish manufacturing capabilities by 2020. The company also is engaging with United States and Canadian nuclear regulators, with the aim to license its SMR design for commercial deployment by 2025. It is expected that the regulatory review of the NuScale SMR design will be completed by the United States Nuclear Regulatory Commission by September 2020, with commercial deployment in 2026.[68] Argentina's prototype CAREM-25 reactor is under construction.[69]

Currently, there are approximately 20 SMR vendors operating in North America, with 10 SMR developers undergoing pre-licensing review with the Canadian Nuclear Safety Commission. The Canadian Government has shown significant support for SMR technologies, with the publication of an *SMR Roadmap* that aims to establish Canada as the global centre of SMR technology development.[70]

Medium-to-long-term reactor technologies

Thorium-fuelled reactors

Although the thorium fuel cycle theoretically can provide a source of electricity, there is limited evidence to suggest that the required significant investments to make thorium technologies commercially viable would be an improvement on the well-established reactor technologies and systems using uranium-based fuels.

As the Nuclear Fuel Cycle Royal Commission Report found, 'Energy generation technologies that use thorium as a fuel component are not commercial and are not expected to be in the foreseeable future. Further, with the low price of uranium and its broad acceptance as the fuel source for the most dominant type of nuclear reactor, there is no commercial incentive to develop thorium as a fuel.'[71]

Moreover, while proponents claim that the thorium fuel cycle is resistant to proliferation risks, the production of uranium-233 during the fuel cycle presents a potential proliferation risk that would require similar safeguards to those that are established for the current uranium fuel cycle.

---

[65] NuScale Power, LLC, *Technology*, NuScale Power, LLC, 2019, https://www.nuscalepower.com/technology.

[66] IMPSA, *Carem, the Argentinean Nuclear Reactor Manufactured by IMPSA, is Launched*, IMPSA, 26 July 2019, https://www.impsa.com/en/carem-the-argentinean-nuclear-reactor-manufactured-by-impsa-is-launched/.

[67] SMART Power Co. Ltd, *Design*, Seoul, Korea, http://smart-nuclear.com/tech/design.php.

[68] Neutron Bytes, *US SMR Firms Mark Progress Milestones in US and Canada*, 27 May 2019, https://neutronbytes.com/2019/05/27/us-smr-firms-mark-progress-milestones-in-us-and-canada/.

[69] World Nuclear News, *Argentina reaches generator milestone for CAREM-25*, World Nuclear News, 8 May 2018, http://www.world-nuclear-news.org/NN-Argentina-reaches-generator-milestone-for-CAREM-25-08051801.html.

[70] Canadian Small Modular Reactor Roadmap Steering Committee, *A Call to Action: A Canadian Roadmap for Small Modular Reactors*, November 2018, Ottawa, Ontario, https://smrroadmap.ca/wp-content/uploads/2018/11/SMRroadmap_EN_nov6_Web-1.pdf.

[71] Nuclear Fuel Cycle Royal Commission, *Nuclear Fuel Cycle Royal Commission Report*, Government of South Australia, 2016, p. 24.

Fusion technology

The great promise of the fusion power reactor is that it can make a significant contribution to the world's energy supply—if the technology can be demonstrated to be both financially viable and technically feasible.

The International Thermonuclear Experimental Reactor (ITER) Project is the world's largest fusion energy research and development mission, and involves six member countries and the European Union in the construction of an experimental tokamak fusion reactor in the south of France.[72]

It is intended that ITER will be the first fusion device to produce net energy—that is, to achieve a higher energy output than that which is required as input to heat the plasma (an ionised gas), with the plasma shown in pink in centre of the tokamak in the image, below. It also is intended to be the first fusion device to test the integrated technologies, materials, and physics regimes necessary for the commercial production of fusion-based electricity.[73]

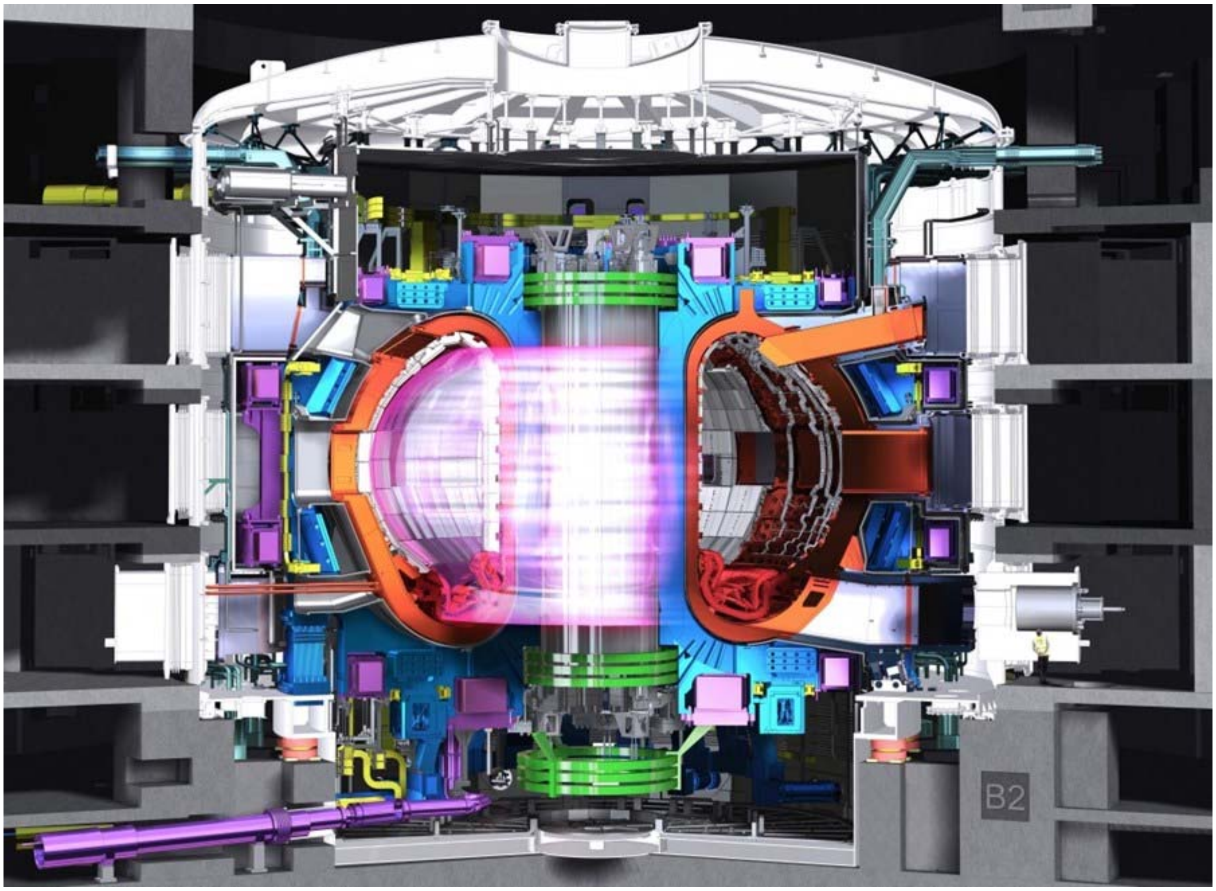

Image courtesy of: ITER Organization, 'First Plasma: 2025', *ITER Mag*, no. 9, August 2016, https://www.iter.org/mag/9/65.

---

[72] The six member states are: China, India, Japan, South Korea, the Russian Federation, and the United States.

[73] ITER Organization, *What is ITER?*, ITER Organization, 2019, https://www.iter.org/proj/inafewlines.

ANSTO, on behalf of the Australian Government and the country's fusion research community, signed a technical cooperation agreement with the ITER Organization in 2016. In so doing, Australia became the first non-member country formally to participate in the Project.

Australia's major contributions to the ITER Protect, drawing on the country's globally unique competencies, are a diagnostic system to image the plasma in real time, plasma theory and modelling, and studies of materials under the extreme conditions that they will experience in the tokamak reactor; all three contributions are the result of collaboration between the Australian National University and ANSTO.

A number of private companies and organisations claim to be working on projects that will achieve net production of energy from fusion before ITER.[74] However, in the absence of publicly available information about these projects, it is not possible for ANSTO to comment on the veracity of these claims.

---

[74] McMahon, J., 'Energy from Fusion in "a couple of years", CEO says, Commercialization in Five', *Forbes*, 14 January 2019, https://www.forbes.com/sites/jeffmcmahon/2019/01/14/private-firm-will-bring-fusion-reactor-to-market-within-five-years-ceo-says/#33753e301d4a.

Further Nuclear Fuel Cycle Activities

The current Act prohibits certain other fuel cycle activities besides nuclear energy generation from occurring in the State.

Conversion, enrichment, and fuel fabrication activities

Most fuel for nuclear power reactors is produced through the conversion, enrichment, and fabrication of newly mined and milled uranium ore. At present, mined Australian uranium is exported with limited additional value added before it is sold and shipped to countries that undertake these activities. Despite Australia being one of the world's largest uranium producers, and holding the world's largest uranium reserves, these activities have been prohibited in both State and Federal legislation.

In order to be useful as an energy source, uranium ore must be mined and milled, converted, enriched, and, subsequently, fabricated into fuel. Milling is the physical and chemical transformation of ore to uranium concentrate, commonly referred to as 'Yellowcake'. Conversion involves the chemical processing of uranium concentrate into uranium hexafluoride – a gaseous form of uranium. Enrichment is the physical separation and concentration of the isotope uranium-235 (U-235) in the uranium hexafluoride[75], and modern enrichment plants use gas centrifuges to achieve this separation. Fuel fabrication is the conversion of enriched gaseous uranium back into a solid form, uranium oxide; the formation of the uranium oxide into pellets; and the consolidation of these pellets into sealed zirconium alloy tubes for loading into a fuel assembly for a reactor core.[76]

The 2007 Uranium Mining, Production and Nuclear Energy Review (UMPNER), commissioned by the former Howard Government, considered the challenges and opportunities for Australia becoming involved in conversion, enrichment, and fuel fabrication activities. The UMPNER taskforce concluded that, while there was no case for the Australian Government to subsidise entry into this value-adding industry, neither was there a strong case to discourage the development of the industry in Australia.[77]

Aside from the market-based issues discussed below, the expansion of activities at the 'front-end' of the nuclear fuel cycle in the State, in particular, enrichment, would require serious consideration of foreign policy requirements and implications. New South Wales also would need to ensure that there is a sufficiently robust regulatory framework and a capable independent regulator (this could be the Australian Radiation Protection and Nuclear Safety Agency were its remit to be extended to cover non-Commonwealth facilities), as with the introduction of any other nuclear fuel cycle activities.

In 2016, the Nuclear Fuel Cycle Royal Commission found, for a range of economic reasons, that 'there would be no opportunity for the commercial development of further processing capabilities in South Australia, assuming they were in competition with existing suppliers.'[78] However, it noted that this position would change if there were to be a substantial growth in demand from Asia not met by

---

[75] Nuclear power reactor fuel for light-water reactors typically is enriched to three to five per cent U-235. Uranium containing up to 20 per cent U-235 is considered low-enriched uranium (LEU), whereas uranium containing more than 20 per cent U-235 is considered high-enriched uranium (HEU). This is an important threshold for technical, regulatory, and diplomatic considerations related to nuclear safeguards, non-proliferation, and nuclear security.

[76] While other forms of fuel are used for certain purposes, in particular, for research reactors and experimental or demonstration power reactors, this is the most common form of uranium fuel for use in nuclear power reactors.

[77] Uranium Mining, Processing and Nuclear Energy Review Taskforce, *Uranium Mining, Processing and Nuclear Energy – Opportunities for Australia?*, Department of the Prime Minister and Cabinet, Commonwealth of Australia, 2006, p. 42.

[78] Nuclear Fuel Cycle Royal Commission, *Nuclear Fuel Cycle Royal Commission Report*, South Australian Government, 2016, p 36.

existing supply or a substantial reduction in capital cost brought about by new technology, or an alternative competitive advantage were to be demonstrated.

Used fuel reprocessing

In some countries, used nuclear fuel is reprocessed, allowing for the recovery and re-use of unexhausted uranium and plutonium. The reprocessing of used nuclear fuel for the production of fresh fuel constitutes a closed fuel cycle. France, Japan, Russia, and China have closed fuel cycle policies.[79]

Australia also has adopted a closed fuel cycle. According to current Australian Government policy, all of Australia's used fuel from the OPAL reactor will be sent to France for reprocessing. The small amount of residual wastes will be shipped back to Australia for management and disposal. The majority of used fuel from the HIFAR reactor was also managed this way; however, some HIFAR fuel, as well as that which was used in the MOATA reactor, was shipped to the United States for disposal under a now closed program for the management of used research reactor fuel.

The alternative to the closed fuel cycle model is an open fuel cycle, which sees used fuel treated as waste. In an open fuel cycle, remaining uranium and plutonium is not recovered. Most countries with a nuclear reactor fleet have chosen open cycle programs due to a variety of challenges associated with reprocessing, including high costs, technical complexity, and political and foreign policy considerations.

Reprocessing has proven to be an expensive and technically challenging undertaking. In 2016, the South Australian Nuclear Fuel Cycle Royal Commission found that 'a new reprocessing facility based on current technology would not be economically viable under current and likely future market conditions.'[80] This finding has been illustrated in the decision of the United Kingdom to close its long-standing reprocessing program, despite its expanding nuclear power program.[81]

ANSTO's expertise

ANSTO and its predecessor organisation, the Australian Atomic Energy Commission, have managed radioactive waste at Lucas Heights in southern Sydney for more than 60 years. There exists, therefore, significant expertise in waste management and processing in the State. As the operator of a number of nuclear facilities generating radioactive wastes, ANSTO maintains the required skills, knowledge, and capabilities to manage and store used nuclear fuel and low- and intermediate-level radioactive wastes.

ANSTO is currently constructing the world's first industrial scale Synroc waste processing facility for the treatment of liquid radioactive waste from the production of nuclear medicines. Synroc is an Australian technology that can be tailored to treat a wide variety of radioactive waste forms. The resulting waste form is up to 97 per cent smaller in volume than existing alternatives and is suitable for disposal in a purpose-built repository. Regardless of whether New South Wales or Australia were to establish a nuclear power program in the future, significant opportunities exist to export this technology to international holders of radioactive wastes that are seeking efficient and effective waste management solutions; this would have benefits for the State's export earnings.

---

[79] WNA, *Radioactive Waste Management*, WNA, April 2018, https://www.world-nuclear.org/information-library/nuclear-fuel-cycle/nuclear-wastes/radioactive-waste-management.aspx.

[80] *Nuclear Fuel Cycle Royal Commission Report*, p. 37.

[81] World Nuclear News, *Reprocessing ceases at UK's Thorp plant*, World Nuclear News, 14 November 2018, http://world-nuclear-news.org/Articles/Reprocessing-ceases-at-UKs-Thorp-plant.

The safety of ANSTO's waste management practices is overseen by the independent Federal regulator, the Australian Radiation Protection and Nuclear Safety Agency. Leaving ANSTO aside, the New South Wales Environment Protection Authority has certain regulatory powers relating to the use, sale, giving away, disposal, storage, possession, transport, installation, maintenance or repair, remediation, or clean-up of regulated material (radioactive substances, ionising radiation apparatuses, non-ionising radiation apparatuses of a kind prescribed by the Regulations, and sealed source devices) by private or State Government entities within the State.

If the State were to embark upon an expansion of nuclear fuel cycle activities, including those relating to—or generating—radioactive waste, consideration would need to be given to the appropriateness of the current regulatory structures. In addition to any structural adjustments, and depending on the scale of the activities envisioned, it is possible that the State would need to significantly strengthen the capacity and capability of the regulator.

Applications of Nuclear Science and Technology

Environmental sustainability, land management, and climate change mitigation

ANSTO undertakes and facilitates beneficial environmental research using nuclear techniques, focusing on water resource sustainability, environmental change, and the impact of contaminants in the environment. Nuclear techniques, tools, and products, including those used and developed by ANSTO, are contributing to better understanding of water management and water availability, food provenance and food quality, airborne particulate management, and the causes of climate change, as well as of potentially effective mitigations for climate change—both in Australia and around the world.

Studies undertaken by the organisation have been able to quantify past and present rates of recharge to key water resource regions. Using nuclear techniques and isotopic tracing analysis, ANSTO provides water resource managers with robust scientific information on water quality and the sustainability of groundwater, surface water, and aquatic ecosystems.

ANSTO’s research also is building Australia’s capacity to respond to environmental and climate change by improving our knowledge of the spatial and temporal scales of both past and modern change. Research undertaken by ANSTO personnel using nuclear techniques focuses on past climate variability, ocean circulation, the global carbon cycle, landscape evolution and degradation, and other human impacts, including past migration patterns.

Nuclear techniques, such as isotopic tracing and analysis, radon measurement, and fine particle analysis, in addition to geochemical and biological techniques, enable ANSTO to identify and quantify the mechanisms that influence the movement of contaminants in soils and the atmosphere, estimate emissions, and assess the interaction of contaminants within and between ecosystems and human populations. Furthermore, they allow ANSTO to ‘fingerprint’ air pollution so that it can be traced to its source across cities and countries, quantifying, also, the effects of such pollution on human health.

Nuclear techniques similarly are being used to explain the role of marine and coastal ecosystems in storing carbon to offset greenhouse gas emissions and to measure the contribution of melting Antarctic ice to past global sea level rise.

Crop losses resulting from climate change necessitate the development of innovative breeding pipelines to ensure global food security. The combination of plant mutation breeding, marker-assisted selection, and high-throughput phenotyping constitutes a powerful mechanism by which plants can rapidly adapt to climate change. Nuclear techniques and methodologies are aiding in the development of these new plant breeds, and thereby are contributing to human—and environmental—security.

Public health

Nuclear techniques and products can be used for the diagnosis, treatment, and monitoring of the progression of disease. Such techniques and products, and other nuclear tools, have the potential to track and measure small physiological variations during the development of disease, in particular, during the non-symptomatic phase. This results in better understanding of the mechanisms that underpin the evolution of chronic disease—from the initial response to disease progression.

ANSTO is a major manufacturer and supplier of nuclear medicines, with the capability to meet about 25 per cent of world demand. Radiopharmaceuticals produced or sourced by ANSTO and distributed for the benefit of Australians’ health and well-being include:

Name	Utility
Chromium-51	Injection indicated for the determination of glomerular filtration rate in the assessment of renal function
Gallium-67	Can be useful in demonstrating the presence of the following malignancies: Hodgkin's disease, lymphomas, and bronchogenic carcinoma
Technetium-99m	Sodium pertechnetate is used for scintigraphy, principally of the brain and thyroid. It also can be used to prepare various technetium-99m labelled injections for selective organ imaging, especially of the liver, lungs, bones, and kidneys
Indium-111 DTPA Injection	Pentetate Indium Disodium is recommended for use in radionuclide cisternography
Lyophilised Kits - MDP Skeleton Agent	Technetium MDP may be used as a bone imaging agent to delineate areas of altered osteogenesis
Lyophilised Kits - Pentastan DTPA Multi	99mTc-Pentastan may be used to perform kidney imaging, brain imaging, to assess renal perfusion and to estimate glomerular filtration rate
Iodine-123 MIBGen® Iobenguane	Diagnostic scintigraphic localisation of phaeochromocytomas, paragangliomas (chemodectomas), ganglioneuroblastomas, and ganglioneuromas. It enables detection, staging, and follow-up on therapy of neuroblastomas
Quadramet® Samarium-153	Quadramet is indicated for the relief of bone pain in patients with painful osteoblastic skeletal metastases as indicated by a positive bone scan
Sodium Iodide – Iodine-131 Therapy Capsules	Sodium Iodide Therapy Capsules are indicated in the treatment of hyperthyroidism and the detection and ablation of residual functioning thyroid tissue in differentiated thyroid carcinoma
Sodium Iodide – Iodine-131 Injection	Sodium Iodide Injections are indicated in the treatment of hyperthyroidism and the detection and ablation of residual functioning thyroid tissue in differentiated thyroid carcinoma
Sodium Iodide – Iodine-131 Solution BP for Therapy	Sodium Iodide Solution BP for Therapy is indicated in the treatment of hyperthyroidism and the detection and ablation of residual functioning thyroid tissue in differentiated thyroid carcinoma

Another area in which nuclear techniques are being used to contribute to better public health outcomes is food science, for example, through the manipulation of food to deliver controlled functions. ANSTO's research assists in the determination of the structure-function relationships in food-based systems, such as lipids, proteins, and polysaccharides, with direct applications to food processing and human nutrition. Neutron and X-ray scattering methods feature extensively in the work, with beneficial outcomes for consumers and industry. ANSTO also is undertaking research to optimise the production of food, increase the efficiency of production methods, and track the physical origin of food for quality, safety, and authentication purposes. This extends to improving food quality through optimised production methods that encompass both tracing and monitoring of high-value nutrients, as well as detecting pollutants and contaminants.

Law enforcement, defence capabilities, and national security

For example, ANSTO develops and assesses technologies that include new detectors and algorithms to improve the ability to identify the illicit trafficking of nuclear and other radioactive materials. In this regard, ANSTO’s Accelerator Mass Spectrometry facility is used as part of the IAEA’s Network of Analytical Laboratories to enable the analysis of samples taken by IAEA safeguards inspectors from nuclear facilities around the world, thereby contributing to nuclear security.

ANSTO also has developed a novel, patented technology, which has the ability to image, identify, and locate gamma-ray and neutron radiation in a safe and timely manner. The quick and accurate identification of radiological signatures has been a significant challenge for a range of industries, including border security and inspection services, first responders, and the nuclear, defence, medical, and research sectors. Traditional imaging methods utilise hand-held instruments, which are cumbersome, higher risk (as workers can be exposed to significant radiation doses), and subject to potential operator error.

The imaging technology developed by ANSTO combines the gamma-ray or neutron images with a panoramic optical image to effectively visualise the location of the radiological signatures, making it significantly easier for the user to identify and interpret the source of the radiation.

Research into industrial processes

ANSTO is home to the National Deuteration Facility, which enables complex investigations of the relationship between the structure of molecules and their function using neutron scattering, nuclear magnetic resonance, and other types of spectroscopy. This has significant benefits and uses across a range of industrial sectors and research areas, including:

Health, pharmaceutical, and drug delivery research	Molecular electronics
Energy and gas storage materials	Structural biology
Bio- and synthetic polymers and biotechnology	Communications and electronics
Thin film nanotech devices	Food-lipid digestion

Neutron scattering can be used to determine the internal structure and dynamics of materials, helping scientists and their partners and clients in industry to understand why materials have the properties they do, and helping to develop new materials, devices, and systems. ANSTO's nuclear scattering facilities enable:

- characterisation of new battery materials with greater storage capacity and discharge capabilities, which is essential to improving energy efficiency and security;
- the study of the structural integrity of materials, such as critical welds in pipes that are used to transport energy resources around Australia, thereby enhancing energy security;
- the improved understanding of the growing problem of food allergies through the observation of interactions between biological molecules, such as proteins, viruses, and cell membranes; and
- determination of the structure and dynamics of materials used in hydrogen fuel systems, thereby providing for more efficient and effective clean energy systems.

The Australian Synchrotron, operated by ANSTO, facilitates research with applications across numerous industries and sectors, including medicine, manufacturing, nanotechnology, and minerals exploration. Using accelerator technology to produce a powerful source of light many times brighter than the sun, the facility allows for the examination of the atomic and molecular detail of materials with applications including:

Additive and chemical manufacturing	Energy storage and transportation
Biofortification and solid state analysis	Environmental monitoring
Commercial process evaluation	Health product and medical device development
Composite materials	Minerals processing
Drug discovery	Resource exploration
Energy extraction and conversion	Waste management and remediation

Experiments with synchrotron light offer advantages over conventional techniques in terms of accuracy, quality, robustness, and the level of detail that can be seen and collected, and are much faster than traditional methods.

Financial and Economic Considerations

As noted earlier in this submission, ANSTO provides periodic advice on aspects of nuclear science and technology, including nuclear power and related energy matters, as mandated by the ANSTO Act.[82] Information and advice on nuclear power and other energy technologies is regularly collected and assessed, and is provided in this context.

System costs

New South Wales'—and, more broadly, Australia's—energy affordability and reliability historically has been underpinned by inexpensive coal generation. However, over the last decade, the falling cost of renewables, particularly of wind and solar photovoltaic generation technologies, and uncertainty in the investment market, has seen an increase in the percentage share of renewables in the National Electricity Market, displacing aging coal-fired generators that traditionally have supplied low-cost, dispatchable electricity.

Variable renewable energy (VRE) sources, such as wind and solar, which have low capacity factors, require firming (backup generation) and storage, preferably from options that require low capital expenditure (CAPEX – build costs) and low operational expenditure (OPEX), with low life-cycle emissions. In another Australian jurisdiction, South Australia, for example, large installations of wind generators have been 'firmed' by Open Cycle Gas Turbine (OCGT) generators[83], which are characterised by relatively low CAPEX, but high OPEX, predominantly caused by the tripling of gas prices in recent years, and relatively high emissions.[84] Despite plans for major VRE roll outs across the country[85], the question of firming by gas, pumped storage, batteries, hydrogen, and smart-grids, among other technologies, remains uncertain in cost, feasibility, and timing.

Should New South Wales and Australia move toward a lower carbon emissions energy mix scenario, there likely will be challenges to cost and reliability of electricity supply in the absence of nuclear power. Indeed, analysis of energy mix scenarios using a combination of nuclear and renewable generation sources, undertaken by the OECD–NEA, has found that:

> [The] total generation capacity [of the electricity system] increases significantly with the deployment of VRE resources. Since the load factor and the capacity credit of VRE is significantly lower than that of conventional thermal power plants, a significantly higher capacity is needed to produce the same amount of electricity.[86]

The OECD–NEA's findings show that VREs require the installation of capacity additional to that which is required to meet demand for electricity. Put differently, the higher the VRE penetration, the higher the required additional capacity, significantly increasing overall system costs.[87] The OECD–NEA observes, though, that, in the international context, VREs complemented with nuclear generation can significantly reduce overall systems costs and the amount of generation capacity

---

[82] Part II, Section 5, (1e) of the *Australian Nuclear Science and Technology Organisation Act 1987*.

[83] Electricity Map, *South Australia*, https://www.electricitymap.org/?page=country&solar=false&remote=true&wind=false&countryCode=AUS-SA.

[84] Australian Competition and Consumer Commission (ACCC), *Restoring electricity affordability and Australia's competitive advantage: Retail Electricity Pricing Inquiry – Final Report*, ACCC, June 2018, https://www.accc.gov.au/system/files/Retail%20Electricity%20Pricing%20Inquiry%E2%80%94Final%20Report%20June%202018_Exec%20summary.pdf.

[85] Energy Networks Australia and CSIRO, *Electricity Network Transformation Roadmap: Key Concepts Report*, Energy Networks Australia, December 2016, https://www.energynetworks.com.au/sites/default/files/key_concepts_report_2016_final.pdf

[86] OECD–NEA, *The Costs of Decarbonisation: System Costs with High Shares of Nuclear and Renewables*, OECD–NEA, Paris, 2019, p. 18, https://www.oecd-nea.org/ndd/pubs/2019/7299-system-costs.pdf

[87] OECD–NEA, *The Costs of Decarbonisation*, p 19.

required, while supporting grid reliability and stability. As such, nuclear power is viewed by the OECD–NEA as a primary source of low-carbon baseload generation, underpinning the future energy systems of major industrialised countries.

The Massachusetts Institute of Technology (MIT) has found that, when combined in a system with other energy generation technologies, nuclear power can balance or offset the high CAPEX and OPEX of the other technologies, due to its low whole-of-life costs; this is despite its high initial capital costs. Indeed, the amortisation of costs for nuclear power can be a critical component in considering the mix of energy generation technologies to ensure that a country has low-cost and reliable energy supplies.[88]

The economics of nuclear power

Nuclear power reactors are a mature technology, which, like the aviation industry, have been the subject of significant innovations and improvements in safety, operational efficiency, and reliability with each new generation of design. As a result, it is argued that future reactor designs will see reductions in cost and up-front capital investment requirements, contributing to the increasing affordability of nuclear power.[89]

Important steps that also are likely to contribute to a reduction in the upfront costs associated with nuclear power programs include potential regulatory harmonisation in response to the growing modularity of new designs, especially small modular reactors. These reactors promise significant economies of scale over large reactors, lower overnight capital costs, and reduced construction and installation costs. Moreover, it is envisaged that the SMR construction model will allow for the generation of revenue from the initial module installations, which will generate cash flow to support the installation of subsequent modules.[90]

In its recent report, Industry Super Australia focused on the potential application of nuclear power in a broader and more cost effective energy mix.[91] Importantly, the peak industry superannuation organisation identified the need to take a longer-term view of the cost to finance nuclear builds, demonstrating the potential availability of finance for a nuclear power program in New South Wales or elsewhere in the country.

In discussing the costs of generating technologies, the levelised cost of electricity (LCOE) typically is used as a comparative measure. In most cases, the LCOE takes into account capital, fuel, and operation and maintenance costs, as well as an assumed utilisation rate for each technology type. However, the LCOE is dependent on local characteristics. Without an existing nuclear power industry and a strong understanding of project-specific factors, such as the cost of finance, it is difficult to establish a meaningful estimate of the potential LCOE for nuclear reactors in jurisdictions that are embarking on—or considering embarking on—new power programs, including New South Wales.[92]

---

[88] MIT Energy Initiative, *The future of nuclear energy in a carbon constrained world: An interdisciplinary study*, Massachusetts Institute of Technology, 2018, http://energy.mit.edu/wp-content/uploads/2018/09/The-Future-of-Nuclear-Energy-in-a-Carbon-Constrained-World.pdf.

[89] [89] MIT Energy Initiative, *The future of nuclear energy in a carbon constrained world*.

[90] Carelli, M.D. and Ingersoll, D.T., *The Handbook of Small Modular Reactors*, Woodhead Publishing, Cambridge, 2015.

[91] Industry Super Australia, *Modernising electricity sectors: a guide to long-run investment decisions*, Discussion Paper, Industry Super Australia, Melbourne and Canberra, 2019, https://www.industrysuper.com/assets/FileDownloadCTA/2daa2c8217/Modernising_electricity_sectors_a_guide_to_long_run_investment_decisions_FINAL-002.pdf.

[92] Riesz, J., Sotiriadis, C., Vithayasrichareon, P., and Gilmore, J., *Quantifying key uncertainties in the costs of nuclear power*, Centre for Energy and Environmental Markets and School of Electrical Engineering and

The LCOE also does not capture the costs of the various externalities of the generating sources. For example, while the cost of nuclear decommissioning and waste management is accounted for in the International Energy Agency and OECD–NEA methodology[93], the true cost of waste (both solid and gaseous) from coal generation is not captured. Similarly, the cost of intermittency from solar or wind, which is displaced across the grid, is not captured.

Owing to these issues, a more useful indicator is that of the levelised avoided cost of electricity (LACE). The LACE measures what the impact to a grid would be to create the electricity that otherwise would be produced as a consequence of a new generation project, and can be used as an evaluation tool for the financial value of a given project.[94]

There would be significant merit in incorporating the LACE into the evaluation of generating capacity in New South Wales, as it could provide an indication of the potential value for a new unit of generation technology in fulfilling projected future energy requirements.

The overnight capital cost[95] of a large (1 GWe) nuclear power plant is dependent on a variety of factors, including the strength of the supply chain, which affects engineering, procurement, and construction costs, the lessons learned from prior reactor builds, and owners' costs, such as land, cooling infrastructure, site works, project management, and licensing fees.

As mentioned above, over the last two decades, large-scale nuclear construction activities have shifted from countries in North America and Europe to countries in East Asia. As a result, lower plant CAPEX costs also have shifted to jurisdictions where there are a high number of new builds. This is reflected in the global range of overnight capital costs, as reported in the International Energy Agency-OECD–NEA's *Nuclear Energy Roadmap 2015*[96], starting from a low end average of US$3500 per kilowatt (kW) of capacity in China to the European Union's overnight capital cost average of US$5500 per kW.

In Western countries, the increase in build costs can be attributed to a number of factors, including improvements in reactor safety features in response to the incidents at Chernobyl and Fukushima, increased production costs per plant as a result of decreasing numbers of new builds, and, in the case of the United States, increasing reactor design certification costs that are wholly carried by reactor vendors.

Despite the challenges of rising large plant build costs, many countries are continuing to invest in nuclear power due to its high capacity factor, which, globally, averaged 80 per cent in 2018[97], as well as the longevity of reactors. For context, New South Wales and the Australian Capital Territory's generation mix in the year 2015–2016 had capacity factors of 61 per cent for coal, 21 per cent for

---

Telecommunications, UNSW Australia, http://nuclearrc.sa.gov.au/app/uploads/2016/02/Dr-Jenny-Riesz-20-10-2015.pdf.

[93] OECD–NEA, *Sustainable Development and the Application of Discounting to the Calculation of the Levelised Costs of Electricity*, NEA/NDC/R(2018)1, Committee for Technical and Economic Studies on Nuclear Energy Development and Fuel Cycle OECD–NEA, Paris, 22 June 2018, http://www.oecd.org/officialdocuments/publicdisplaydocumentpdf/?cote=NEA/NDC/R(2018)1&docLanguage=En.

[94] U.S. Energy Information Administration, *Levelized Cost and Levelized Avoided Cost of New Generation Resources in the* Annual Energy Outlook 2019, February 2019, https://www.eia.gov/outlooks/aeo/pdf/electricity_generation.pdf.

[95] U.S. Energy Information Administration, 'Updated Capital Cost Estimates for Utility Scale Electricity Generating Plants', *Capital Cost for Electricity Plants*, 12 April 2013, https://www.eia.gov/outlooks/capitalcost/.

[96] OECD–NEA, *Technology Roadmap: Nuclear Energy*, 2015 edition, OECD–NEA and International Energy Agency, https://www.oecd-nea.org/pub/techroadmap/techroadmap-2015.pdf.

[97] WNA, *World Nuclear Performance Report 2019*, WNA, London, 2019.

natural gas, 14 per cent for hydropower, 32 per cent for wind, and 24 per cent for other forms of generation.[98]

Nuclear power plants are viewed as long-term investments, which can operate for between 40 and 60 years (on average) and, internationally, are viewed as an attractive, low-carbon, baseload option for the replacement of existing baseload generators, as they can be deployed on pre-existing electricity grids without the need for new investments in transmission infrastructure.

In the desire to further reduce the cost, increase the safety, and enable the integration of nuclear reactors with small grid systems, small modular reactors have been the subject of research and development activities for several decades. Due to the intended smaller upfront investment required for one unit, SMRs are expected to be easier to finance, and the modularity of construction and reactor designs could allow for easier decommissioning.

In a recent Massachusetts Institute of Technology study, the projected overnight cost of capital for SMRs falls to between US$4000 and $5000 per kW.[99] A near-term deployable SMR vendor, NuScale, has quoted a first-of-a-kind overnight capital cost of US$4350 per kW and an nth-of-a-kind cost of $3600 per kW.[100] Less near-term, GE Hitachi has quoted its BWRX-300 SMR at an nth-of-a-kind overnight capital cost of US$2250 per kW. Advanced non-water coolant-based SMRs are believed to have even lower overnight capital costs. For example, Moltex Energy Ltd quotes US$2000 per kW and ThorCon quotes below $2000 per kW. However, the accuracy of these cost estimates is hard to ascertain as the projects are not at a stage of detailed design; nevertheless, a costing of around US$2000 per kW is supported by industry studies.[101]

---

[98] Australian Energy Council, Capacity factors https://www.energycouncil.com.au/analysis/capacity-factors-understanding-the-misunderstood/ (2017)

[99] MIT Energy Initiative, *The future of nuclear energy in a carbon constrained world*.

[100] Black, G.A., Aydogan, F., and Koerner, C.L., ‘Economic viability of light water small modular nuclear reactors: General methodology and vendor data’, *Renewable and Sustainable Energy Reviews*, vol. 103, April 2019, pp. 248-258.

[101] Energy Innovation Research Project, *What will Advanced Nuclear Power Plants Cost?: A Standardized Cost Analysis of Advanced Nuclear Technologies in Commercial Development*, Energy Options Network, 2017, https://www.innovationreform.org/wp-content/uploads/2018/01/Advanced-Nuclear-Reactors-Cost-Study.pdf.

Environmental Considerations

With all energy generation technologies and systems, there are environmental issues to be considered, risks to be assessed, and challenges to be addressed. An ideal energy source that is at the same time efficient, cost-effective, environment-friendly, and risk-free does not exist. However, nuclear power provides secure, base-load electricity with negligible life-cycle greenhouse gas emissions, and the wastes generated are low in volume and are able to be managed safely and effectively.[102] Common issues of concern are addressed in turn, below.

Management of radioactive waste

Radioactive waste has three main classifications

Radioactive waste encompasses any material that either is intrinsically radioactive or that has been contaminated by radioactivity, and that is identified as having no further use.[103] According to guidance established by the International Atomic Energy Agency, radioactive waste can be classified either as exempt waste, (EW), very short-lived waste (VSLW), very low-level waste (VLLW), low-level waste (LLW), intermediate-level waste (ILW), or high-level waste (HLW)[104], with the management of LLW, ILW, and HLW being the focus of this submission.

Low-level waste does not require shielding during handling and transport, and is suitable for disposal in near surface or surface facilities. Low-level waste is generated in hospitals and in industrial applications, as well as in the nuclear fuel cycle. It typically comprises paper, rags, tools, clothing, and filters, which contain small amounts of mostly short-lived radioactivity. To reduce its volume, LLW often is compacted before disposal. It comprises some 90 per cent of the volume, but only one per cent of the radioactivity, of all radioactive waste.

Intermediate-level waste is more radioactive than LLW, but the heat it generates (less than 2 kW/m^3) is not sufficient to be taken into account in the design or selection of storage and disposal facilities. However, due to its higher levels of radioactivity, ILW requires a certain level of shielding. Intermediate-level waste typically comprises resins, chemical sludges, and metal fuel cladding, as well as contaminated materials from reactor decommissioning and the waste arising from the reprocessing of research reactor fuel. It comprises about seven per cent of the volume and has four per cent of the radioactivity of all radioactive waste in the world.

High-level waste is sufficiently radioactive for its decay heat (greater than 2 kW/m^3) to increase its temperature, and the temperature of its surroundings, significantly. Consequently, it requires both cooling and shielding. High-level waste arises from the ‘burning’ of uranium fuel in a nuclear reactor, and contains the fission products and transuranic elements generated in the reactor core. It accounts for three per cent of the volume, but 95 per cent of the total radioactivity of all produced waste in the world. There are two kinds of HLW:

- used fuel that has been designated as waste; and
- separated waste from the reprocessing of used fuel—where the decay heat generated by the waste residues is greater than 2 kW/m^3.[105]

Australia does not possess, or produce, high-level waste.

---

[102] McCombie, A. and Jefferson, M., ‘Renewable and nuclear electricity: Comparison of environmental impacts’, *Energy Policy*, vol. 96, 2016, pp. 758-769.
[103] WNA, *Radioactive Waste Management*.
[104] IAEA Safety Standards Series No. GSG-1, *Classification of Radioactive Waste – General Safety Guide*, IAEA, Vienna, 2009, https://www-pub.iaea.org/MTCD/Publications/PDF/Pub1419_web.pdf, pp. 5-6.
[105] WNA, *Radioactive Waste Management*.

Issues in radioactive waste management

Nuclear fuels have a high energy density; therefore, nuclear power plants produce far less waste than fossil-based power plants per unit of electricity produced. Contextualising the amount of waste produced on the basis of electricity generated provides for an effective comparison between technologies.

A 1 GWe light water reactor generates, on average, 200 to 350 m^3 of low- and intermediate-level waste per year.[106] A reactor of this size also generates approximately 1500 tonnes of used fuel over a 60-year operating life.[107] In comparison, a coal-fired power plant of the same electrical output generates approximately 400,000 tonnes of fly ash, in addition to its generation of CO_2.[108]

When comparing the management of radioactive waste with waste produced from renewable sources, the amount—and burden—again is relative. A 1 GWe solar-electric plant would generate approximately 13,000 tonnes of hazardous waste from metals processing over the same 60-year operating lifetime. Moreover, a 1 GWe solar-thermal plant has been found to generate approximately 850,000 tonnes of manufacturing waste over the same period, of which 32,000 tonnes would be contaminated with heavy metals.[109]

The management of radioactive waste is an area of significant public concern, despite geological disposal of used reactor fuel, either of the fuel assemblies directly or of the reprocessed residues, being widely recognised as a safe and effective long-term management approach.[110] The long lifetime for radioactive decay is an issue of contention. However, as shown in the image on the next page, the radiotoxicity and, therefore, the hazard of used fuel is well understood and decays with time.

Other electricity generation technologies also produce wastes that require long-term management and that remain toxic indefinitely (unlike radioactive wastes). Solar modules, for example, contain potentially dangerous materials that do not decay with time; these materials can have significant impacts on the environment and on human health. The use of cadmium in the manufacture of thin film solar panels is a major issue of concern; indeed, it was deemed one of the world's six major pollution problems in 2015.[111]

---

[106] McCombie and Jefferson, pp. 758-769.

[107] The 60-year operating life factors in an initial 40 year operating licence plus a 20 year licence extension, which is standard industry experience around the world.

[108] McCombie and Jefferson, pp. 758-769.

[109] Rhodes, R. and Beller, D., 'The Need for Nuclear Power', *Foreign Affairs*, 2000, p. 1; Clare, R., *Tidal Power: Trends and Developments*, Thomas Telford, London, pp. 307-308.

[110] OECD–NEA, *The Environmental and Ethical Basis of Geological Disposal of Long-Lived Radioactive Wastes: A Collective Opinion of the Radioactive Waste Management Committee of the OECD Nuclear Energy Agency*, OECD–NEA, Paris, 1995.

[111] McCombie and Jefferson, pp. 758-769.

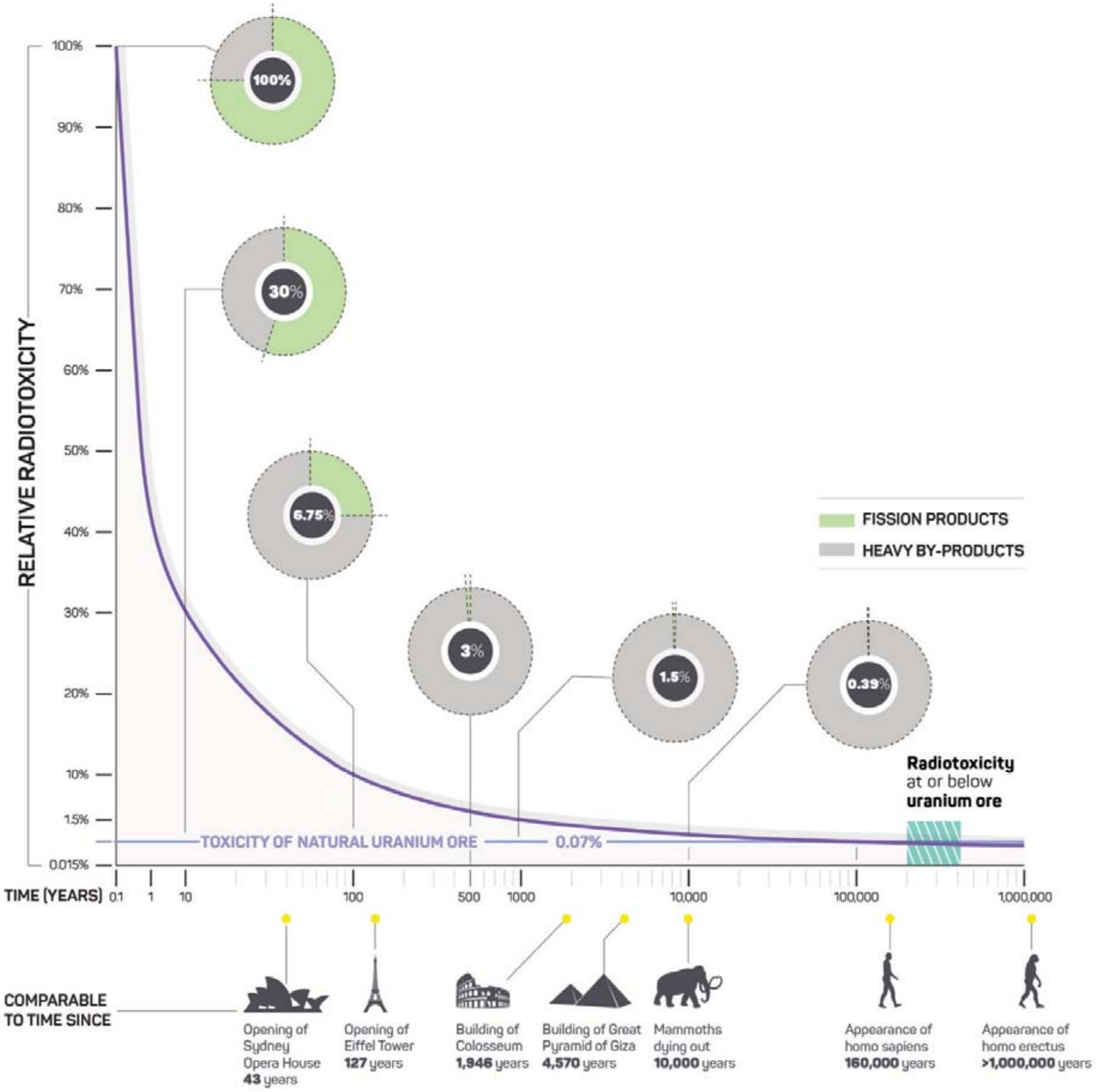

Image courtesy of: *Nuclear Fuel Cycle Royal Commission Report*, p. 82.

Approaches to used fuel and radioactive waste management

Nuclear power programs may be differentiated between those that are ‘open cycle’ and those that are ‘closed cycle’. An open cycle sees nuclear fuel passed through a reactor only once, with the used fuel then being managed for storage and, ultimately, disposal in a mined geological facility. A closed cycle involves the reprocessing of used fuel so that the extracted and separated uranium and plutonium may be reused as a mixed oxide reactor fuel; the waste by-products—or residues—subsequently are conditioned into a stable, solid, and safe form for interim storage and future disposal, presently via a process of vitrification or cementation. Most countries with a nuclear power reactor fleet have chosen open cycle programs; however, reprocessing is the stated policy intent of

France, Japan, Russia, and China.[112] The United Kingdom historically has reprocessed its used fuel, though it is in the process of transitioning to an open cycle.[113]

There are now approximately 390,000 tonnes of used nuclear fuel in temporary storage around the world, with this figure expected to rise to over one million tonnes by the end of the century.[114] Used fuel (and radioactive waste) is stored in purpose-built above-ground facilities. When discharged from the reactor, the fuel is transferred to a cooling pond, where, typically, it will remain for a period of five to 10 years. It then will be transferred to a dry storage cask, again, typically, for a period of 30 to 40 years before it is safe to be disposed of.[115] As shown in the image on the previous page, during the storage period, the radiotoxicity and heat generation will reduce—with the radiotoxicity reducing by 70 per cent in the first ten years after discharge.[116]

Storage practices for used fuel and reprocessed waste residues are well understood, safe, and effectively regulated internationally, including in Australia in the case of the reprocessed residues arising from the operation of the country's research reactors (discussed in further detail below). Storage practices for LLW and ILW are discussed in further detail later in this submission.

The international consensus is that the only safe, permanent solution for the management of used fuel and other high-activity, long-lived radioactive wastes involves the disposal of such wastes in a mined geological repository.[117] Other waste classes, for example, low- and intermediate-level wastes, may be disposed of in above-ground, near-surface, or shallow mined facilities, though practices differ from country to country and depend partly on the level of radioactivity of the waste to be disposed of.

Finland, France, and Sweden are the most advanced states in terms of planning for, and constructing, geological facilities—either for the direct disposal of fuel assemblies in a multi-barrier system in the case of Finland and Sweden, or for the disposal of reprocessed, vitrified waste residues in the case of France. Finland has received a construction licence for its geological disposal facility, which is expected to be operational in the early 2020s.[118] France and Sweden have submitted licence applications and aim to commence operation in 2030 (in the case of France) or construction within the next decade (in the case of Sweden).[119]

Radioactive waste and used fuel management practices, including storage and disposal systems, are well understood—from technical, social, environmental, and financial perspectives—and there is extensive international guidance and experience in radioactive waste management on which New South Wales and Australia could draw should a decision be made to introduce nuclear power in the

---

[112] WNA, *Radioactive Waste Management*.

[113] World Nuclear News, *Reprocessing ceases at UK's Thorp plant*, World Nuclear News, 14 November 2018, http://world-nuclear-news.org/Articles/Reprocessing-ceases-at-UKs-Thorp-plant.

[114] *Nuclear Fuel Cycle Royal Commission Report*, p. 291.

[115] This storage period applies to the direct disposal of used fuel. For fuel assemblies that are intended to be reprocessed, the storage period will be shorter.

[116] *Nuclear Fuel Cycle Royal Commission Report*, p. 82. In the first 100 years following discharge from the reactor, the used fuel will reduce in radiotoxicity by approximately 93 per cent; by year 500, it will have reduced by 97 per cent.

[117] OECD–NEA, *The Environmental and Ethical Basis of Geological Disposal of Long-Lived Radioactive Wastes*.

[118] Posiva Oy, *General Time Schedule for Final Disposal*, Posiva Oy, 2019, http://www.posiva.fi/en/final_disposal/general_time_schedule_for_final_disposal#.XXiCFpj_yUk.

[119] Andra, *Cigeo's facilities and operation: Key figures*, Andra, 2019, https://international.andra.fr/projects/cigeo/cigeos-facilities-and-operation/key-figures; SKB, *The Spent Fuel Repository: The review process*, SKB, 2019, https://www.skb.com/future-projects/the-spent-fuel-repository/the-review-process/.

future. However, ANSTO notes that a condition of any future nuclear power program would be to establish—at the outset of that program—policies, plans, and systems, as well as a hypothecated fund, to enable the responsible management of waste arisings and decommissioning liabilities. International practice is to impose a small levy on the kilowatt hours of electricity produced to cover the costs of waste management and decommissioning activities. Typically, this levy is not a significant portion of the cost of electricity production given the extremely small volumes of waste that arise per kilowatt hour. For example, utilities contribute $US0.1 cents per kilowatt hour in the United States, €0.14 cents per kilowatt hour in France, and €0.436 cents per kilowatt hour in Sweden.[120]

Advances in waste conditioning processes

Radioactive wastes must be conditioned and/or packaged for safe storage and disposal to minimise the risk of environmental and human impacts from a potential breach of containment. As noted above, vitrification and cementation are common treatment processes, though they result in vastly different volumes of waste to be disposed; vitrified waste forms are able to hold a higher load of radioisotopes and, therefore, result in smaller waste volumes to be managed than cemented forms.

Australia has developed world-leading knowledge, technology, and engineering solutions in radioactive waste management, with this expertise centring on Australia's novel Synroc waste treatment process. Synroc is an innovative techno-process for the containment of radionuclides. It was invented at the Australian National University in 1978, while its development subsequently was progressed by ANSTO.

Synroc mimics the ability of natural rock forms to bind radioactive atoms in a crystalline structure through the application of heat and pressure. It will have significant advantages over vitrification and cementation, including the capacity for higher waste loadings, reduced volume, greater durability, and greater proliferation resistance.[121]

ANSTO is constructing the world's first industrial-scale facility to use Synroc technology to treat the waste that will arise from the operation of the new ANSTO Nuclear Medicine production facility.[122] With the establishment of this demonstration facility potentially will come opportunities for commercialisation in foreign markets, including for the management of historically intractable radioactive waste streams, strengthening nuclear non-proliferation objectives.

The environmental footprint of nuclear power

Nuclear power is a carbon dioxide (CO_2)-free energy source at the point of generation. While precise estimates of the global emissions avoided due to the use of nuclear power vary, one study has found that 'global nuclear power has prevented an average of 1.84 million air pollution-related deaths and 64 gigatonnes of CO_2-equivalent ($GtCO_2$-eq) greenhouse gas (GHG) emissions that would have resulted from fossil fuel burning.'[123] It generally is acknowledged that nuclear energy avoids the production of more than 600 million tonnes of total carbon emissions and 2.5 billion tonnes of CO_2, each year. Put differently, nuclear power currently saves approximately 10 per cent of total CO_2

---

[120] WNA, *National Policies and Funding*, WNA, 2017, https://www.world-nuclear.org/information-library/nuclear-fuel-cycle/nuclear-wastes/appendices/radioactive-waste-management-appendix-2-national-p.aspx.

[121] ANSTO, *ANSTO Synroc - Waste Treatment Technology*, ANSTO, 2019, https://www.ansto.gov.au/business/products-and-services/ansto-synroc-waste-treatment-technology.

[122] ANSTO, *New global, first-of-a-kind ANSTO Synroc facility*, ANSTO, 9 April 2019, https://www.ansto.gov.au/news/new-global-first-of-a-kind-ansto-synroc-facility.

[123] Kharecha, P.A. and Hansen, J.E., 'Prevented Mortality and Greenhouse Gas Emissions from Historical and Projected Nuclear Power', *Environmental Science and Technology*, vol. 47, no. 9, 2013, p. 4889.

emissions from world energy use.[124] However, the capacity of nuclear power to mitigate or abate greenhouse gas emissions into the future depends on the extent to which nuclear power displaces carbon-based energy sources of electricity generation and on the extent to which it is deployed to support renewable energy generation technologies.[125]

While nuclear power abates emissions at the point of energy production, it is estimated that the construction of a 1 GWe nuclear power plant results in 300,000 tonnes of CO_2 emissions. For a 40-year plant life (which is the typical period for which a plant initially is licensed), this corresponds to approximately 1 g of CO_2 per kWh(e) produced. This is much lower than figures that have been calculated for fossil fuel-based energy generation technologies across the same 40-year time horizon (400 g CO_2/kWh (e)).[126]

The direct and indirect CO_2 emissions from various energy sources are outlined in the table below, drawing on data published by the United Nations Intergovernmental Panel on Climate Change (IPCC)[127]:

Primary Energy Source	**Direct Emissions Min / Median / Max**	**Infrastructure and Supply Chain Emissions (gCO_2eq/kWh)**	**Lifecycle Emissions (gCO_2eq/kWh) Min / Median / Max**
Coal–PC	670 / 760 / 870	9.6	740 / 820 / 910
Gas–Combined Cycle	350 / 370 / 490	1.6	410 / 490 / 650
Biomass–co-firing	N/A[128]	–	620 / 740 / 890
Biomass–dedicated	N/A – as above	210	130 / 230 / 420
Geothermal	0	45	6.0 / 38 / 79
Hydropower	0	19	1.0 / 24 / 2200
Nuclear	0	18	3.7 / 12 / 110
Concentrated Solar Power	0	29	8.8 / 27 / 63

---

[124] House of Representatives Standing Committee on Industry and Resources, *Australia's uranium — Greenhouse friendly fuel for an energy hungry world - A case study into the strategic importance of Australia's uranium resources for the Inquiry into developing Australia's non-fossil fuel energy industry*, 2006, pp. 152-153.

[125] Kharecha and Hansen, p. 4889.

[126] MacKay, D., *Sustainable Energy – Without the Hot Air*, UIT, Cambridge, England, 2009.

[127] Schlömer, S., Bruckner, T., Fulton, L., Hertwich, E., McKinnon, A., Perczyk, D., Roy, J., Schaeffer, R., Sims, R., Smith, P., and Wiser, R., 'Annex III: Technology-specific cost and performance parameters', in: Edenhofer, O., Pichs-Madruga, R., Sokona, Y., Farahani, E., Kadner, S., Seyboth, K., Adler, A., Baum, I., Brunner, S., Eickemeier, P., Kriemann, B., Savolainen, J., Schlömer, S., von Stechow, C., Zwickel, T., and Minx, J.C., eds., *Climate Change 2014: Mitigation of Climate Change. Contribution of Working Group III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*, Cambridge University Press, Cambridge, United Kingdom, and New York, NY, USA., p. 1335.

[128] According to the IPCC, 'Direct emissions from biomass combustion at the power plant are positive and significant, but should be seen in connection with the CO_2 absorbed by growing plants. They can be derived from the chemical carbon content of biomass and the power plant efficiency.' See: Schlömer, *et al.*, p. 1335.

Solar PV–rooftop	0	42	26 / 41 / 60
Solar PV–utility	0	66	18 / 48 / 180
Wind–onshore	0	15	7.0 / 11 / 56
Wind–offshore	0	17	8.0 / 12 / 35

Land requirements for nuclear power reactors

Footprint—or land—requirements are a critical consideration when determining the environmental impacts of nuclear power. It has been estimated that the land requirements for the operation of a nuclear power plant correspond to only 0.6 m^2 per GWh(e). This value is dependent upon the type and size of the power reactor, noting that small modular reactors promise to substantially decrease the footprint occupied by the larger power stations currently in operation. Put in context, the footprint required for hydropower and large solar power plants is 49 m^2 and 1275 m^2 per GWh(e), respectively. Other studies have shown that wind farms require 300 to 500 times more land than a nuclear power plant.[129]

Water use

Water consumption in conventional large nuclear power plants is high, and second only to that required by the agricultural sector.[130] Water is a requirement for cooling; however, the majority of cooling water used in power reactors around the world is drawn from the sea, which is returned to the environment only a few degrees warmer and with minimal loss due to evaporation.[131] The rate of return of water utilised in nuclear power reactors is demonstrated by data obtained from the 1 GWe Leibstadt plant in Switzerland, at which the required cooling water throughput is 32 m^3 per second and the losses from evaporation amount to 1 m^3 per second.[132]

When compared with other electricity generation technologies, power reactor water requirements are, on average, two to four times lower than that which is required for solar-thermal and geothermal power plants. According to the IPCC, as quoted in McCombie and Jefferson, hydropower plants can lose 17,000 litres per MWh(e) produced due to evaporation and, accordingly, are the most water resource-intensive of the power generation technologies.[133] That IPCC report, again quoted in McCombie and Jefferson, further shows that nuclear power is better than coal or biogas in terms of its operational water consumption, but wind power uses almost none.[134]

Other toxic emissions

Nuclear power plants emit small quantities of radioactive gases, such as krypton-85, xenon-133, and iodine-131, under controlled and monitored conditions during normal operations. Radioactive liquids also may be emitted in very small quantities.[135] Because these discharges may have environmental and/or human health impacts, the nuclear industry is subject to strict regulations and licensing conditions. Nuclear power plants, and, more broadly all nuclear facilities, are mandated to collect

---

[129] MacKay, D., *Sustainable Energy – Without the Hot Air*; *Water Use and Nuclear Power Plants*, Nuclear Energy Institute, Washington, D.C., 2013.
[130] McCombie and Jefferson, pp. 758-769.
[131] McCombie and Jefferson, pp. 758-769.
[132] McCombie and Jefferson, pp. 758-769.
[133] McCombie and Jefferson, pp. 758-769.
[134] McCombie and Jefferson, pp. 758-769.
[135] McCombie and Jefferson, pp. 758-769.

and analyse environmental samples and gaseous discharges to ensure that their environmental impacts are minimised.

Alternative energy technologies also produce air and other pollutants. These include particulates, carbon monoxide, nitrous oxides, sulphur dioxide, and volatile organic compounds, which are highly potent and detrimental to the environment and air quality. For example, solar photovoltaic power is estimated to emit 263 kg of nitrous oxides and 731 kg of sulphur oxides per GWh(e) generated.[136] Wind energy also releases 71 kg of nitrous oxides and 137 kg of sulphur oxides per GWh(e).[137] Data reported by the IPCC shows that the sulphur dioxide and nitrogen dioxide emissions per GWh(e) generated by fossil fuels and biomass exceed those from nuclear power and all other renewables.[138]

Summary of environmental impacts

It is clear that nuclear and renewables outperform fossil fuels as generation technologies from the standpoint of their capacity to abate emissions. The major environmental concerns pertaining to nuclear as an source of electricity are around water utilisation, radioactive waste management practices, and land management. However, the studies cited in this submission would indicate that nuclear is competitive against fossil fuels when compared with other low-carbon technologies.

---

[136] McCombie and Jefferson, pp. 758-769.
[137] McCombie and Jefferson, pp. 758-769.
[138] McCombie and Jefferson, pp. 758-769.

Health, Safety, and Security Considerations

The safety record of nuclear technology

Nuclear power is a safe technology[139], outperforming other established electricity generation technologies in human health outcomes. This is true even when the effects of nuclear accidents, which are extremely rare in comparison to other technologies, are considered.[140] Moreover, and as shown above, nuclear power has been found to save lives. The same aforementioned study estimates ‘that nuclear power could additionally prevent an average of 420000 [to] 7.04 million deaths and 80 [to] 240 $GtCO_2$-eq emissions due to fossil fuels by midcentury, depending on which fuel it replaces.’[141]

Nuclear power has been found to result in the lowest number of fatalities of any major electricity source, many times lower than coal, natural gas, and oil, and lower than biomass, as shown in the table below, which presents the health effects of electricity generation in Europe by primary energy source (deaths/cases per TWh):

Source	Deaths from Accidents		Air Pollution-Related Effects		
	The Public	Occupational	Deaths*	Serious Illness†	Minor Illness‡
Lignite	0.02 (0.005–0.08)	0.10 (0.025–0.4)	32.6 (8.2–130)	298 (74.6–1193)	17,676 (4419–70,704)
Coal	0.02 (0.005–0.08)	0.10 (0.025–0.4)	24.5 (6.1–98)	225 (56.2–899)	13,288 (3322–53,150)
Gas	0.02 (0.005–0.08)	0.001 (0.0003–0.004)	2.8 (0.70–11.2)	30 (7.48–120)	703 (176–2813)
Oil	0.03 (0.008–0.12)	–	18.4 (4.6–73.6)	161 (40.4–645.6)	9551 (2388–38,204)
Biomass	–	–	4.63 (1.16–18.5	43 (10.8–172.6)	2276 (569–9104)
Nuclear	0.003	0.019	0.052	0.22	–

Data are mean estimate (95% CI). *Includes acute and chronic effects. Chronic effect deaths are between 88% and 99% of total. For nuclear power, data include all cancer-related deaths. †Includes respiratory and cerebrovascular hospital admissions, congestive heart failure, and chronic bronchitis. For nuclear power, data include all non-fatal cancers and hereditary effects. ‡Includes restricted activity days, bronchodilator use cases, cough, and lower-respiratory symptom days in patients with asthma, and chronic cough episodes. TWh=1012 Watt hours.

Source: Markandya, A. and Wilkinson, P., ‘Electricity Generation and Health’, *The Lancet*, vol. 370, iss. 9591, 15 September 2007, p. 981.

Nuclear power reactors are endowed with extensive design elements and preventive maintenance, inspection, and monitoring programs to ensure their safe and reliable operation.[142] Operators of power reactors undertake periodic safety, security, and other threat-based risk assessments to

---

[139] Deutch, J. and Forsberg, W., *MIT, Update of the MIT 2003 Future of Nuclear Power,* 2009.

[140] OECD–NEA, *The Full Costs of Electricity Provision: Extended Summary*, OECD, NEA No. 7437, 2018, https://www.oecd-nea.org/ndd/pubs/2018/7437-full-costs-sum-2018.pdf.

[141] Kharecha and Hansen, p. 4889.

[142] Ahmed, W. H., Mohany, A., and Li, B., ‘Nuclear power plants safety and maintenance’, *Science and Technology of Nuclear Installations*, 2014.

identify external and internal factors that detrimentally could affect facility operations, and worker and public safety.

Nuclear reactor incidents

Despite their design, maintenance and monitoring programs, and periodic risk assessments, although rare, major incidents at nuclear power plants have occurred. The three most prominent are discussed in turn.

Three Mile Island (United States, 1979)

The first major incident at a commercial nuclear power plant occurred at Three Mile Island (United States, 1979) due to a loss of coolant (water). This caused a partial melting of the fuel assemblies, which resulted in a small amount of radiation release to the environment. Subsequent inquiries and studies by independent investigators concluded that most radiation was effectively contained, with the release found to have had negligible effects on the physical health of individuals or the environment.[143] Indeed, no individual, among either workers of members of the public, died or suffered from acute radiation syndrome as a result of the Three Mile Island incident. According to the United States Nuclear Regulatory Commission (NRC), which conducted detailed studies of the accident's radiological consequences (as did the Environmental Protection Agency, the Department of Health, Education and Welfare (now Health and Human Services), the Department of Energy, and the Commonwealth of Pennsylvania):

> The approximately 2 million people around TMI-2 during the accident are estimated to have received an average radiation dose of only about 1 millirem [0.01 milliSieverts (mSv)] above the usual background dose. To put this into context, exposure from a chest X-ray is about 6 millirem [0.06 mSv] and the area's natural radioactive background dose is about 100-125 millirem [1–1.25 mSv] per year for the area. The accident's maximum dose to a person at the site boundary would have been less than 100 millirem [1 mSv] above background.
>
> In the months following the accident, although questions were raised about possible adverse effects from radiation on human, animal, and plant life in the TMI area, none could be directly correlated to the accident. Thousands of environmental samples of air, water, milk, vegetation, soil, and foodstuffs were collected by various government agencies monitoring the area. Very low levels of radionuclides could be attributed to releases from the accident. However, comprehensive investigations and assessments by several well respected organizations, such as Columbia University and the University

---

[143] GPU Nuclear Corporation, *Radiation and health effects – a report on the TMI-2 accident and related health studies*, GPU Nuclear Corporation, Middletown, PA, 1986; United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR), *Sources and Effects of Ionizing Radiation: United Nations Scientific Committee on the Effects of Atomic Radiation: UNSCEAR 1993 Report to the General Assembly, with Scientific Annexes: Annex B. Exposures from man-made sources of radiation*, United Nations, New York, 1993, p. 114.
The Three Mile Island Reactor Unit 2 (TMI-2) permanently was shut down following the incident, with the reactor coolant system being drained, the radioactive water being decontaminated and evaporated, radioactive waste relocated, and reactor fuel and core debris relocated to a Department of Energy facility, while the remainder of the site was the subject of ongoing monitoring.
Reactor Unit 1 had its licence temporarily suspended following the incident in at TMI-2; however, it was permitted to resume operations in 1985 following a four-to-one vote by commissioners of the United States Nuclear Regulatory Commission (NRC). In 2009, the NRC granted a licence extension, enabling the TMI-1 reactor to operate until April 19 2034. However, in 2017, it was announced that operations would cease on September 30, 2019, for financial reasons.

of Pittsburgh, have concluded that in spite of serious damage to the reactor, the actual release had negligible effects on the physical health of individuals or the environment.[144]

Chernobyl (Union of Soviet Socialist Republics, 1986)

The Chernobyl incident (Ukraine – then in the Union of Soviet Socialist Republics, 1986) is the worst nuclear incident in history and the first to receive the maximum level 7 rating on the International Nuclear Event Scale (INES). The incident was caused by inherent reactor instability owing to its design, an inadequate safety culture, and the deliberate overriding of safety systems by operators during an unauthorised test of the reactor's control systems. The overheating of the reactor resulted in two chemical explosions and a fire that caused the deaths of two workers.[145] Of the 600 personnel involved in the emergency response, 134 developed acute radiation syndrome, with 28 dying from their exposure to radiation.[146]

The incident led to the release of a large amount of radioactive material (including iodine) into the atmosphere. Although members of the public were reported to have been exposed to radioactive iodine in low doses, increased cancer incidence owing to that exposure has not been established.[147] The United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR) has found that there are generally positive prospects for the future health of most members of the public exposed to radiation as a result of the incident.[148] However, 220,000 people were displaced from their homes and there have been undoubted long-term psychosocial effects.[149]

The incident involved a reactor design that would not have been licensed in a Western country, due to the lack of safety features – including a containment vessel.[150]

Fukushima Dai-Ichi (Japan, 2011)

The Fukushima Dai-Ichi incident (Japan, 2011) was the result of hydrogen explosions in several reactor units. The incident occurred when cooling of the reactor cores could not be maintained due to the severing of external and back-up power and water supplies following an earthquake and two tsunami waves.[151] It is reported that 50,000 households, comprising 156,000 people, were displaced as a result of the compound disaster. While there have been no deaths or reports of radiation sickness attributed to the hydrogen explosions and subsequent release of radiation, as with the Chernobyl accident, the displacement of households and fears about the effects of radiation have resulted in significant social and mental health impacts.[152] The economic costs of the incident have also been significant.

---

[144] United States Nuclear Regulatory Commission, *Backgrounder on the Three Mile Island Accident*, June 2018, United States Nuclear Regulatory Commission, https://www.nrc.gov/reading-rm/doc-collections/fact-sheets/3mile-isle.html#effects.

[145] *Nuclear Fuel Cycle Royal Commission Report*, p. 44.

[146] UNSCEAR, *Sources and Effects of Ionizing Radiation: United Nations Scientific Committee on the Effects of Atomic Radiation: UNSCEAR 2008: Report to the General Assembly with Scientific Annexes: Volume I*, United Nations, New York, 2010, pp. 15-16.

[147] UNSCEAR, *Sources and Effects of Ionizing Radiation*, 2010, pp. 15-16.

[148] UNSCEAR, *Sources and Effects of Ionizing Radiation*, 2010, pp. 15-16.

[149] González, A.J., 'Chernobyl vis-à-vis the nuclear future: an international perspective', *Health Physics*, vol. 93, 2007, pp. 571-592.

[150] *Nuclear Fuel Cycle Royal Commission Report*, pp. 43-44.

[151] Report by the Director General, *The Fukushima Daiichi Accident*, GC(59)/14, IAEA, Vienna, 2015.

[152] Weightman, M., Transcript of Evidence, *Nuclear Fuel Cycle Royal Commission*, 22 October 2015, p. 831; UNSCEAR, *Sources, Effects and Risks of Ionizing Radiation: UNSCEAR 2013 Report: Volume I: Report to the General Assembly: Scientific Annex A: Levels and effects of radiation exposure due to the nuclear accident after the 2011 great east-Japan earthquake and tsunami*, United Nations, New York, 2014, pp. 77, 80.

It is notable that, of the 54 Japanese reactors that were idled for review, maintenance, upgrade, and/or decommissioning following the earthquake and tsunami that affected the Fukushima Dai-Ichi nuclear power plant in March 2011, nine have been restarted and a further 17 are in the process of receiving approval to restart.[153] Thirty-seven of the 54 are considered operable by Japan's independent nuclear safety regulator.[154]

Lessons learned

Separate investigations into the causes of all three incidents have found that they were attributable to several factors, including unchallenged design assumptions and operational and emergency response procedural flaws.[155] Moreover, the safety and regulatory cultures prevailing at the time these incidents occurred also have been found to have contributed to the incidents and to the severity of their impacts.[156]

Following the Fukushima incident, the IAEA recommended a global review of all operating reactors. These reviews have been the basis for ongoing improvements into the safety of reactors globally. Indeed, 14 key lessons to improve nuclear safety and emergency preparedness were identified during the global review.[157] The Fukushima incident, in particular, highlighted the importance to the nuclear industry of the presence of a robust regulatory framework and strong independent regulator, which, respectively, were deficient or absent in the case of Japan.[158]

Examination of the most severe nuclear incidents, as well as of the resources that have been directed to their investigation and reporting of learnings, illustrates a worldwide commitment to safe, continuously improving, and responsible nuclear power generation. The nuclear power industry is continuing—iteratively—to improve reactor technologies in light of the acute and prolonged risks nuclear accidents present to individuals, communities, and the environment.[159] In particular, the common feature of the Three Mile Island and Fukushima incidents was the fact that the fuel used in those reactors melted on exposure to air. There is, therefore, a lot of research being directed to the development of so-called 'accident tolerant fuels, which will be less vulnerable to melt. As the emerging nuclear technologies progress to commercialisation, their enhanced safety features will ensure that nuclear reactors remain one of the safest electricity generation technologies available.

Nuclear security

The IAEA has developed a range of standards and conventions regarding the security of nuclear facilities and nuclear material that would be applied in the event that nuclear power plants were introduced in Australia.

Nuclear security 'relates to [the] theft, sabotage, unauthorized access and illegal transfer or other *malicious acts* involving nuclear material and other radioactive substances and associated

---

[153] WNA, *Nuclear Power in Japan*, WNA, August 2019, http://www.world-nuclear.org/information-library/country-profiles/countries-g-n/japan-nuclear-power.aspx.

[154] WNA, *Nuclear Power in Japan*.

[155] *Nuclear fuel cycle Royal Commission Report*, pp. 44, 210.

[156] *Nuclear fuel cycle Royal Commission Report*, p. 210.

[157] Report by the Director General, *The Fukushima Daiichi Accident*, pp. 70-73.

[158] *Nuclear fuel cycle Royal Commission Report*, p. 210; Vivoda, V. and Graetz, G., 'Nuclear Policy and Regulation in Japan after Fukushima: Navigating the Crisis', *Journal of Contemporary Asia*, vol. 45, iss. 3, 2015, pp. 490-509.

[159] Sarkar, A.J., 'Nuclear power and uranium mining: current global perspectives and emerging public health risks', *Journal of Public Health Policy*, July 2019, https://doi.org/10.1057/s41271-019-00177-2.

facilities.'[160] According to the IAEA, the 'legal foundation for nuclear security consists of international instruments and recognized principles designed to control nuclear material and other radioactive substances.'[161]

Responsibility for ensuring nuclear security vests with each country that possesses or controls nuclear and radioactive materials. In this context, it is important to note that, in 2012, 2014, 2016, and 2018, Australia was ranked first in the biennial assessment of nuclear security in countries with significant holdings of nuclear material by the Nuclear Threat Initiative[162], an independent non-government organisation that works to reduce global threats from nuclear, biological, and chemical weapons. Australia has maintained its top ranking through steps such as reducing the quantities of highly enriched uranium it holds and its leadership role in the Global Initiative to Combat Nuclear Terrorism (GICNT) and other global nuclear security forums.

Aware of the importance of nuclear security, ANSTO actively contributes to its promotion in Australia, the Asia-Pacific region, and around the world. The organisation strongly supports Australia's non-proliferation efforts, and provides international leadership in nuclear security operations. ANSTO also undertakes research in the principal areas of nuclear security, including nuclear forensics and border security technology development. Moreover, on Australia's behalf, ANSTO participates in the GICNT steering group, the Implementation and Assessment Group, has chaired the Nuclear Forensics Working Group, and participates in two other working groups.

ANSTO's nuclear forensics facility is staffed with experts in radiochemistry and forensic science, who:

- conduct research into methods to determine the origin of radioactive materials, decontamination, and examination of contaminated evidence;
- provide training to Australian response agencies that may have to attend crime scenes potentially contaminated with radioactive materials; and
- undertake forensic analysis of seized samples.

Because of this capability, Australia has the necessary tools to prevent and respond to nuclear security threats—both at home and abroad. ANSTO also engages actively in domestic and international discussions regarding emerging nuclear cyber security threats.

---

[160] Schriefer, D., 'Safeguards, security, safety and the nuclear fuel cycle', in Crossland, I., ed., *Nuclear Fuel Cycle Science and Engineering*, National Nuclear Laboratory, Woodhead Publishing, Oxford, Cambridge, Philadelphia, New Delhi, 2012, p. 60.

[161] IAEA, *Security*, IAEA, Vienna, 2019, https://www.iaea.org/topics/security.

[162] Nuclear Threat Initiative (NTI), *NTI Nuclear Security Index: Theft* **|** *Sabotage: Building a Framework for Assurance, Accountability, and Action*, 4th edn., NTI with The Economist Intelligence Unit, September 2018, p. 10.

Social and Community Considerations

International research has found that public support for, and positive sentiment toward, nuclear activities is highest in communities that are located in close proximity to nuclear facilities. This is attributable to reported perceptions of benefits, including employment opportunities and social and economic activity. Public support for nuclear power, in particular, also has been found to be higher when the public is aware of its role in combatting climate change.

Civilian nuclear fuel cycle activities are the subject of significant public interest, concern, and, as documented earlier in this submission, benefit. Despite these benefits, there is significant concern about the nature of the risks of nuclear fuel cycle activities (and their consequences) stemming from human exposure to ionising radiation—including the pathways and controls that are established to ensure the safety of radiation workers and members of the public. Education and outreach, therefore, are foundational to increasing knowledge of the fuel cycle, including nuclear power, and to public understanding of the benefits that might accrue from the peaceful uses of nuclear science and nuclear technology.

In this context, were the prohibitions to be lifted, it would be essential for any new nuclear activities in New South Wales to obtain the broad support of the community. Methods for determining and assessing public sentiment exist, and are routinely used by domestic and international policy-makers on a range of policy issues.[163]

The support of any potential host community/ies that stand/s to be most affected by the siting of a nuclear facility also would need to be obtained. Accordingly, any proposal to establish nuclear power the State or elsewhere in Australia would require comprehensive plans for community engagement and education—delivered at the local, regional, and national levels. It is only through such engagement that the community could gain the sufficient familiarity with, and understanding of, nuclear technology to be in a position to make an informed judgement as to whether the State could—and should—consider the inclusion of nuclear power in its energy mix.

There is a significant body of work undertaken internationally on community engagement and communications regarding the establishment of nuclear industries and facilities.[164] For example, the OECD–NEA’s Forum on Stakeholder Confidence publishes guidance and summaries of leading practice from around the world.[165]

The international experience shows that community engagement activities should not be the subject of arbitrary timeframes and inadequate resourcing, and that communities and other stakeholders can play a constructive role in project planning and delivery. Examples of public contributions to the establishment and operation of nuclear facilities include the provision of local knowledge regarding environmental and heritage factors, design enhancements, and the supply of labour and services throughout the supply chain.

ANSTO wishes to put on record in this submission its gratitude for the ongoing bipartisan support that it receives for its activities at the Federal level, which was demonstrated most recently during the process to enable Australia’s membership of the Generation IV International Forum. ANSTO also is grateful for the bipartisan support it receives in New South Wales and Victoria—both jurisdictions in which it operates facilities. Moreover, as one of the major employers in the Sutherland Shire, ANSTO has deep and congenial connections with its local community. The organisation maintains

---

[163] *Nuclear Fuel Cycle Royal Commission Report*, p. 121.

[164] *Nuclear Fuel Cycle Royal Commission Report*, pp. 121-131, 223-244.

[165] OECD–NEA, *Forum on Stakeholder Confidence (FSC)*, OECD–NEA, Paris, 19 February 2019, https://www.oecd-nea.org/rwm/fsc/.

strong relationships with key stakeholders, including the Sutherland Shire Council, local education and community groups, and business and industry associations.

ANSTO has played a significant role in engaging with the Australian community on nuclear, and broader science and technology issues, for many years. In 2018, ANSTO welcomed more than 17,000 visitors to its Lucas Heights campus in southern Sydney. The majority of these visits were from school groups undertaking tours specifically tailored to the science curriculum. Beyond engagement with school students, ANSTO contributes to the education and training of Australia's future nuclear experts—and scientists more broadly—through:

- support for, and supervision of, undergraduate, masters, and doctoral students;
- the provision of internship and fellowship opportunities; and
- the provision of support for university courses, such as the Master of Engineering Science (Nuclear Engineering) at the University of New South Wales.

Legal and Legislative Considerations

The effect of the repeal of the *Uranium Mining and Nuclear Facilities (Prohibitions) Act 1986* would be the removal of State prohibitions on the potential establishment of uranium mines and nuclear facilities in New South Wales.

Other legislative and regulatory barriers

At the Federal level, the *Environment Protection and Biodiversity Conservation Act 1999* (Cth) (EPBC Act) prohibits the construction or operation of nuclear fuel fabrication plants, nuclear power plants, enrichment plants, and reprocessing facilities anywhere in Australia. In addition, the *Australian Radiation Protection and Nuclear Safety Act 1998* (Cth) (ARPANS Act) prevents the Chief Executive Officer of Australian Radiation Protection and Nuclear Safety Agency from licensing the siting, construction, or operation of proscribed nuclear facilities by Australian Government entities.

If there were a decision by Government to allow the development of nuclear power reactors or other fuel cycle facilities, in addition to the removal of the State and Federal legislative impediments, the provision of additional resourcing would also likely be required to upgrade the existing regulatory architecture so that it is capable of performing the functions needed for the licensing and oversight of nuclear power reactors and any other facilities. Moreover, there would need to be legislation governing nuclear liability in order to bring Australia into line with international legal norms.

Nuclear liability legislation

The issue of liability—and compensation—for nuclear accidents is of significant importance for the nuclear industry, both for people who might suffer some form of injury or other damage as a result of a nuclear accident, and for industry and suppliers that need certainty as to their potential risk exposure and insurance needs. At the international level, that need has been met by the development of a number of conventions (including the Convention on Supplementary Compensation) reflecting common principles of nuclear liability. Those principles include strict liability, guaranteed amounts of compensation, and the concentration of liability on the operator of a nuclear facility.

In the absence of legislation governing nuclear liability and compensation, the Australian Government has provided ANSTO with a Deed of Indemnity to cover its potential liability and that of its contractors. Under that Deed, the Commonwealth undertakes, essentially, to step into ANSTO’s shoes, or those of an ANSTO officer (including an ANSTO contractor), if a claim is brought against them for damage from ionising radiation. The Deed provides assurance to the local community and to ANSTO’s nuclear suppliers—which generally are companies that operate in the international nuclear marketplace—that, in the very unlikely event of an accident at ANSTO’s facilities or in the course of transport of radioactive material to or from an ANSTO facility, they would not be required to provide compensation.

While it is has been judged to be appropriate for the Australian Government to provide ANSTO, which is an arm of that Government, with the aforementioned Deed of Indemnity, it would not appear appropriate for Government to do so in respect of a private entity or an Australian State. For these circumstances, then, it would appear necessary for the Australian Government to adopt nuclear liability legislation. Once legislation were adopted, Australia also would need to consider joining the Convention on Supplementary Compensation so as to provide a further level of reassurance to potential international partners.

Part Three

Useful Reports and Publications

Members of the Committee may find the following reports and publications valuable as they conduct their investigations:

Name	Link
World Nuclear Performance Report 2019	World Nuclear Association
A Call to Action: A Canadian Roadmap for Small Modular Reactors	SMR Roadmap
The Costs of Decarbonisation: System Costs with High Shares of Nuclear and Renewables	OECD–NEA
Responsibilities and Functions of a Nuclear Energy Programme Implementing Organization	International Atomic Energy Agency
Options for Management of Spent Fuel and Radioactive Waste for Countries Developing New Nuclear Power Programmes	International Atomic Energy Agency
Nuclear Fuel Cycle Royal Commission Report	Get to Know Nuclear
Modernising Electricity Sectors: A Guide to Long-run Investment Decisions	Industry Super Australia
The Future of Nuclear Energy in a Carbon Constrained World: An Interdisciplinary Study	Massachusetts Institute of Technology
Nuclear Power Reactors in the World: Reference Data Series No. 2 2019 Edition	International Atomic Energy Agency
Understanding the Formation of Attitudes to Nuclear Power in Australia	Australian Academy of Technology and Engineering
Advanced Nuclear Technologies – A UK Framework	Clean Energy Ministerial
Global Energy & CO2 Status Report: The Latest Trends in Energy and Emissions in 2018	International Energy Agency
Advancing Nuclear Innovation: Responding to Climate Change and Strengthening Global Security	Global Nexus Initiative
Uranium 2018: Resources, Production and Demand	OECD–NEA

Upcoming Meetings and Events

ANSTO draws Committee members' attention to the following upcoming meetings and events, which may be of interest to their Inquiry:

Meeting / Event	Location and Date	Further Information
Applications for SMRs and Advanced Reactors to promote clean growth	Dubai, 29 – 30 October 2019	http://www.stratcoms.com/SMRsARs2019/
5th International Symposium on the System of Radiological Protection South Australia	Adelaide, 17 – 21 November 2019	https://icrp2019.com/
International Conference on Research Reactors: Addressing Challenges and Opportunities to Ensure Effectiveness and Sustainability	Buenos Aires, 25 – 29 November 2019	https://www.iaea.org/events/conference-on-research-reactors-2019
International Youth Nuclear Congress	Sydney, 8 – 13 March 2020	https://iync2020.org/
International Nuclear Supply Chain Symposium	Munich, 12 – 13 May 2020	https://www.tuev-sued.de/academy/conference-management/plant-engineering-industrial-safety/nuclear-supply-chain-symposium?utm_medium=cooperation&utm_source=nti&utm_campaign=supply-chain-2020-nti-eng
World Nuclear Exhibition 2020	Paris Nord Villepinte, 23 – 25 June 2020	https://www.world-nuclear-exhibition.com/en-gb.html