28 February 2020

Mr Cesar Melhem
Chair, Environment and Planning Committee
Parliament of Victoria
Via Email: nuclearprohibition@parliament.vic.gov.au

Dear Mr Melhem

Thank you for the opportunity to provide a submission to the Committee's Inquiry into Nuclear Prohibition. Please find attached the submission from the Australian Nuclear Science and Technology Organisation (ANSTO).

As the custodian of Australia's nuclear expertise and capabilities, ANSTO is well positioned to advise the Committee on matters of relevance to the Inquiry's Terms of Reference. I trust that you will find our submission informative.

Should you or other members of the Committee have further questions in relation to our submission, please do not hesitate to contact me on [redacted]

Yours sincerely

[redacted]

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Australian Government

ANSTO

ANSTO Submission

The Parliament of Victoria – Environment and Planning Committee’s Inquiry into Nuclear Prohibition

ANSTO

28 February 2020

Introduction and Scope

As the custodian of Australia's nuclear science, nuclear technology, and nuclear engineering capabilities and expertise, ANSTO (the Australian Nuclear Science and Technology Organisation) is pleased to make this submission to the Parliament of Victoria Environment and Planning Committee's Inquiry into Nuclear Prohibition.

While ANSTO is agnostic about whether Victoria—or Australia—might in future introduce, or consider the introduction of, nuclear fuel cycle activities currently prohibited by Victorian and Federal legislation, the Organisation is an 'intelligent observer' of developments in the peaceful uses of nuclear science and nuclear technology. Our knowledge and expertise is gained through our staff and, importantly, our representation of the Australian Government in various International Atomic Energy Agency (IAEA) and Organisation for Economic Co-operation and Development – Nuclear Energy Agency (OECD–NEA) forums, as well as our engagement with bilateral and multilateral partners.

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

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

Through the agency of ANSTO, Australia has developed a strong international role and reputation in nuclear science and nuclear 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.

Particularly relevant to this Inquiry's first Term of Reference, 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. The unit has expertise in the leaching and processing of uranium ores, and has been active in the development and application of technologies for the global 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. It also has supported numerous preliminary, definitive, and bankable feasibility studies.

In addition, ANSTO is represented in the OECD–NEA Expert Group on Uranium Mining and Economic Development, which 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 mining projects.

Specifically, ANSTO has a strong presence in Victoria, with the Organisation operating the Clayton-based Australian Synchrotron, a world-class national research facility that uses accelerator technology to produce a powerful source of light X-rays and infrared radiation for use in scientific and industrial applications.

ANSTO's capabilities and expertise

Our capabilities, and the extent of our expertise through the various stages and focus areas of the nuclear fuel cycle, are highlighted in the table below:

Capability / Area of Expertise	Description
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 Australian Synchrotron in Clayton, Victoria, and the Open Pool Australian Light-water Reactor, the Australian Centre for Neutron Scattering, the Centre for Accelerator Science, the National Deuteration Facility, and the National Research Cyclotron in Sydney. ANSTO is mandated under its Act to facilitate their use by academic, research, and scientific communities, government agencies, and commercial clients.
Community engagement on nuclear fuel cycle activities	By taking the time to engage and educate non-scientific audiences, including members of the public, about the benefits of nuclear science and nuclear technology, and about how the application of nuclear technologies relates to daily lives, ANSTO has introduced new ways to discuss and think about nuclear issues. Our Organisation 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.
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.
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.

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.
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.
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.
Management of radioactive wastes	ANSTO has developed significant capabilities and expertise in the management of radioactive wastes and the safe 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.
Engineering and manufacturing	ANSTO has developed in-house capability to design and manufacture specialised equipment for use in radioactive environments.
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.
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.
Reactor operations	ANSTO has overseen the design and construction, commissioning, and operation of nuclear research reactors (three in total) safely and efficiently for over 60 years, providing the Organisation with substantial reactor operations capability and knowledge.
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.

Submission Outline

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

- the potential repeal of prohibitions on the establishment of nuclear fuel cycle facilities and activities in New South Wales;
- the prerequisites 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 use of nuclear science and technology to assist sustainable development in the Indo-Pacific region;
- the steps required for nuclear power to become a viable option in Australia; and
- other potential nuclear fuel cycle opportunities for Australia.

The submission proceeds as follows:

- Part One addresses the first Term of Reference—that is, to 'investigate the potential for Victoria to contribute to global low carbon dioxide energy production through enabling exploration and production of uranium and thorium', with a focus on uranium mining. It does this by examining the technical, economic, environmental, and social and community matters associated with uranium exploration and mining activities.
- Part Two addresses the second and third Terms of Reference—that is, to 'identify economic, environmental and social benefits for Victoria, including those related to medicine, scientific research, exploration and mining' and the 'opportunities for Victoria to participate in the nuclear fuel cycle'. It does this by providing a status report on global nuclear power installation and research and development activities, other nuclear fuel cycle activities, and the beneficial applications of nuclear science and nuclear technology. It then examines the financial and economic; environmental; health, safety, and security; and social and community considerations of nuclear fuel cycle activities.
- Part Three addresses the fourth Term of Reference—that is, to 'identify any barriers to participation, including limitations caused by federal or local laws and regulations'.
- Part Four provides lists of useful reports and publications and upcoming meetings and events.

ANSTO is not a policy-making body. Accordingly, ANSTO does not make any policy recommendations in this submission.

Part One

—investigate the potential for Victoria to contribute to global low carbon dioxide energy production through enabling exploration and production of uranium and thorium

Technical Matters

Uranium is an important global energy commodity

A single 20-gram uranium pellet is equivalent to the energy contained in 400 kilograms of coal, 410 litres of oil, or 350 cubic metres of natural gas. Owing to this inherent energy, uranium-fuelled nuclear power reactors generate about 10 per cent of global electricity production and 29 per cent of global low-carbon electricity production.[1] Clearly, nuclear power continues to be a significant component of many countries' energy systems, and will become even more so as the world transitions to a low-carbon future.[2] To meet this demand, the World Nuclear Association predicts that there will be growth in the global production of uranium over the next 20 years.[3]

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 units of Becquerels (Bq). If the radiation, which can be in particle or electromagnetic form, 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), generally expressed as thousandths of a Sievert (millisieverts). Dose limits for exposure to humans 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, and, put in context, a routine abdomen X-ray will result in a dose of 13 mSv[4], while a worker at the Olympic Dam polymetallic mine[5] in South Australia would receive an average dose of less than 1 mSv in a year.[6] 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.

Uranium mining 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, comprising: leaching of 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 the substance to produce a uranium oxide compound known as 'yellowcake'. This is the current practice at the Ranger Mine in the Northern Territory and at the Olympic Dam Mine in South Australia.

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[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] Olympic Dam principally is a copper mine; gold and silver also are extracted, and uranium is mined as a by-product.
[6] 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.

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 to collect the uranium-laden run-off. This is known as ‘heap-leaching’, and has been proposed for Olympic Dam.

Finally, leaching solution can be injected underground directly into the unmined orebody, and then pumped back to the surface to recover the leached uranium. This is known as ‘in-situ recovery’, and is the current practice at the Beverley and Four Mile uranium mines in South Australia. 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.

Risks

Uranium mining is a well-established activity that has been undertaken for more than 60 years. There are operating mines on 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 uranium mining also must 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 when 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 also must be carefully considered. While these risks are explored in further detail 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 leach solution into the host rock. 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.

Thorium

Like uranium, thorium is a naturally occurring radioactive heavy metal with immense inherent energy and is found in significant abundance in Australia. Typical of the Australian deposits, thorium is found in monazite deposits.[7] Monazite resources generally are found in heavy mineral sands and rare earth deposits. Australia has a number of known mineral sands deposits, including many in Victoria (along the eastern and southern beaches, and in the Bonang district, the Koetong area, Bethanga, the LaTrobe River, Stawell, and Nhill).[8][9]

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[7] Geoscience Australia, *Uranium and thorium*, Australian Energy Facts, 2020, https://www.ga.gov.au/education/classroom-resources/minerals-energy/australian-energy-facts/uranium-and-thorium.

[8] Baker, G., *Thorium in Australia*, Research Paper no. 11 2007-08, Parliamentary Library, 17 September 2007, https://www.aph.gov.au/About_Parliament/Parliamentary_Departments/Parliamentary_Library/pubs/rp/RP0708/08rp11.

[9] Overstreet, W.C., *The Geologic Occurrence Of Monazite*, Geological Survey Professional Paper 530, U.S. Department of the Interior, United States Government Printing Office, Washington, 1967, pp. 93-94; Geoscience Australia, *Uranium and thorium*.

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 South Australian Nuclear Fuel Cycle Royal Commission 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.’[10]

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

Economic Matters

Uranium production and demand

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.[11]

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.[12]

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.

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 tU – 13 per cent), respectively.[13] 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.[14] 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

According to the OECD–NEA, citing data produced by TradeTech, banks and hedge funds recently have begun to display 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 increased in order to meet contractual terms.[15] Global trade of natural uranium amounted to about US$4 billion in 2018.[16]

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[11] 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.

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

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

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

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

[16] 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.

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 13 February 2020, the spot price stood at US$24.90 per pound.[17] 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 projects.

Contribution to socio-economic development

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.'[18] 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.[19]

Operations at the Ranger mine in the Northern Territory have resulted in the payment of more than AU$500 million in royalties over the lifetime of the mine.[20] 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.[21]

However, it is important to acknowledge that not all experiences of uranium projects have been reported to have been positive and beneficial. The public statements of the Mirrar people, the Traditional Owners of the lands on which the Ranger mine is located, are instructive in this regard.[22]

In the absence of reliable data about the uranium resource in Victoria due to limited 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 were new uranium mines to become economic.

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[17] Cameco, *Uranium Price*, Cameco Corp., 2020, https://www.cameco.com/invest/markets/uranium-price.
[18] *Nuclear Fuel Cycle Royal Commission Report*, p. 23.
[19] Department for Energy and Mining, *Uranium*, Department for Energy and Mining, 2019, http://energymining.sa.gov.au/minerals/mineral_commodities/uranium.
[20] Energy Resources of Australia, *Sustainability Report*.
[21] Energy Resources of Australia, *Sustainability Report*.
[22] 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 precipitates 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.[23] However, adverse impacts to the environment are less likely to occur today as responsible mining practices involve the early identification of risks and the implementation of strategies to prevent, mitigate, and/or manage those risks across a mine's life-cycle.

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 certain freshwater plants in high concentrations.[24] 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.[25]

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.[26] 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 a consequence of 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.

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[23] 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.

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

[25] Kay, *Australia's Uranium Mines – Past and Present*.

[26] 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 decay progeny.[27] Heavy metals also are by-products of many other mineral/metal extraction processes, particularly those associated with gold mining.[28] Acid mine drainage, therefore, is not specific to the mining of uranium.[29] 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.[30] However, the other heavy metals have been, for reasons stated above, of greater environmental impact than the failure to contain the uranium and its progeny.[31]

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.[32]

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 Agriculture, Water and the Environment (and its predecessors), is indicative of the significant progress in the Australian uranium industry’s environmental performance and in the

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

[28] 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.

[29] 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.

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

[31] 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.

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

development of robust regulatory frameworks that mandate the effective and safe operation of uranium mines.[33]

The Olympic Dam mine 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 extractive 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 prevent, mitigate, and control potential impacts. Environmental consequences share the same cause across all mining operations. 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.[34]

ANSTO's role in reducing the environmental impacts of uranium mines

ANSTO Minerals, a business 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 footprints, 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, Science, Energy and Resources) and ASNO to ensure that Australian uranium only is exported to countries for peaceful uses and under bilateral safeguards agreements.

In addition to the need to obtain approval from the relevant state or territory minister with responsibility for the regulation of mining, uranium mines also are subject to approval by the

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[33] 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 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.

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

Commonwealth minister with responsibility for the Environment portfolio under section 22 (1) of the *Environment Protection and Biodiversity Conservation Act 1999* (Cth), and thereby are treated differently than other mining operations. This treatment hinges on uranium mines being considered a 'nuclear action'.

State-based laws and regulations

Section 5(1) of the *Nuclear Activities (Prohibitions) Act 1983* (Vic) prohibits exploration for, and mining of, uranium and thorium in Victoria. Exploration alone is permitted in New South Wales, though ANSTO notes that that State's Legislative Council Standing Committee on State Development currently is undertaking an inquiry into the *Uranium Mining and Nuclear Facilities (Prohibitions) Repeal Bill 2019*.[35] In Queensland, while there are no restrictions under the *Mineral Resources Act 1989* (Qld), the incumbent State Government has adopted a policy stance that prevents the development of uranium mines.[36] In the Northern Territory, the Commonwealth controls decisions pertaining to uranium mining; however, joint agreements between the Commonwealth and Northern Territory Governments also may allow for uranium to be mined. There are no legislative restrictions in Tasmania.[37] Uranium exploration and mining is permitted in South Australia and, with some policy irregularity, in Western Australia. In the jurisdictions where uranium mining is permitted, the operations are subject to the normal regulations that are applicable to all mineral or metal extraction activities, as well as 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, the responsible minister will determine whether to approve a mine's development.

As noted above, in addition to the necessary state and territory approvals, assessment and approval under the Commonwealth *Environment 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 (currently by the South Australian Department for Energy and Mining) prior to a mine's operation and is regularly updated during the life of the mine.[38] The current regulatory framework also requires a plan for the remediation of mine

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[35] Parliament of New South Wales, Legislative Council, Standing Committee on State Development, *Uranium Mining and Nuclear Facilities (Prohibitions) Repeal Bill 2019*, https://www.parliament.nsw.gov.au/committees/inquiries/Pages/inquiry-details.aspx?pk=2525.

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

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

[38] 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.

sites to be established at the outset of operations in order to minimise ongoing risks to the environment.[39] 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. Moreover, 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 also requires compliance with national radiation safety measures and provides for enforceable penalties in the event of a breach.[40]

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

[40] 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 are generally no greater than for the extraction of any other mineral or metal, they remain the subject of considerable community debate and, in some cases, concern. It would be necessary, then, for any potential future uranium mining activities in Victoria 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 for government to assess whether there is sufficient support 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 levels of 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.[41] 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.[42] 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.[43] 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.[44]

There also is a substantial body of literature regarding optimal approaches and processes to facilitate community engagement generally and with specific regard to exploration and mining activities.[45]

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.[46] Australian and international legal instruments and principles recognise the rights of these peoples to control access to those lands and the types of activities that

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[41] 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.

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

[43] 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.

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

[45] 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.

[46] 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.[47] In the event that prohibitions on uranium exploration and mining activities were removed in Victoria 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, the host communities, and the surrounding regions. The consequence of not meeting community expectations in this regard could be the withdrawal of public support and community consent for those activities to occur.

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[47] 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

—identify economic, environmental and social benefits for Victoria, including those related to medicine, scientific research, exploration and mining, and the opportunities for Victoria to participate in the nuclear fuel cycle

Nuclear Power – Status and Developments

ANSTO is aware that, in 1967, the Victorian State Electricity Commission undertook a feasibility assessment for the potential establishment of a nuclear power plant on French Island in Western Port. It is understood there also was consideration of other locations including Portland and Giffard; however, due to unsuitable conditions and community sentiment at the time, no site was progressed.[48]

While Victoria decided not to pursue the development of nuclear power plants in the 1960s, many other countries and jurisdictions have adopted nuclear power as part of their energy generation systems such that, at 20 January 2020, there were 447 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.[49]

Latest power reactor utilisation figures are available for 2018.[50] In that year, nine new reactors were connected to grids, three were permanently shut down, and construction commenced on five. Importantly, growth in the adoption of nuclear power demonstrably is shifting from the Western Hemisphere to Asia, where 35 of the current 55 reactors under construction are located and where 58 of 68 reactors have been connected to grids since 2005.[51]

While the number of reactors under construction is significant, at the end of 2018, nearly half (47 per cent) of the operating reactors had been in service for between 30 and 40 years, with a further 17 per cent in service for more than 40 years.[52] 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.[53]

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 uncertainty regarding the proportion of global electricity generation that will be derived from nuclear power in the coming decades.[54] 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.[55]

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.[56] South Korea, the United Arab Emirates, and Bangladesh also are key centres of activity.

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[48] 'How Victoria's N-power future became its past', *The Age*, 28 February 2005, https://www.theage.com.au/national/how-victorias-n-power-future-became-its-past-20050228-gdzon6.html.

[49] International Atomic Energy Agency (IAEA) Power Reactor Information System, *Operational & Long-Term Shutdown Reactors* IAEA, 2020, https://pris.iaea.org/PRIS/WorldStatistics/OperationalReactorsByCountry.aspx.

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

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

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

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

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

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

[56] 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,

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.[57]

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.[58]

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. Generation II reactors, such as the Fukushima Daiichi reactors, first were commissioned in the early 1970s, and many are close to retirement. Gen III and Gen III+ reactors have an enviable record on safety and reliability, 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 principally 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:

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.

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

[58] This point notwithstanding, the current reactor build in the United States—the construction of two new reactors at the Vogtle site in Georgia—appears to be meeting, and even exceeding, its targets in terms of timeline and budget. See: World Nuclear News, *Southern CEO: Early start-up of Vogtle units possible*, World Nuclear News, 21 February 2020, https://www.world-nuclear-news.org/Articles/Early-start-up-of-Vogtle-units-possible-says-South.

- 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;
- a forecast 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 scarcer. 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.[59] 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 also is active in North America and Europe, as evidenced in the projects being pursued by various private companies, including TerraPower[60], Terrestrial Energy[61], Elysium Industries[62], ThorCon[63], Moltex Energy[64], and Kairos Power.[65]

Australia is maintaining its knowledge base in advanced reactors. In addition to the Organisation’s representation of Australia in the GIF, ANSTO has completed a joint research project with SINAP, which examined high-performance materials for use in MSRs.

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[59] 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.

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

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

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

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

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

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

Small modular reactors

Small modular reactors (SMRs)—the next wave of reactor designs—are defined as nuclear power plants that generate less than 300 MWe.[66] The initial development of SMRs can be traced back two decades to the IRIS program[67], which investigated the use of proven pressurised water reactor (PWR) technology in smaller, simpler, 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'.

A sub-class of SMRs generating less than 10 MWe is commonly referred to as 'micro-reactors'; these reactors are designed for remote deployment for service in 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 deployed and producing electricity at the end of 2019.[68]

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.[69]

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

- the potential for most SMR designs to provide back-up power for renewable energy sources;

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[66] 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/.

[67] 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.

[68] ROSATOM, *Projects*, The State Atomic Energy Corporation ROSATOM, 2019, https://rosatom.ru/en/investors/projects/; World Nuclear News, *Russia connects floating plant to grid*, World Nuclear News, 19 December 2019, https://www.world-nuclear-news.org/Articles/Russia-connects-floating-plant-to-grid.

[69] 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.

- 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.[70]

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.

Near-term deployable SMRs—those in development by NuScale (United States)[71], CAREM (Argentina)[72], and SMART (South Korea)[73]—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.[74] Argentina's prototype CAREM-25 reactor is under construction.[75]

Currently, there are approximately 20 SMR vendors operating in North America, with 10 designs 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.[76]

Medium-to-long-term reactor technologies

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 at scale.

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.[77]

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

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

[72] 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/.

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

[74] 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/.

[75] 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.

[76] 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.

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

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). The plasma is shown in pink in the 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.[78]

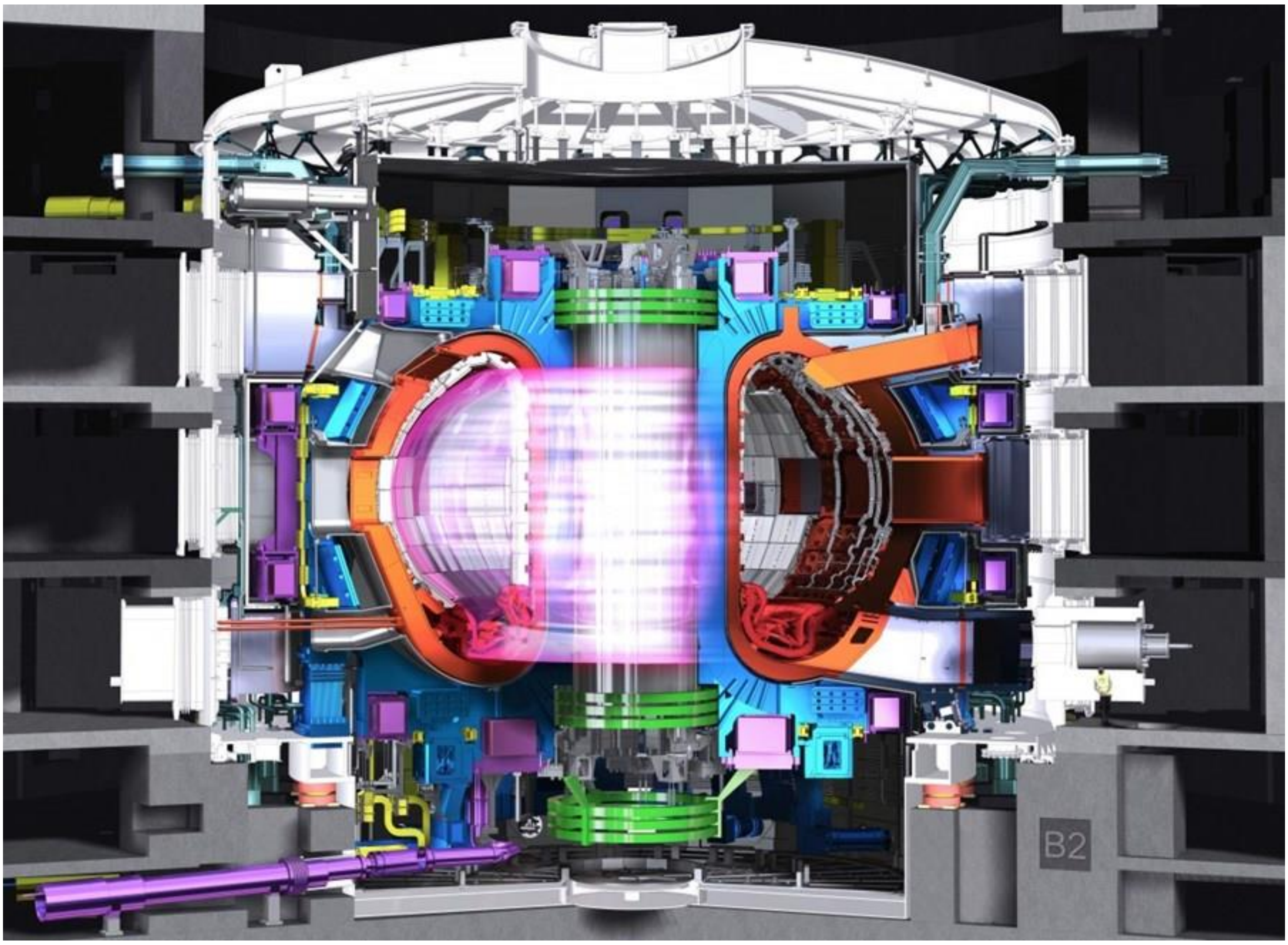

Image courtesy of: ITER Organization, 'First Plasma: 2025', *ITER Mag*, no. 9, August 2016, https://www.iter.org/mag/9/65.

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 to which they will be subjected in the reactor; all three contributions are the result of collaboration between the Australian National University and ANSTO.

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

A number of private companies and organisations claim to be working on projects that will achieve net production of energy from fusion before ITER.[79] 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.

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[79] See, for example: Blain, L., ‘Radical hydrogen-boron reactor leapfrogs current nuclear fusion tech’, *New Atlas*, 21 February 2020, https://newatlas.com/energy/hb11-hydrogen-boron-fusion-clean-energy/; 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 from occurring, or being established, in the State. These are addressed in turn, below.

Conversion, enrichment, and fuel fabrication

Most fuel for nuclear power reactors is produced through the conversion and enrichment of newly mined and milled uranium ore, and the subsequent fabrication of the enriched uranium into fuel. At present, mined Australian uranium is sold and shipped to countries that undertake these activities—with limited additional value added prior to export. Despite Australia being one of the world's largest uranium producers, and holding the world's largest uranium resources, these activities have been prohibited by 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 into 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[80], with modern enrichment plants using 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.[81]

The 2006 *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 the country.[82]

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. Victoria 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.'[83] However, it noted that this position would change if there were to be substantial growth in demand from Asia not met by

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[80] 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.

[81] 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.

[82] 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.

[83] *Nuclear Fuel Cycle Royal Commission Report*, 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.[84]

Australia also has adopted a type of closed fuel cycle. According to current Australian Government policy, all of Australia's used fuel from the OPAL multi-purpose research reactor will be sent to France for reprocessing. The small amount of residual wastes will be shipped back to Australia for management and disposal, while the uranium extracted during the reprocessing operation will be fabricated into fresh fuel for use in nuclear power reactors in Europe. The majority of used fuel from the HIFAR reactor also was 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 terminated 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 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, as well as the low price of uranium.

In 2016, the 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.'[85] 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.[86]

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 Australia. As the operator of a number of facilities that generate 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 intermediate-level radioactive waste from the production of nuclear medicines. Synroc is an Australian technology that can be tailored to treat a range of radioactive waste streams. The resulting waste form is up to 97 per cent smaller in volume than existing alternatives (for example, cemented waste forms) and is suitable for disposal in a purpose-built repository. Regardless of whether Victoria or Australia were to establish a nuclear power program in the future, significant opportunities exist to export this technology to overseas holders of radioactive wastes, which are seeking efficient and effective management solutions.

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

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

[86] 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.

If Victoria were to introduce 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. Depending on the scale of the activities envisioned, the State may need to significantly strengthen the capacity and capability of its regulator, the Environment Protection Authority Victoria (EPA), or the jurisdiction of the national nuclear regulator, ARPANSA, may need to be broadened.

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, contribute 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 quantified 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 historical and modern changes. 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 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, such as energy or nutrient release. 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 this 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 detection of pollutants and contaminants.

Law enforcement, defence capabilities, and national security

Nuclear techniques and tools are crucial to law enforcement, national defence capabilities, and national security. In this regard, 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. For example, ANSTO's Accelerator Mass Spectrometry facility forms part of the IAEA's Network of Analytical Laboratories, which enables the Organisation to analyse samples obtained by IAEA safeguards inspectors from nuclear facilities around the world, thereby contributing to global 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 to develop new materials, devices, and systems. ANSTO's neutron 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, which is located in Clayton, Victoria, and 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 speed, accuracy, quality, robustness, and the level of detail that can be seen and collected.

Current benefits and future opportunities for Victoria

As noted previously, ANSTO operates much of Australia’s most significant scientific infrastructure, including the Australian Synchrotron in Melbourne. This infrastructure, of which the Synchrotron is a key component, places Australia at the forefront of innovation in the areas of public health and environmental management, as well as across multiple industries and sectors of the economy.

The Synchrotron is an ‘anchor tenant’ of the medical research, technology, and innovation hub in Clayton, southeast Melbourne. The advanced techniques that it enables are applied to research in areas including health and medicine, food, the environment, biotechnology, nanotechnology, energy and mining, agriculture, advanced materials, and cultural heritage. As such, it is a critical part of Victoria’s—and Australia’s—industrial knowledge, research, and skills bases, and has more than 140 employees and an annual appropriation from the Australian Government of approximately $40 million. The Synchrotron also supports approximately 4000 national and international user visits from across industry and academia each year.

The Synchrotron has been used to anchor a number of medical sector collaborations with Victorian institutions in recent years. This includes its crucial role in the discovery of Venetoclax, a new medication for the treatment of Chronic Lymphocytic Leukaemia (CLL). Around 350 people die from CLL and 1300 new cases are diagnosed each year in Australia, making it the most common type of leukaemia in the country.

ANSTO also has established relationships with a range of Victorian stakeholders, including in government, across industry, and with research institutions. These partnerships enable creative and forward-thinking outcomes, including the first pilot project between ANSTO’s *nandin* Innovation Centre, Swinburne University of Technology, and Design Factory Melbourne (DFM). The partnership with DFM provided two students with the opportunity to help re-design the special purpose instrument cabins that are used at the Australian Synchrotron to prepare instrument samples, run experiments, and analyse data.

As Australia’s major manufacturer of nuclear medicine, ANSTO clearly is central to enabling diagnostic and treatment procedures for a range of acute diseases and conditions, delivering product to more than 250 hospitals, clinics, and pharmaceutical suppliers country-wide each week. In Victoria, ANSTO provides these life-saving nuclear medicines to a range of urban and rural centres, including Melbourne, Geelong, Ballarat, Bendigo, Sale, Mildura, Shepparton, and Warrnambool.

By supporting the utilisation of nuclear-based activities in Victoria, there will be greater opportunities to deliver more of these and other benefits.

Financial and Economic Considerations

As noted earlier in this submission, ANSTO provides advice on aspects of nuclear science and nuclear technology, including nuclear power and related energy matters, as mandated by the *ANSTO Act*.[87] Information and advice on nuclear power and other energy technologies is regularly collected and assessed, and is provided in this context.

System costs

Victoria's—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 comparatively low capacity (availability) factors, require firming (backup generation) and storage, preferably from options that have low capital costs (CAPEX – build costs), low operational costs (OPEX), and low life-cycle emissions. In South Australia, for example, large installations of wind generators have been 'firmed' by Open Cycle Gas Turbine (OCGT) generators[88], which are characterised by relatively low CAPEX, but also by high OPEX—predominantly caused by the tripling of gas prices in recent years—and relatively high emissions.[89] Despite plans for major VRE roll outs across the country[90], the question of firming by gas, pumped storage, batteries, hydrogen, and smart-grids, among other technologies, remains uncertain in cost, feasibility, and timing.

Should Victoria move toward a lower emissions energy generation system, there likely will be challenges to cost and reliability of electricity supply in the absence of nuclear power. 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.[91]

The OECD–NEA's findings indicate that VREs require the installation of capacity additional to that which is required to meet electricity demand. Put differently, the higher the VRE penetration, the higher the required additional capacity, significantly increasing overall system costs.[92] However, the OECD–NEA observes that, in the international context, VREs complemented with nuclear generation can significantly reduce overall systems costs and the amount of generation capacity

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

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

[89] 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.

[90] 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

[91] 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

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

required, while also supporting grid reliability and stability. Accordingly, nuclear power is viewed by the OECD–NEA as a primary source of low-emissions baseload generation, which will underpin the future energy systems of major industrialised countries.

In another study, the Massachusetts Institute of Technology (MIT) 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, despite its own high initial capital costs. Indeed, the amortisation of the costs associated with the establishment of nuclear power can be a critical component in considering the mix of energy generation technologies to ensure that a country has a low-cost, reliable, and low-emissions energy system.[93]

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 believed that future reactor designs will see reductions in cost and, therefore, up-front capital investment requirements, contributing to the increasing affordability of nuclear power.[94]

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 SMRs, as promoted by the President and Chief Executive Officer of the Canadian Nuclear Safety Commission in a speech at the Advanced Reactors Summit VII in Tennessee in February 2020.[95] 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 sale of electricity from the initial module installations, which will generate cash flow to support the installation of subsequent modules.[96]

Obtaining finance has been a key challenge for new nuclear builds around the world, in large part due to the long project time-lines involved. Addressing this challenge in its 2019 report, *Modernising electricity sectors: a guide to long-run investment decisions*, Industry Super Australia focused on the potential application of nuclear power in a broader and more cost effective energy mix.[97] The organisation identified the need to take a longer-term view of the cost to finance nuclear builds, indicating the potential availability of finance for a nuclear power program in Victoria or elsewhere in the country.

In discussing the respective 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

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[93] 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.
[94] MIT Energy Initiative, *The future of nuclear energy in a carbon constrained world*.
[95] Velshi, R., *Speech: Regulatory harmonisation for SMRs*, Advanced Reactors Summit VII, Knoxville, Tennessee, 12 February 2020, https://world-nuclear-news.org/Articles/Speech-Regulatory-harmonisation-for-SMRs.
[96] Carelli, M.D. and Ingersoll, D.T., *The Handbook of Small Modular Reactors*, Woodhead Publishing, Cambridge, 2015.
[97] 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.

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 power reactors in jurisdictions that are embarking on—or considering embarking on—new build programs, including, potentially, Victoria.[98] The LCOE also does not capture the costs of the various externalities of the generation technologies. For example, while the cost of nuclear decommissioning and waste management is accounted for in the International Energy Agency and OECD–NEA methodology[99], the true cost of waste generation (both solid and gaseous) and its management, for example, from coal-fired power stations is not captured. Similarly, the costs of accounting for the intermittency of solar or wind generation, which are displaced across the grid, as well as the costs associated with the management of life-cycle waste arisings of renewable technologies, are not captured in LCOE models.

Owing to these issues, a more useful indicator is that of the levelised avoided cost of electricity (LACE), which 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.[100] There would be significant merit in incorporating the LACE into an evaluation of generating capacity in Victoria, as it could provide an indication of the potential value for a new unit of generation technology in fulfilling projected future electricity requirements in the State.

The overnight capital cost 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.[101]

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 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*[102], 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, increased production costs per plant as a result of

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

[99] 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.

[100] 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.

[101] 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/.

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

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 associated with 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 (the most recent available figures)[103], as well as the longevity of reactors, their safety records, and their low life-cycle emissions. For context, Victoria's generation mix across 2015 and 2016 had capacity factors of 81 per cent for coal, five per cent for natural gas, 15 per cent for hydropower, and 30 per cent for wind generation.[104]

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

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

In a recent MIT study, the projected overnight cost of capital for SMRs fell to between US$4000 and $5000 per kW.[105] In contrast, 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.[106] 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 forecast 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 estimates is hard to verify as the projects are not at a stage of detailed design; nevertheless, a costing of around US$2000 per kW is supported by other industry studies.[107]

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

[104] Tran, C., *Capacity factors: Understanding the misunderstood*, Australian Energy Council, 13 September 2017, https://www.energycouncil.com.au/analysis/capacity-factors-understanding-the-misunderstood/.

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

[106] 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.

[107] 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 entirely without risk does not yet exist. However, nuclear power provides safe, 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.[108] Notwithstanding the historical record of nuclear power, which shows reactors to be generally safe, reliable, and environmentally sustainable, there are a range of common issues of concern; these are addressed in turn.

Management of radioactive waste

Classification of radioactive waste

Radioactive waste encompasses any material that either is intrinsically radioactive or that has been contaminated by radioactivity, which is identified as having no further use.[109] According to guidance provided by the IAEA, 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)[110], with the management of LLW, ILW, and HLW being the focus of further discussion in 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 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 and isolation. 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 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 power reactor, and contains the fission products and transuranic elements generated in the reactor core. It accounts for only three per cent of the volume, but 95 per cent of the total radioactivity of all waste produced in the world. There are two kinds of HLW:

- used (sometimes referred to as 'spent') 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.[111]

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[108] McCombie, C. and Jefferson, M., 'Renewable and nuclear electricity: Comparison of environmental impacts', *Energy Policy*, vol. 96, 2016, pp. 758-769.
[109] WNA, *Radioactive Waste Management*.
[110] 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.
[111] WNA, *Radioactive Waste Management*.

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

Issues in radioactive waste management

Nuclear fuels have a high energy density; therefore, nuclear power plants produce far less waste than fossil fuel-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.

For example, a 1 GWe light water reactor generates, on average, 200 to 350 m^3 of low- and intermediate-level waste per year.[112] A reactor of this size also generates approximately 1500 tonnes of used fuel over a 60-year operating life, or 25 tonnes per year.[113] In comparison, a coal-fired power plant of the same electrical output generates, over the same 60-year time period, approximately 400,000 tonnes of fly ash, in addition to its generation of carbon dioxide (CO_2).[114] It is worth noting further that ‘the fly ash emitted by a [coal] power plant—a by-product from burning coal for electricity—carries into the surrounding environment 100 times more radiation than a nuclear power plant producing the same amount of energy.’[115]

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.[116]

The management of high-level radioactive waste in particular is an area of significant public concern, despite geological disposal being widely recognised as a safe and effective long-term management solution.[117] The long lifetime for radioactive decay is a common 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 reduces 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.[118] The use of cadmium in the manufacture of thin

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

[113] 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.

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

[115] Hvistendahl, M., ‘Coal Ash Is More Radioactive Than Nuclear Waste’, *Scientific American*, 13 December 2007, https://www.scientificamerican.com/article/coal-ash-is-more-radioactive-than-nuclear-waste/.

[116] 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.

[117] 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.

[118] Shellenberger, M., ‘If Solar Panels Are So Clean, Why Do They Produce So Much Toxic Waste?’, *Forbes*, 23 May 2018, https://www.forbes.com/sites/michaelshellenberger/2018/05/23/if-solar-panels-are-so-clean-why-do-they-produce-so-much-toxic-waste/#60c0d8c7121c.

film solar panels is a principal concern[119]; indeed, it was deemed one of the world's six major pollution problems in 2015.[120]

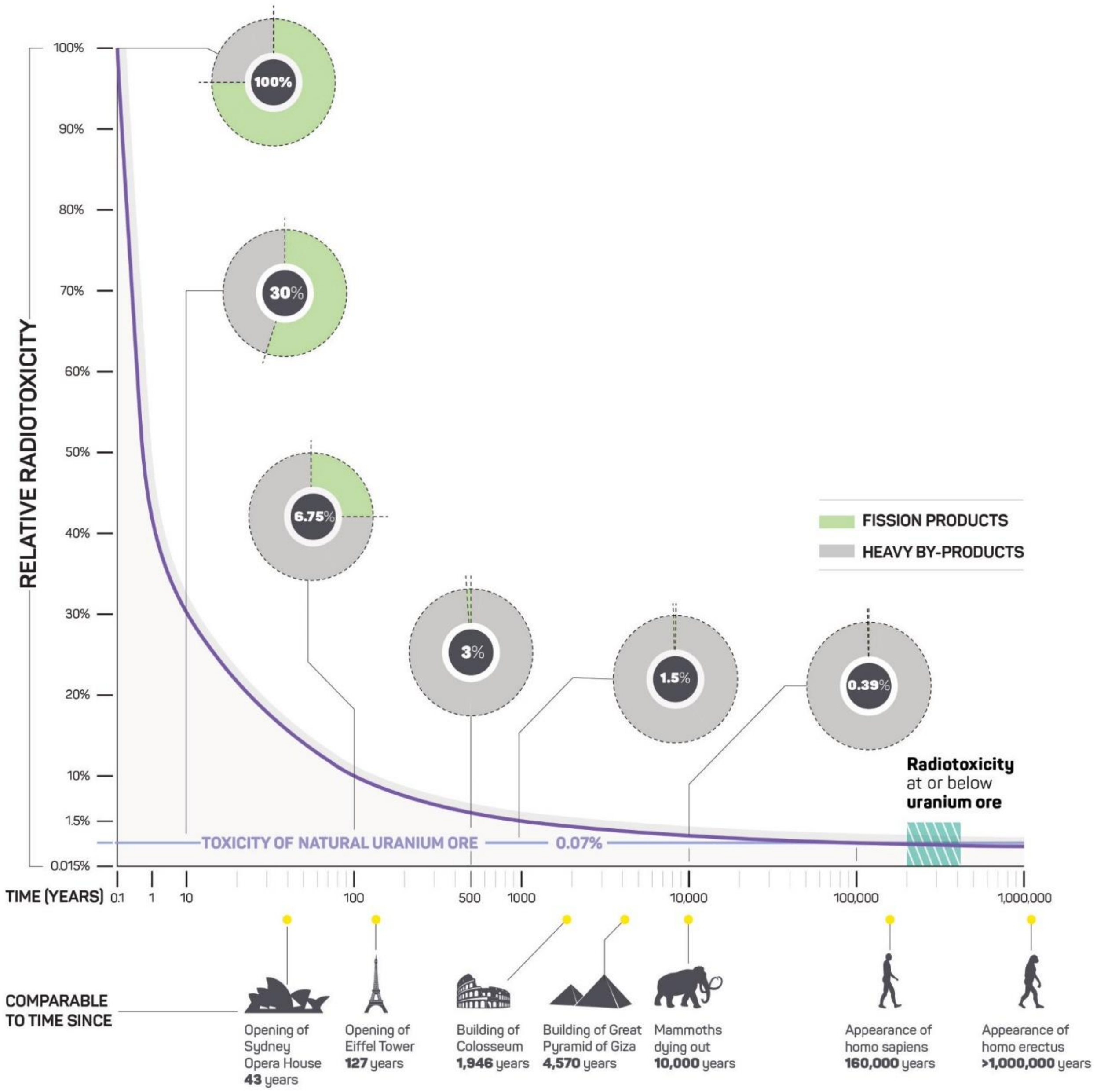

Image courtesy of: *Nuclear Fuel Cycle Royal Commission Report*, p. 82.

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[119] Wetzel, D., 'Studie warnt vor Umweltrisiken durch Solarmodule', *Welt*, 13 May 2018, https://www.welt.de/wirtschaft/article176294243/Studie-Umweltrisiken-durch-Schadstoffe-in-Solarmodulen.html.

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

Approaches to used fuel and radioactive waste management

As discussed above, 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 so-called ‘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.[121] The United Kingdom historically has reprocessed its used fuel, though it is in the process of transitioning to an open cycle.[122]

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.[123] Used fuel (like with other radioactive wastes) is stored in purpose-built above-ground facilities. When discharged from a 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 for disposal.[124] As shown in the graphic 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 10 years after discharge.[125]

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 ILW residues arising from the operation of the country’s research reactors (discussed in further detail below).

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.[126] 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 countries 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.[127] France and Sweden have submitted licence

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[121] WNA, *Radioactive Waste Management*.
[122] 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.
[123] *Nuclear Fuel Cycle Royal Commission Report*, p. 291.
[124] 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.
[125] *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.
[126] OECD–NEA, *The Environmental and Ethical Basis of Geological Disposal of Long-Lived Radioactive Wastes*.
[127] 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.

applications for their facilities and aim to commence operation in 2030 (in the case of France) or construction within the next decade (in the case of Sweden).[128]

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 Victoria (and Australia) could draw should a decision be made to introduce nuclear power in the future. However, ANSTO notes that a condition of any future nuclear power program in the State 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 future 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 proportion of the cost of electricity production given the extremely small volumes of waste that arise per kilowatt hour. For example, utilities contribute $US0.1 cent per kilowatt hour in the United States, €0.14 cents per kilowatt hour in France, and €0.436 cents per kilowatt hour in Sweden.[129]

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 managed; 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.[130]

ANSTO is currently 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 at its Lucas Heights campus in New South Wales.[131] 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 and protection of the environment.

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[128] 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/.

[129] 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.

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

[131] 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.

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.'[132]

A 2006 report by the Parliament of Australia's House of Representatives Standing Committee on Industry and Resources found:

> Nuclear power currently avoids the emission of 600 million tonnes of carbon per year. If the world were not using nuclear power, CO2 emissions from electricity generation would be at least 17 per cent higher and 8 per cent higher for the energy sector overall. By 2030, the cumulative carbon emissions saved due to the use of nuclear power could exceed 25 billion tonnes.[133]

Put differently, nuclear power saves approximately 10 per cent of total CO_2 emissions from world energy use.[134] However, the capacity of nuclear power to mitigate or abate greenhouse gas emissions into the future depends on the extent to which nuclear technologies displace carbon-based energy sources of electricity generation and on the extent to which they are deployed to support renewable energy generation technologies.[135]

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 gram (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)).[136]

The direct and indirect CO_2 emissions from various energy sources are shown in the table below, drawing on data published by the United Nations Intergovernmental Panel on Climate Change (IPCC)[137]:

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[132] 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.

[133] 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*, Parliament of Australia, Canberra, 2006, p. 142.

[134] House of Representatives Standing Committee on Industry and Resources, *Australia's uranium*, pp. 152-153.

[135] Kharecha and Hansen, p. 4889.

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

[137] 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.

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[138]	–	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
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

Land requirements are a critical consideration when determining the environmental impacts of a source of energy, including nuclear power. In this regard, it is estimated that the land requirements for the operation of a nuclear power plant correspond to only 0.6 m^2 per GWh(e). However, SMRs promise substantially to reduce this footprint. In contrast, the footprint required for hydropower and large solar power plants is 49 m^2 and 1275 m^2 per GWh(e), respectively.[139] Another study has shown that wind farms require 300 to 500 times more land than a nuclear power plant.[140]

Water use

Water consumption in conventional large nuclear power plants is high, and second only to that required by the agricultural sector.[141] Water is a requirement for cooling; however, the majority of cooling water used in power reactors around the world is drawn from the sea or rivers, to which the water is returned only a few degrees warmer and with minimal loss due to evaporation.[142] The rate

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[138] 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.

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

[140] MacKay, D., *Sustainable Energy – Without the Hot Air*; *Water Use and Nuclear Power Plants*, Nuclear Energy Institute, Washington, D.C., 2013.

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

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

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.[143]

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.[144] 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.[145]

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.[146] 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 required to collect and analyse environmental samples and gaseous discharges to ensure that their environmental impacts are minimised.

Alternative sources of energy generation also result in the production of air and other pollutants during the energy generation life-cycle (encompassing, for example, exploration for, and mining of, materials and inputs, manufacture, transport, maintenance, and waste management). 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 result in 263 kg of nitrous oxides and 731 kg of sulphur oxides per GWh(e) generated over the energy generation life-cycle.[147] Wind energy also results in the production of 71 kg of nitrous oxides and 137 kg of sulphur oxides per GWh(e).[148] 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.[149]

Summary of environmental impacts

It is clear that nuclear and renewables outperform fossil fuels as energy generation technologies from the standpoint of their emissions. The major environmental concerns pertaining to nuclear as a source of electricity are around water utilisation, radioactive waste management practices, and land use. However, nuclear reactors compare favourably with other low-carbon technologies on these and other measures.

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[143] McCombie and Jefferson, pp. 758-769.
[144] McCombie and Jefferson, pp. 758-769.
[145] McCombie and Jefferson, pp. 758-769.
[146] McCombie and Jefferson, pp. 758-769.
[147] McCombie and Jefferson, pp. 758-769.
[148] McCombie and Jefferson, pp. 758-769.
[149] McCombie and Jefferson, pp. 758-769.

Health, Safety, and Security Considerations

The safety record of nuclear technology

Nuclear power is a safe technology[150], 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 energy generation technologies, are considered.[151] Moreover, and as shown above, nuclear power has been found to prevent deaths from poor air quality. 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 (*sic*), depending on which fuel it replaces.'[152]

Nuclear power has 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 have extensive safety systems and are the subject of preventive maintenance, inspection, and monitoring programs to ensure their safe and reliable operation.[153] Moreover, operators of power reactors undertake periodic safety, security, and other threat-based

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[150] Deutch, J. and Forsberg, W., *MIT, Update of the MIT 2003 Future of Nuclear Power,* 2009.
[151] 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.
[152] Kharecha and Hansen, p. 4889.
[153] Ahmed, W. H., Mohany, A., and Li, B., 'Nuclear power plants safety and maintenance', *Science and Technology of Nuclear Installations*, 2014.

risk assessments to identify external and internal factors that detrimentally could affect facility operations and worker and public safety.

Nuclear reactor incidents

Although very 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 (TMI) due to a loss of coolant (water). This caused a partial melting of the fuel assemblies, which resulted in a small release of radiation to the environment. Subsequent inquiries and studies by independent investigators have concluded that most radiation was effectively contained, with the release found to have had negligible effects on the physical health of individuals and the environment.[154] Indeed, no individual, among either workers or 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, which conducted detailed studies of the incident'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 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.[155]

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[154] 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 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.

[155] 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.

Chernobyl (Union of Soviet Socialist Republics, 1986)

Chernobyl is the worst nuclear incident in history and the first to receive the maximum Level 7 rating on the International Nuclear Event Scale—the second being the Fukushima incident, which is discussed in further detail below.

The Chernobyl incident is attributable to 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. It is noteworthy that the reactor design would not have been licensed outside of the former Union of Soviet Socialist Republics, due to the lack of safety features, including the absence of a containment vessel.[156] The overheating of the reactor resulted in two chemical explosions and a fire that caused the deaths of two workers.[157]

The explosions precipitated the release of a large amount of radioactive material (including iodine) into the atmosphere. Of the 600 personnel involved in the emergency response, 134 developed acute radiation syndrome, with 28 dying from radiation exposure.[158]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.[159] 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 in the affected area.[160] However, 220,000 people were displaced from their homes and there have been undoubted long-term psychosocial effects.[161]

Fukushima Dai-Ichi (Japan, 2011)

The Fukushima Dai-Ichi incident 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.[162] It is reported that 50,000 households, comprising 156,000 people, were displaced as a result of the 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 incident, the displacement of households and fears about the effects of radiation have resulted in significant social and mental health impacts.[163] The economic costs of the incident also have been significant.

Of the 54 Japanese reactors that were idled for review, maintenance, upgrade, and/or decommissioning following the incident, nine have been restarted and a further 17 are in the process of receiving approval to restart.[164] Thirty-seven of the 54 have been considered operable by Japan's independent nuclear safety regulator.[165]

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[156] *Nuclear Fuel Cycle Royal Commission Report*, pp. 43-44.
[157] *Nuclear Fuel Cycle Royal Commission Report*, p. 44.
[158] 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.
[159] UNSCEAR, *Sources and Effects of Ionizing Radiation*, 2010, pp. 15-16.
[160] UNSCEAR, *Sources and Effects of Ionizing Radiation*, 2010, pp. 15-16.
[161] González, A.J., 'Chernobyl vis-à-vis the nuclear future: an international perspective', *Health Physics*, vol. 93, 2007, pp. 571-592.
[162] Report by the Director General, *The Fukushima Daiichi Accident*, GC(59)/14, IAEA, Vienna, 2015.
[163] 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.
[164] WNA, *Nuclear Power in Japan*, WNA, August 2019, http://www.world-nuclear.org/information-library/country-profiles/countries-g-n/japan-nuclear-power.aspx.
[165] WNA, *Nuclear Power in Japan*.

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 flaws.[166] 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.[167]

Following the Fukushima incident, the IAEA recommended a global review of all operating reactors. These reviews have been the basis for ongoing improvements to the safety of reactors globally. Indeed, 14 key lessons to improve nuclear safety and emergency preparedness were identified during the review.[168] The Fukushima incident, in particular, highlighted the importance to the nuclear industry of the presence of a robust regulatory framework and strong independent regulator.[169]

Examination of these three incidents, as well as of the resources that have been directed to their investigation, is evidence of the significant international effort to provide safe, continuously improving, and responsible nuclear power generation.[170] A 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, much effort now being directed to the development of so-called ‘accident tolerant fuels’, which will be less vulnerable to melting. As emerging nuclear technologies—such as accident tolerant fuels—progress to commercialisation, their enhanced safety features will assist in ensuring 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 or other fuel cycle facilities/activities were introduced in Victoria.

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 facilities.’[171] 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.’[172]

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[173], an independent non-

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[166] *Nuclear Fuel Cycle Royal Commission Report*, pp. 44, 210.
[167] *Nuclear Fuel Cycle Royal Commission Report*, p. 210.
[168] Report by the Director General, *The Fukushima Daiichi Accident*, pp. 70-73.
[169] *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.
[170] 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.
[171] 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.
[172] IAEA, *Security*, IAEA, Vienna, 2019, https://www.iaea.org/topics/security.
[173] 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.

government organisation that works to reduce global threats from nuclear, biological, and chemical weapons.

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 Global Initiative to Combat Nuclear Terrorism steering group and the implementation and assessment group, has chaired the nuclear forensics working group, and participates in two other working groups.

ANSTO's nuclear forensics laboratory 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 first responders, who 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 help prevent and respond to nuclear security threats—both domestically and internationally. ANSTO also engages actively in domestic and international discussions regarding emerging cyber security threats.

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 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 Victoria to obtain the broad support of the community. Methods for determining and assessing public sentiment exist and routinely are used by domestic and international policy-makers on a range of policy issues.[174]

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 potential future proposal to establish nuclear power in 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 Victoria 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.[175] For example, the OECD–NEA's Forum on Stakeholder Confidence publishes guidance and summaries of leading practice from around the world.[176]

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.

ANSTO has played a significant role in engaging with the Australian community on nuclear, and broader science and technology, issues for many years. In 2019, 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:

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[174] *Nuclear Fuel Cycle Royal Commission Report*, p. 121.
[175] *Nuclear Fuel Cycle Royal Commission Report*, pp. 121-131, 223-244.
[176] OECD–NEA, *Forum on Stakeholder Confidence (FSC)*, OECD–NEA, Paris, 19 February 2019, https://www.oecd-nea.org/rwm/fsc/.

- 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.

Part Three

—identify any barriers to participation, including limitations caused by federal or local laws and regulations

Legal and Legislative Considerations

The effect of the repeal of the *Nuclear Activities (Prohibitions) Act 1983* would be the removal of State prohibitions on the potential establishment of uranium mines and nuclear facilities in Victoria.

However, at the Federal level, the *Environment Protection and Biodiversity Conservation Act 1999* (Cth) 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) prevents the Chief Executive Officer of the Australian Radiation Protection and Nuclear Safety Agency from licensing the siting, construction, or operation of those proscribed nuclear facilities by Australian Government entities.

If there were a decision by the Victorian Government to allow the development of nuclear power reactors or other fuel cycle facilities in the State, in addition to the removal of Victorian and Federal legislative impediments, the provision of additional resourcing also likely would be required to upgrade the existing regulatory architecture so that it would be 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), which reflect 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 the Deed, the Commonwealth essentially undertakes 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 resulting from exposure to 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 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 and local stakeholders.

Part Four

—useful reports and publications and upcoming meetings and events

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 during their Inquiry:

Meeting / Event	Location and Date	Further Information
International Youth Nuclear Congress	Sydney, 8–13 March 2020	International Youth Nuclear Congress
World Nuclear Fuel Cycle 2020	Stockholm, 20–22 April 2020	World Nuclear Fuel Cycle 2020
International Nuclear Supply Chain Symposium	Munich, 12–13 May 2020	International Nuclear Supply Chain Symposium
Generation IV International Forum Policy Group Meeting	Sydney, 27–28 May 2020	Generation IV International Forum
World Nuclear Exhibition 2020	Paris Nord Villepinte, 23–25 June 2020	World Nuclear Exhibition
International Uranium Conference 2020	Adelaide, 1–2 July 2020	International Uranium Conference 2020
World Nuclear Symposium 2020	London, 9–11 September 2020	World Nuclear Symposium 2020
Nuclear Energy: Challenges and Prospects	Sochi, 30 September – 3 October 2020	International Scientific and Technical Conference: "Nuclear Energy: Challenges and Prospects"