Australian Government

ANSTO

ANSTO Submission

to the House of Representatives Standing Committee on the Environment and Energy Inquiry into the prerequisites for nuclear energy in Australia

ANSTO

16 September 2019

Introduction and Scope

As the custodian of Australia's nuclear science, technology, and engineering capabilities and expertise, ANSTO (the Australian Nuclear Science and Technology Organisation) is pleased to make this submission to the House of Representatives Standing Committee on the Environment and Energy's Inquiry into the Prerequisites for Nuclear Energy in Australia.

While ANSTO is agnostic about whether Australia might in future adopt, or consider the adoption of, nuclear power, the organisation is an 'intelligent observer' of international developments in nuclear power and other peaceful uses of nuclear science and nuclear technology. This knowledge and expertise is gained through 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, in addition to our engagement with bilateral and multilateral partners.

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

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

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

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

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

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

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

This submission responds to the Inquiry's Terms of Reference and proceeds as follows:

- Nuclear Power in the World Today
- Waste Management, Transport and Storage
- Health and Safety
- Environmental Impacts
- Energy Affordability and Reliability
- Economic Feasibility
- Community Engagement
- Workforce Capability
- Security Implications
- National Consensus
- Other Relevant Matters.

Also provided are lists of Useful Reports and Publications, and Upcoming Meetings and Events. Locations for the siting of potential future nuclear power reactors are not considered or advocated in this submission. ANSTO also does not make any policy recommendations in this submission.

1. Nuclear Power in the World Today

Status of Nuclear Power Reactor Installation and Development

Nuclear power is an important source of global electricity supply. Indeed, as of 31 December 2018, there were 451 nuclear power reactors operating across 30 countries and Taiwan, with a combined generating capacity of about 400 gigawatts electrical (GWe), representing over 10 per cent of the world's electricity supply.[1]

In 2018, nine new reactors[2] were connected to grids, three were permanently shut down, and construction commenced on five. Growth in nuclear power is shifting from the Western Hemisphere to Asia, which is home to 35 of the 55 reactors under construction and to 58 of the 68 reactors that have been connected to grids since 2005.[3]

While the number of reactors under construction is significant, at the end of 2018, nearly half (47 per cent) of the 451 reactors had been in operation for between 30 and 40 years, with a further 17 per cent in operation for more than 40 years.[4] Accordingly, a number of reactors will require retirement and decommissioning over the next few decades. Importantly, decisions to extend the life of, or shut down, these reactors will have significant implications for global energy security, investment, and the achievement of international emissions reduction targets.[5]

The uncertainty regarding the potential replacement of reactors scheduled to be retired around 2030 and beyond—particularly in North America and Europe—means that there also is uncertainly regarding the proportion of global electricity generation that is likely to be derived from nuclear power in the coming decades.[6] 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.[7]

It is notable that, of the 54 Japanese reactors that were idled for review, maintenance, upgrade, and/or decommissioning following the earthquake and tsunami that affected the Fukushima Dai-Ichi nuclear power plant in March 2011, only nine have yet been restarted and a further 17 are in the process of receiving approval to restart.[8] Thirty-seven of the 54 are considered operable by Japan's independent nuclear safety regulator.[9]

[1] International Atomic Energy Agency (IAEA), *Nuclear Power Reactors in the World*, Reference Data Series No. 2, 2019 Edition, IAEA, Vienna, 2019, https://www-pub.iaea.org/MTCD/Publications/PDF/RDS-2-39_web.pdf.
[2] For the purposes of this submission, the term, 'reactor/s', refers to nuclear power reactors and not nuclear research reactors, unless stated otherwise.
[3] IAEA Board of Governors, *Nuclear Technology Review 2019*, GOV/2019/4, 15 January 2019, p. 1.
[4] IAEA Board of Governors, *Nuclear Technology Review 2019*, p. 6.
[5] International Energy Agency (IEA), *World Energy Outlook 2018: Executive Summary*, IEA, 2018, p. 3.
[6] IAEA Board of Governors, *Nuclear Technology Review 2019*, p. 9.
[7] IAEA Board of Governors, *Nuclear Technology Review 2019*, p. 1.
[8] World Nuclear Association, *Nuclear Power in Japan*, August 2019, http://www.world-nuclear.org/information-library/country-profiles/countries-g-n/japan-nuclear-power.aspx.
[9] World Nuclear Association, *Nuclear Power in Japan*.

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

While some jurisdictions have reassessed their existing (Germany and Taiwan) or planned (Vietnam and the Philippines) nuclear power programs in the wake of the Fukushima 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. Among these are Egypt, Kenya, Niger, Nigeria, and Saudi Arabia.[11]

Importantly, the centre of nuclear construction expertise, like nuclear power programs more broadly, is also shifting away from the Western Hemisphere. Historically, reactor vendors and service/supply chain providers were based in the United States, the United Kingdom, and France; however, Russia, South Korea, and, increasingly, China are emerging as key suppliers. While this shift may present certain challenges that will need to be navigated carefully, robustness in the Russian, Chinese, and South Korean supply chains is resulting in lower plant costs and quicker build times.

Generation IV Reactor Designs

Currently deployable power reactors are of the third generation, and are often referred to as Gen III or Gen III+ designs. These reactors are safe and reliable, but advancements 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 facilitating international cooperation for the shared objective of developing safer and more sustainable power reactor technologies. It is an association of member countries committed to collaboration on long-term research into, and development of, advanced Generation IV reactor designs.

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 Australia can make to its work, which largely is attributable to ANSTO's nuclear and materials engineering capabilities. ANSTO was the lead agency for the treaty process for Australia's accession to the Framework Agreement, with that Agreement entering into force on 13 December 2017.

Australia's participation in the GIF is enabling Australia to benefit from the activities of this major international research program, helping Australia to maintain and extend our national capabilities in leading-edge nuclear technologies, such as materials science and fuel technology. Participation is also providing Australia with improved knowledge and understanding of the next generation of nuclear reactor technologies and their applications, thereby 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.

[10] For its part, China is on track to double its installed nuclear capacity from 27 GWe to 54 GWe in the period 2016 to 2020, with a projected growth to 130 GWe by 2030 and, potentially, to around 500 GWe by 2050, which would account for 28 per cent of China's total annual electricity generation. See: Xiao, X. and Jiang, K., 'China's nuclear power under the global 1.5C target: Preliminary feasibility study and prospects', *Advances in Climate Change Research*, vol. 9, no. 2, 2018, pp. 138-143.
[11] IAEA Board of Governors, *Nuclear Technology Review 2019*, p. 9.

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

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

Another Generation IV reactor design, the sodium fast reactor (SFR), is characterised by its high level of neutron generation, which can be used either for actinide (long-lived radioactive waste) burning or fuel 'breeding'. The Russian BN-600 sodium fast reactor has been used to burn and extinguish weapons-grade plutonium since the 1990s and the newer BN-800 SFR will be used as a test-bed to trial advanced fuel forms for improved utilisation. China and India are also undertaking research and development into SFRs, with India hoping to use these reactors to breed uranium-233 fuel from thorium.

Molten salt reactors (MSRs), another advanced design, have the potential to address many of the objectives of the GIF, including the production of high-temperature industrial heat and the capacity to burn actinides in an inherently safe, yet cost effective, design. Currently, China is leading investigations into MSRs via the agency of a US$3.3 billion research and development program. The construction of the first-of-a-kind Shanghai Institute of Applied Physics (SINAP) Thorium MSR (TMSR) 2 MWth test reactor is scheduled to be completed within the next five years. Research into MSRs is also active in North America and Europe, as evidenced in the projects being pursued by private companies, including TerraPower[12], Terrestrial Energy[13], Elysium Industries[14], ThorCon[15], Moltex Energy[16], and Kairos Power.[17]

Australia is maintaining its knowledge base in advanced reactors, having completed a joint research centre project with SINAP on high-performance materials for use in molten salt reactors.

Small Modular Reactors

Small modular reactors (SMRs) are defined as nuclear power plants that generate less than 300 MWe.[18] The initial development of SMRs can be traced back to the IRIS program two decades ago[19], which investigated the use of proven pressurised water reactor (PWR) technology in smaller,

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

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

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

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

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

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

[18] 300 MWe is enough to power approximately 250,000 homes. In contrast, a large nuclear power plant that produces 1000 MWe (or 1GWe) 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/.

[19] 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.

simplified, and safer reactor designs that are easier to manufacture than large 1 GW PWRs. Since the IRIS program, the term, small modular reactor, has come to also encompass non-PWR-based technologies, including HTGRs SFRs, lead fast reactors (LFRs), and MSRs, which loosely can be termed, 'Advanced SMRs'.

Near-term deployable SMRs—those in development by NuScale (United States)[20], CAREM (Argentina)[21], and SMART (South Korea)[22]—predominantly are PWR-based technologies, with the exception of the Chinese HTR-PM, which is an HTGR technology.

A sub-class of SMRs outputting less than 10 MWe is commonly referred to as 'micro-reactors'; these reactors are designed for remote deployment to service hard-to-reach communities, or for mobile deployment into disaster areas. Also in development are transportable—including floating or truck-mounted—SMRs, which are designed to be returned to their point of origin at the end of their life. Russia is leading research and development activities in this area.[23]

Small modular reactors and Advanced SMRs have the potential to reduce build costs using a variety of strategies, including:

- the elimination of costly active safety systems by using passive safety features or inherently-safe reactor designs;
- shifting the majority of construction off-site to an enclosed factory environment using modular manufacturing techniques;
- reducing plant build times from six to eight years for large reactors to two and a half to four years for SMRs via the use of series-production methods;
- increasing learning rates to be in line with the learning rates 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.[24]

The smaller size of SMRs and SMR-based plants can offer distinct advantages of particular relevance to Australia for future grids:

- most SMR designs have the potential to operate in load following regimes in concert with variable renewable energy sources;
- the smaller output of SMRs will require less transmission overheads compared to large gigawatt plants;

[20] NuScale Power, LLC, *Technology*, NuScale Power, LLC, 2019, https://www.nuscalepower.com/technology.
[21] 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/.
[22] SMART Power Co. Ltd, *Design*, Seoul, Korea, http://smart-nuclear.com/tech/design.php.
[23] ROSATOM, *Projects*, The State Atomic Energy Corporation ROSATOM, 2019, https://rosatom.ru/en/investors/projects/.
[24] 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.

- they are able to provide for district heating and desalination requirements; and
- they are able to provide for industrial heat requirements.[25]

Currently, there are approximately 20 SMR vendors operating in North America, with 10 SMR developers undergoing pre-licensing review with the Canadian Nuclear Safety Commission. The Canadian Government is demonstrating its support for SMR technologies through the development of an SMR Roadmap, which aims to establish Canada as the centre of global research and development regarding SMR technologies.[26]

Westinghouse, a reactor vendor, 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 aiming to license its SMRs for commercial deployment by 2025. It is expected that the regulatory review of the NuScale design will be completed by the United States Nuclear Regulatory Commission by September 2020.[27] The prototype CAREM-25 reactor in Argentina is under construction.[28]

Status of the Thorium Fuel Cycle

Thorium-fuelled reactors are often championed as a possible alternative to uranium-fuelled reactors; however, the arguments put forward require some analysis and scrutiny. For example, proponents frequently claim that the thorium fuel cycle is resistant to proliferation risks. However, the production of uranium-233 during the cycle presents a potential proliferation risk that would require similar safeguards to those that are established for the current uranium fuel cycle.

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

As the Nuclear Fuel Cycle Royal Commission Report found, ‘Energy generation technologies that use thorium as a fuel component are not commercial and are not expected to be in the foreseeable future. Further, with the low price of uranium and its broad acceptance as the fuel source for the most dominant type of nuclear reactor, there is no commercial incentive to develop thorium as a fuel.’[29]

Developments in Fusion Reactor Technology

Fusion technology, as a large, constant, and—it is hoped—sustainable source of baseload power, is the subject of ongoing research and development activities. The great promise of the fusion reactor is that it can make a significant contribution to the world’s energy supply—if it can be proved to be both viable and feasible.

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[25] Canadian Nuclear Association, *SMR Roadmap*, 2018, https://smrroadmap.ca/.
[26] 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.
[27] 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/.
[28] 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.
[29] *Nuclear Fuel Cycle Royal Commission Report*, Government of South Australia, 2016, p. 24.

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.[30]

It is planned 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. 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.[31]

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 engage with the Project.

Australia's major research contributions are a diagnostic system to image the ITER plasma in real time and studies of materials under the extreme conditions that they will experience in the tokamak reactor; both are collaborations between the Australian National University and ANSTO.

A number of private companies and organisations claim to be working on projects that will achieve net production of energy from fusion before ITER.[32] 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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[30] The six member states are: China, India, Japan, South Korea, the Russian Federation, and the United States.

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

[32] 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.

2. Waste Management, Transport and Storage

Radioactive Waste Classifications

Radioactive waste encompasses any material that either is intrinsically radioactive or that has been contaminated by radioactivity, and that is identified as having no further use.[33] According to guidance established by the International Atomic Energy Agency, radioactive waste can be classified either as exempt waste, (EW), very short-lived waste (VSLW), very low-level waste (VLLW), low-level waste (LLW), intermediate-level waste (ILW), or high-level waste (HLW)[34], with the management of LLW, ILW, and HLW being the focus of this submission.

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

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

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

- used fuel that has been designated as waste; and
- separated waste from the reprocessing of used fuel – where the decay heat generated by the waste residues is greater than $2kW/m^3$.[35]

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

Used Fuel and Radioactive Waste Management Practices in Nuclear Power Programs

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. A closed cycle involves the reprocessing of used fuel so that the extracted and separated uranium and plutonium may be reused as a mixed oxide reactor fuel; the waste by-products are subsequently 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 reactor fleet have chosen open cycle programs; however,

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[33] World Nuclear Association, *Radioactive Waste Management*, April 2018, https://www.world-nuclear.org/information-library/nuclear-fuel-cycle/nuclear-wastes/radioactive-waste-management.aspx.
[34] 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.
[35] World Nuclear Association, *Radioactive Waste Management*.

reprocessing is the stated policy intent of France, Japan, Russia, and China.[36] The United Kingdom historically has reprocessed its used fuel, though it is in the process of closing its reprocessing program.[37]

There are now approximately 300,000 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. Used fuel (and radioactive waste) is stored in purpose-built above-ground facilities. When discharged from the reactor, the fuel is transferred to a cooling pond, where, typically, it will remain for a period of five to 10 years. It then will be transferred to a dry storage cask, again, typically, for a period of 30 to 40 years before it is safe to be disposed of.[38] During the storage period, the radiotoxicity and heat generation will reduce—with the radiotoxicity reducing by 70 per cent in the first ten years after discharge.[39]

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

The international consensus is that the only safe, permanent solution for the management of used fuel and other high-activity, long-lived radioactive wastes involves the disposal of such wastes in a deep geological repository.[40] Other waste classes, for example, low- and intermediate-level wastes, may be disposed of in above-ground / near-surface vaults 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, Sweden, and France are the most advanced states in terms of planning for, and constructing, geological facilities—either for the direct disposal of fuel assemblies in a multi-barrier system in the case of Finland and Sweden, or for the disposal of reprocessed, vitrified waste residues in the case of France. Finland has received a construction licence for its geological disposal facility, which is expected to be operational in the early 2020s.[41] Sweden and France have submitted licence applications and aim to commence construction within the next decade (in the case of Sweden) or operation in 2030 (in the case of France).[42]

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

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[36] World Nuclear Association, *Radioactive Waste Management*.
[37] 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.
[38] 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.
[39] *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.
[40] 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.
[41] 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.
[42] 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/.

Australia could draw should a decision be made to introduce nuclear power in the future. ANSTO notes that a prerequisite for any nuclear power program would be to establish—at the outset of that program—policies, plans, and systems, as well as a hypothecated fund, to enable the responsible management of waste arisings and decommissioning liabilities. International practice is to impose a small levy on the kilowatt hours of electricity produced to cover the costs of waste management and decommissioning (addressed in further detail below).

Advancements in Waste Conditioning Processes

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

Australia is among the world's leaders in radioactive waste management knowledge, technology, and engineering solutions, with this expertise centring on Australia's novel Synroc waste treatment process. Synroc is an innovative technology-cum-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.

The Australian Government has provided financial support to ANSTO to construct 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. 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.

Decommissioning

In the years to come, considerable decommissioning work on power reactors, research reactors, and other fuel cycle facilities, including critical assemblies, accelerators, and irradiation facilities, as well as related remediation activities, is expected. Both proven and new technologies are delivering continuous improvements in this area.[43]

At 31 December 2018, 169 power reactors had been shut down or were undergoing decommissioning worldwide. Of those, 17 reactors had been fully decommissioned, while more were approaching the final stages of decommissioning. More than 150 fuel cycle facilities had been permanently shut down or were undergoing decommissioning, and close to 130 facilities had completed decommissioning. In addition, more than 120 research reactors had been shut down or were undergoing decommissioning, and over 440 such reactors had completed decommissioning.[44]

Decommissioning of the Fukushima Dai-Ichi nuclear power plant is the subject of significant global interest. The IAEA reports that decommissioning activities are progressing, with completion of the land-side impermeable walls and preparation for the removal of used fuel from storage pools and

[43] IAEA Board of Governors, *Nuclear Technology Review 2019*, p. 1.
[44] IAEA Board of Governors, *Nuclear Technology Review 2019*, p. 14.

from the reactor vessels in which fuel melted.[45] Significant technological advancements are being identified through this decommissioning program, for example, in robotics, imaging, sensor technology, and water treatment processes, which may be applied in future decommissioning programs elsewhere in the world and, potentially, in other industries and sectors.

As noted above, having a robust plan and funding arrangements for the decommissioning of any reactors and associated facilities would be a prerequisite for the potential future introduction of nuclear power in Australia. This would contribute to community and stakeholder confidence in the financial and environmental management of any nuclear power program.

Radioactive Waste Management at ANSTO

Nuclear medicine produced by ANSTO, in addition to the range of research activities undertaken at ANSTO, have benefited generations of Australians since the 1960s; however, with benefits come responsibilities. A by-product of these activities is the generation of radioactive waste, which needs to be managed responsibly to ensure the safety of workers and members of the public, as well as to minimise potentially detrimental environmental impacts.

ANSTO has more than 60 years of experience managing its radioactive wastes. During this time, the organisation has demonstrated that radioactive waste management in Australia can be undertaken efficiently, safely, and with the support of government and the local community.

Management of Used Fuel from the OPAL Multi-purpose Research Reactor

The OPAL Reactor is the most efficient reactor of its kind, operating, on average, for more than 300 days each year. OPAL's fuel assemblies are comprised of low-enriched uranium, thereby contributing to Australia's non-proliferation objectives.[46]

In accordance with Australian Government policy and legislative requirements, used fuel produced during the operation of OPAL is sent overseas for reprocessing. In July 2016, ANSTO entered into a long-term contract with the French company, Orano (formerly AREVA), to undertake the reprocessing activities. Importantly, this contract puts in place a low-risk and cost-effective used fuel management strategy for the lifetime of the reactor.

In mid-2018, ANSTO made its first transport of used fuel arisings from OPAL. The fuel was transported from ANSTO's Lucas Heights campus by road to Port Kembla for shipment to La Hague, France, where it will be reprocessed. Reprocessing involves extraction of useful materials, such as uranium and plutonium, for recycling into mixed oxide fuels for use in nuclear power programs. The remaining waste residues will be immobilised in a glass matrix through vitrification.

It is intended that the vitrified waste will be returned to Australia in the mid-2030s for storage, management, and, ultimately, disposal. Waste arising from future used fuel shipments to France will likely be returned in the 2050s.

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[45] IAEA Board of Governors, *Nuclear Technology Review 2019*, p. 15.

[46] OPAL is a 20 MW (thermal) multi-purpose research reactor designed for making medical radioisotopes. OPAL uses ordinary 'light water' to do a number of things: to cool the reactor, to moderate neutrons (i.e. enhance fission reactions and maximise the use of uranium fuel), and to shield personnel from ionising radiation. OPAL has an unpressurised core with 16 fuel assemblies containing 37 kg of uranium in total. For comparison, the Russian RBMK reactor (the kind that was operated at Chernobyl) is a much larger reactor, operating at 3200 MW (thermal) or 1000 MW (electric). The pressurised core of the RBMK reactor contains 1661 fuel assemblies with 192,000 kg of uranium. See: ANSTO, *Why OPAL is an advanced reactor*, ANSTO, 7 June 2019, https://www.ansto.gov.au/news/why-opal-is-an-advanced-reactor.

The transportation of used fuel is safe and, moreover, is routine around the world. ANSTO's used fuel shipments are undertaken in line with international practice, and all of ANSTO's used fuel transports have occurred without incident.

Transport

Used fuel and high-level wastes are transported in casks that are able to withstand a range of severe, high-impact accidents and/or intentional threats; they are heavily shielded and, therefore, during storage, are able to be touched by workers and authorised members of the public without the need for personal protective equipment. As noted above, in accordance with Australian legislative requirements, Australia's used fuel is transported overseas for reprocessing. The transportation of used fuel is safe and routine.

Since 1971, at least 25,000 international shipments of used fuel have been completed without an incident that has had significant radiological consequences for humans or the environment.

3. Health and Safety

Nuclear power is a safe technology[47], outperforming other established electricity generation technologies in human health outcomes. This is true even when the effects of nuclear accidents, which are extremely rare in comparison to other technologies, are considered.[48]

Nuclear power reactors are endowed with extensive design elements and preventive maintenance, inspection, and monitoring programs to ensure their safe and reliable operation.[49] Operators of power reactors undertake periodic safety, security, and threat-based risk assessments to identify external and internal factors that detrimentally could affect facility operations, and worker and public safety.

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

Three Mile Island

The first major incident at a commercial nuclear power plant occurred at Three Mile Island (United States, 1979) due to a loss of coolant (water). This caused a partial melting of the fuel assemblies, which resulted in a small amount of radiation exposure to the public. Subsequent investigations and studies by independent organisations concluded that most radiation was effectively contained, with the release found to have had negligible effects on the physical health of individuals or the environment.[50] No individual, either workers of members of the public, died or suffered from acute radiation syndrome as a result of the Three Mile Island Incident. Indeed, according to the United States Nuclear Regulatory Commission (NRC):

> The NRC conducted detailed studies of the accident's radiological consequences, as did the Environmental Protection Agency, the Department of Health, Education and Welfare (now Health and Human Services), the Department of Energy, and the Commonwealth of Pennsylvania. Several independent groups also conducted studies. 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-

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[47] Deutch, J. and Forsberg, W., *MIT, Update of the MIT 2003 Future of Nuclear Power,* 2009.
[48] 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.
[49] Ahmed, W. H., Mohany, A., and Li, B., 'Nuclear power plants safety and maintenance', *Science and Technology of Nuclear Installations*, 2014.
[50] GPU Nuclear Corporation, *Radiation and health effects – a report on the TMI-2 accident and related health studies*, GPU Nuclear Corporation, Middletown, PA, 1986; United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR), *Sources and Effects of Ionizing Radiation: United Nations Scientific Committee on the Effects of Atomic Radiation: UNSCEAR 1993 Report to the General Assembly, with Scientific Annexes: Annex B. Exposures from man-made sources of radiation*, United Nations, New York, 1993, p. 114.
The Three Mile Island Reactor Unit 2 (TMI-2) permanently was shut down following the incident, with the reactor coolant system being drained, the radioactive water being decontaminated and evaporated, radioactive waste relocated, and reactor fuel and core debris relocated to a Department of Energy facility, while the remainder of the site was the subject of ongoing monitoring.
Reactor Unit 1 had its licence temporarily suspended following the incident in at TMI-2; however, it was permitted to resume operations in 1985 following a four-to-one vote by commissioners of the United States Nuclear Regulatory Commission (NRC). In 2009, the NRC granted a licence extension, enabling the TMI-1 reactor to operate until April 19 2034. However, in 2017, it was announced that operations would cease on September 30, 2019, for financial reasons.

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.[51]

Chernobyl

The Chernobyl (Ukraine – then Union of Soviet Socialist Republics, 1986) incident, the second of three major incidents, is the worst nuclear accident in history and was the first to receive the maximum level 7 rating on the International Nuclear Event Scale (INES), due to the major release of radioactive material. In the incident, the reactor core exploded and there was a fire in the reactor facility. Of the 600 workers involved in the emergency response, 134 developed acute radiation syndrome, resulting in 28 deaths.[52] The incident also led to the release of radioactive material (specifically, iodine) into the atmosphere through the explosion-induced plume. 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.[53] 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 civilians exposed to radiation as a result of the incident.[54] However, as the accident resulted in the displacement of 220,000 civilians from their homes, there have been undoubted long-term psychosocial effects.[55]

ANSTO notes that the incident involved a reactor design that would not have been licensed in a Western country, due to the lack of safety features – including containment vessel, and deliberate overriding of the limited safety systems by operators.[56]

Fukushima

The third and most recent incident—that which occurred at the Fukushima Dai-Ichi nuclear power plant (Japan, 2011)—was the result of hydrogen explosions in several reactor units that occurred when cooling of the reactor cores could not be maintained due to the severing of power and water supplies following an earthquake and two tsunami waves. It is reported that 50,000 households, comprising 156,000 people, were displaced as a result of the compound disaster. While there have been no deaths or reports of radiation sickness attributed to the incident, as with the Chernobyl

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[51] 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.
[52] 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.
[53] UNSCEAR, *Sources and Effects of Ionizing Radiation*, 2010, pp. 15-16.
[54] UNSCEAR, *Sources and Effects of Ionizing Radiation*, 2010, pp. 15-16.
[55] González, A.J., 'Chernobyl vis-à-vis the nuclear future: an international perspective', *Health Physics*, vol. 93, 2007, pp. 571-592.
[56] *Nuclear Fuel Cycle Royal Commission Report*, pp. 43-44.

accident, the displacement of households and fears about the effects of radiation have resulted in significant social and mental health impacts.[57]

Lessons and Conclusions

Investigations into the causes of all three incidents separately have found that they were attributable to several factors, including unchallenged design assumptions and operational, design, and emergency response flaws.[58] Moreover, the safety culture prevailing at the time these incidents occurred also is found to have contributed to the incidents and to the severity of their impacts.[59]

Following the Fukushima incident, the IAEA recommended a global review and assessment of all operating reactors. These reviews have been the basis for ongoing improvements into the safety of reactors globally. Indeed, 45 lessons to improve nuclear safety and emergency preparedness were identified during the global review.[60]

Fukushima also highlighted the importance to the nuclear industry of the presence of a robust regulatory framework, which reportedly was deficient in the case of Japan.[61] On this basis, a prerequisite for nuclear power in Australia would be the provision of additional resources to ARPANSA, Australia's independent nuclear regulator, to increase the Agency's capacity and capability to effectively regulate a power industry in the country.

Examination of the most detrimental nuclear accidents, as well as of the resources that have been directed to their investigation and to ensuring that similar incidents cannot occur in the future, illustrates a worldwide commitment to safe, constantly improving, and responsible nuclear power generation. Indeed, the nuclear power industry is continuing—iteratively—to improve reactor technologies in light of the acute and prolonged effects nuclear accidents present to individuals, communities, and the environment.[62] As the emerging nuclear technologies progress to commercialisation, their enhanced safety features, will ensure that nuclear reactors remain one of the safest energy generation technologies available.

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57 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.
58 *Nuclear fuel cycle Royal Commission Report*, p. 210.
59 *Nuclear fuel cycle Royal Commission Report*, p. 210.
60 *Nuclear fuel cycle Royal Commission Report*, p. 210.
61 *Nuclear fuel cycle Royal Commission Report*, p. 210.
62 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.

4. Environmental Impacts

With all energy generation technologies and systems, there are environmental issues to be considered, risks to be assessed, and challenges to be addressed. An ideal energy source that is at the same time efficient, cost-effective, environment-friendly, and risk-free does not exist. However, nuclear power provides secure, base-load electricity with negligible life-cycle greenhouse gas emissions, and has the potential to expand at a large scale.[63] Several key issues are discussed in turn.

Emissions Abatement

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, it generally is acknowledged that nuclear energy avoids the production of more than 600 million tonnes of total carbon emissions and 2.5 billion tonnes of CO_2, each year. Put differently, nuclear power currently saves approximately 10 per cent of total CO_2 emissions from world energy use.[64] The capacity of nuclear power to mitigate or abate greenhouse gas emissions into the future depends on the extent to which nuclear power displaces carbon-based energy sources in electricity generation and on the extent to which it is deployed to support renewable energy generation technologies.

Life-Cycle Assessment (LCA) of Emissions

While nuclear power abates emissions at the point of energy production, it is estimated that the construction of a 1 GWe nuclear power plant results in 300,000 tonnes of CO_2 emissions. For a 40-year plant life (which is the typical period for which a plant initially is licensed), this corresponds to approximately 1 g of CO_2 per kWh(e) produced. This is much lower than figures that have been calculated for fossil fuel-based energy generation technologies across the same 40-year time horizon (400 g CO_2/kWh (e)).[65]

The direct and indirect CO_2 emissions from various energy sources are outlined in the table below, drawing on data published by the United Nations Intergovernmental Panel on Climate Change (IPCC)[66]:

[63] McCombie, A. and Jefferson, M., 'Renewable and nuclear electricity: Comparison of environmental impacts', *Energy Policy*, vol. 96, 2016, pp. 758-769.
[64] House of Representatives Standing Committee on Industry and Resources, *Australia's uranium — Greenhouse friendly fuel for an energy hungry world - A case study into the strategic importance of Australia's uranium resources for the Inquiry into developing Australia's non-fossil fuel energy industry*, 2006, pp. 152-153.
[65] MacKay, D., *Sustainable Energy – Without the Hot Air*, UIT, Cambridge, England, 2009.
[66] 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[67]	–	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

Water Use

The utilisation of water is also important when considering the environmental impacts of nuclear power. Water usage by nuclear power plants is high, and second only to that required by the agricultural sector.[68] Water is a requirement for cooling; however, the majority of water used in power reactors around the world is derived from the sea, which is returned to the environment only a few degrees warmer and with minimal loss due to evaporation.[69] The rate of return of water utilised in nuclear power reactors is demonstrated by data obtained from the 1 GWe Leibstadt plant in Switzerland, at which the required cooling water throughput is 32 m^3 per second and the losses from evaporation amount to 1 m^3 per second.[70]

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, which can lose 17,000 L/MWh(e) produced due to evaporation, are

[67] 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.
[68] McCombie and Jefferson, pp. 758-769.
[69] McCombie and Jefferson, pp. 758-769.
[70] McCombie and Jefferson, pp. 758-769.

the most water resource-intensive of the power generation technologies.[71] 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-generated power uses almost none.[72]

Environmental Footprint

Footprint—or land—requirements are a critical consideration when determining the environmental impacts of nuclear power. It has been estimated that the necessary land requirements for the operation of a power plant correspond to only 0.6m^2 per GWh(e). This value is highly dependent upon the type and size of the power reactor, noting that small modular reactors have the ability to substantially decrease the footprint occupied by the larger power stations currently in operation. Put in context, the footprint required for hydropower and large solar power plants is 49 m^2 and 1275 m^2 per GWh(e), respectively. Other studies have shown that wind farms require 300 to 500 times more land than a nuclear power plant.[73]

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.[74] Because these radioactive discharges potentially create environmental impacts, the nuclear industry is subject to strict regulations and licensing conditions regarding emissions and discharges. Nuclear power plants, and, more broadly all nuclear facilities, are mandated to collect and analyse environmental samples and gaseous discharges to ensure that their environmental impacts are minimised.

Alternative energy technologies also produce air and other pollutants. These include particulates, carbon monoxide, nitrous oxides, sulphur dioxide, and volatile organic compounds, which are highly potent and detrimental to the environment and air quality. For example, solar photovoltaic power is estimated to emit 263 kg of nitrous oxides and 731 kg of sulphur oxides per GWh(e) generated.[75] Wind energy also releases 71 kg and 137 kg of nitrous oxides and sulphur oxides per GWh(e), respectively.[76] 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.[77]

Waste

While radioactive waste management was the subject of extensive discussion above, the volume of waste produced is also an important consideration when establishing the environmental impacts of nuclear power. Nuclear fuels have a high energy density; therefore, nuclear power plants produce far less waste than fossil-based power plants per unit of energy produced. Normalising the quantity of waste produced on the basis of energy generated provides for an effective comparison between technologies.

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71 McCombie and Jefferson, pp. 758-769.
72 McCombie and Jefferson, pp. 758-769.
73 MacKay, D., *Sustainable Energy – Without the Hot Air*; *Water Use and Nuclear Power Plants*, Nuclear Energy Institute, Washington, D.C., 2013.
74 McCombie and Jefferson, pp. 758-769.
75 McCombie and Jefferson, pp. 758-769.
76 McCombie and Jefferson, pp. 758-769.
77 McCombie and Jefferson, pp. 758-769.

Low- and intermediate-level waste generated by a 1 GWe light water reactor totals, on average, 200 to 350 m^3 per year.[78] A reactor of this size also generates approximately 1500 t of used fuel over a 60-year operating life.[79] In comparison, a coal-fired power plant of the same electrical output generates approximately 400,000 t of fly ash.[80] Despite the quantity of waste being far less for nuclear power than for fossil fuel-based generation technologies, the radiotoxicity of nuclear waste and its heat generation increases its management burden.

When comparing the management of nuclear waste with alternative waste forms produced from renewable sources, the burden is relative. A 1 GWe solar-electric plant generates approximately 13,000 t 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 t of manufacturing waste, of which 32,000 t would be contaminated by heavy metals, over the same period.[81]

The management of nuclear waste is an area of significant scrutiny and debate, despite geological disposal widely being recognised as a suitable and safe long-term approach. The long lifetime for radioactive decay is an issue of contention. However, other generation technologies also produce wastes that require long-term management and that remain toxic indefinitely (unlike radioactive wastes, which decay with time). Solar modules, for example, contain potentially dangerous materials that do not decay with time; these materials can potentially have significant impacts on the environment and on human health. The use of cadmium in the manufacture of thin film solar panels is a major issue of concern; indeed, it was deemed one of the world's six major pollution problems in 2015.[82] Despite the concerns around cadmium and its use in solar panels, it still is acceptable to manufacture cadmium panels in the United States. While use of cadmium is generally forbidden in the European Union, there is an exemption for use in solar panels.[83]

Environmental Monitoring and Research

As mentioned above, the nuclear industry is heavily regulated, ensuring that environmental impacts are effectively mitigated and monitored to the maximum extent possible. Within Australia, ANSTO is required to undertake radiation monitoring activities, environmental impact assessments, and thorough contamination monitoring activities by ARPANSA. ANSTO also actively monitors and manages its non-radioactive wastes, in compliance with New South Wales Environmental Protection Authority (EPA) standards and requirements.

More broadly, 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 (isotopic) techniques deployed by ANSTO are contributing to better understanding of water management and water availability, food provenance, the causes of climate change, and airborne particulate management, as well as of potentially effective mitigations for climate change. ANSTO personnel either conduct, or enable others to conduct, research using nuclear techniques to address some of Australia's most challenging environmental problems.

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[78] McCombie and Jefferson, pp. 758-769.
[79] 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.
[80] McCombie and Jefferson, pp. 758-769.
[81] 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.
[82] McCombie and Jefferson, pp. 758-769.
[83] Directive 2011/65/EU of the European Parliament and of the Council of 8 June 2011 on the restriction of the use of certain hazardous substances in electrical and electronic equipment.

5. Energy Affordability and Reliability

Reliability

As noted above, ANSTO provides periodic advice on aspects of nuclear science and technology, including nuclear power and related energy matters, as mandated by the ANSTO Act.[84] Information and advice on nuclear power developments is regularly collected, assessed, and provided in this context.

Australia's energy affordability and reliability has historically been underpinned by inexpensive coal generation. Over the last decade, the falling cost of renewables, particularly of wind and photovoltaic solar generation technologies, has seen an increase in their percentage share of the National Electricity Market (NEM), which has displaced coal generators that traditionally have supplied low cost, dispatchable electricity.

Variable renewable energy (VRE) sources require firming (backup generation), preferably from a generation option that requires low capital expenditure (CAPEX) and operational expenditure (OPEX), operating with low carbon emissions. In South Australia, for example, large installations of wind generators have been firmed by Open Cycle Gas Turbine (OCGT) generators[85], which are characterised by relatively low CAPEX (build costs), but high OPEX, predominantly caused by the tripling of gas prices in recent years.[86] Despite plans for major VRE roll outs across the country[87], the question of firming by gas, pumped storage, batteries, hydrogen, and smart-grids, among other technologies, remains uncertain in cost and availability.

Should Australia move toward a lower carbon emissions energy mix scenario, there likely will be challenges to cost and reliability of electricity supply. However, analysis of energy mix scenarios using a combination of nuclear and renewable generation sources, undertaken by the Nuclear Energy Agency, 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.[88]

The NEA's findings show that VREs require the installation of capacity additional to that which is required to meet electricity demand. The larger the VRE penetration, the larger the required additional capacity. This significantly increases overall system costs.[89] The NEA observes, though, that, in the international context, VREs complemented with nuclear generation can significantly reduce overall systems costs and the amount of generation capacity required. As such, nuclear power is viewed as a primary source of low-carbon baseload generation, underpinning the future energy systems of major industrialised countries.

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[84] Part II, Section 5, (1e) of the *Australian Nuclear Science and Technology Organisation Act 1987*.
[85] Electricity Map, *South Australia*, https://www.electricitymap.org/?page=country&solar=false&remote=true&wind=false&countryCode=AUS-SA.
[86] 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.
[87] 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
[88] 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
[89] OECD–NEA, *The Costs of Decarbonisation*, p 19.

Affordability

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

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 up-front capital investment requirements, contributing to the increasing affordability of nuclear power.

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

In its recent report, Industry Super Australia focused on the potential application of nuclear power in a broader and more cost effective energy mix.[90] Importantly, the peak industry superannuation organisation identified the need to take a longer-term view of the cost to finance nuclear builds, demonstrating the potential availability of finance for a nuclear power program in the country.

In discussing the costs of generating technologies, the levelised cost of electricity (LCOE) typically is used as a comparative measure. In most cases, the LCOE takes into account capital costs, fuel costs, operation and maintenance costs, and an assumed utilisation rate for each technology type. However, the LCOE is dependent on local characteristics. Without an existing nuclear 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 in countries that are embarking on—or considering—new nuclear programs. The LCOE also does not capture the costs of the various externalities of the generating sources. For example, while the cost of nuclear decommissioning and waste management is accounted for in the International Energy Agency and OECD–NEA methodology, the true cost of waste from coal generation is not captured. Similarly, the cost of intermittency from solar or wind, which is displaced across the grid, is not captured.

Owing to these issues, another indicator worth considering is that of the levelised avoided cost of electricity (LACE). The LACE measures what the impact to the 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.

There is significant value in incorporating the LACE into the evaluation of generating capacity, as it can provide indicators of the potential value for a new unit of generation technology in fulfilling projected future energy requirements.

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[90] 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.

6. Economic Feasibility

The overnight capital cost of large (1 GWe) nuclear power plants 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, which include land, cooling infrastructure, site works, project management, and licensing fees.

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 have also shifted to regions where there is a high number of new builds. This is reflected in the global range of overnight capital costs as reported in the IEA-OECD–NEA's *Nuclear Energy Roadmap 2015*[91], starting from a low end average of US$3500 per kilowatt (kW) of capacity in China to the European Union's overnight capital cost average of US$5500 per kW.

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

Despite the challenges of rising large plant build costs, many countries continue to invest in nuclear power for their high capacity factor, which, globally, averaged 80 per cent in 2018[92], as well as their longevity. Nuclear power plants are viewed as long-term investments, which can operate for between 40 and 80 years and, internationally, are viewed as an attractive low-carbon baseload option for the replacement of existing baseload generators. As such, they can be deployed on pre-existing electricity grids without extra investments in transmission infrastructure.

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

In a recent Massachusetts Institute of Technology study, the projected overnight cost of capital for SMRs falls to between US$4000 and $5000 per kW.[93] 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.[94] Less near-term, GE Hitachi has quoted its BWRX-300 SMR at an nth-of-a-kind overnight capital cost of US$2250 per kW. Advanced non-water coolant-based SMRs are believed to have even lower overnight capital costs. For example, Moltex Energy Ltd quotes US$2000 per kW and ThorCon quotes below $2000 per kW. The accuracy of these cost estimates

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[91] OECD–NEA, *Technology Roadmap: Nuclear Energy*, 2015 edition, OECD–NEA and International Energy Agency, https://www.oecd-nea.org/pub/techroadmap/techroadmap-2015.pdf.
[92] World Nuclear Association (WNA), *World Nuclear Performance Report 2019*, WNA, London, 2019.
[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] 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.

is hard to ascertain as these projects are not at a stage of detailed design, but a costing of around the US$2000 per kW is supported by industry studies.[95]

7. Community Engagement

Civilian nuclear fuel cycle activities are the subject of significant public interest, concern, and, to be sure, benefit. Despite these benefits, there is significant misunderstanding about the nature of the risks (and their consequences) stemming from human exposure to ionizing 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, it would be essential for an Australian nuclear power program to obtain the broad support of the Australian community. Methods for determining and assessing public sentiment exist, and are routinely used by domestic and international policy-makers on a range of policy issues.[96]

The support of any potential host community/ies that stand/s to be most affected by the siting of a nuclear facility would also need to be obtained. Accordingly, any proposal to establish nuclear power 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 Australian 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 Australia could—and should—consider the inclusion of nuclear power in its energy mix.

There is a significant body of guidance and work undertaken internationally on community engagement and communications regarding the siting of nuclear facilities; lessons also could be drawn from experiences in particular siting programs.[97] Moreover, the OECD–NEA has established the Forum on Stakeholder Confidence, which publishes guidance and summaries of leading practice from its assessment of engagement programs on the establishment of nuclear facilities around the world.[98]

Internationally, host communities are shown to be among the strongest supporters of nuclear facilities, owing to reported perceptions of benefits, including employment opportunities and social and economic activity. International experience also shows that community engagement activities should not be the subject of arbitrary timeframes and resources, and that communities and other stakeholders can play a constructive role in project planning and delivery. Examples of public contributions to the establishment and operation of nuclear facilities include the provision of local knowledge regarding environmental and heritage factors, design enhancements, and the supply of labour and services throughout the supply chain.

ANSTO has played a significant role in engaging with the Australian community on nuclear, and broader science and technology issues, for many years. Last year, ANSTO welcomed more than 17,000 visitors to its Lucas Heights campus in southern Sydney. The majority of these visits were

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[95] 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.

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

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

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

from school groups undertaking tours specifically tailored to the curriculum. Beyond engagement with school students, ANSTO contributes to the education and training of Australia's future nuclear experts—and scientists more broadly—through:

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

ANSTO notes that community engagement has been a key focus of the National Radioactive Waste Management Facility site selection process. Lessons for a future engagement program regarding the merits or otherwise of introducing nuclear power in Australia, and any subsequent siting activities, could be learnt from this process.

8. Workforce Capability

Human Resource Considerations when Initiating Nuclear Power Programs

The IAEA acknowledges that it is unrealistic to expect that a Member State initiating a new nuclear power program would have sufficiently skilled personnel, with the required levels of competence, to implement that program. In order to establish the necessary human capacity, it is expected that:

- a national system would be developed to build the human resource base;
- the first reactor project would be turnkey to leverage the knowledge and experience gained during the build from the provider;
- there will be recruitment of competent staff for the commissioning and operational phases of the program; and
- a loose partnership will be formed between the operator, vendor(s), regulatory bodies, established nuclear facilities, academic/educational institutions, and trade organisations.

Given the long lead times between any decision to introduce nuclear power in Australia and the commencement of operation of the first reactor, the current lack of a trained workforce should not be regarded as a constraint.

Australia, through the agency of ANSTO, has experience in sourcing a turnkey research reactor for medical and scientific purposes. As a result, and after 12 years of safe and successful operation, the OPAL reactor is serviced and operated solely by Australians.

The IAEA and OECD–NEA provide human resource guidance documents and reports, organise workshops, and conduct review missions; they also assist in the development and implementation of workforce training planning tools. Both agencies may assist in the development of national human resource plans and in the provision of guidance for long-term reactor operation.[99] These resources would be available to Australia in the event that a decision were made in future to introduce nuclear power.

Preparing for Decommissioning Activities

Australia's nuclear decommissioning program, when compared to countries with nuclear power, is relatively nascent. However, Australia is considered to be the custodian of significant decommissioning expertise in the region. ANSTO has fully decommissioned one of its two retired research reactors, MOATA.[100] Through the successful decommissioning of MOATA, ANSTO has become a training ground for international decommissioning engineers and project managers. Australia's expertise in this area has also been recognised by the IAEA through the appointment of an ANSTO staff member as chair of its Decommissioning Network. Australia's first research reactor, HIFAR, remains in its non-decommissioned state at ANSTO, though it has been shut down safely, with all fuel elements removed.

[99] OECD–NEA, *Nuclear Education and Training: From Concern to Capability: Executive Summary*, OECD–NEA, Paris, 2010, http://www.oecd-nea.org/ndd/reports/2012/nuclear-edu-training-ex.pdf; IAEA, *Human Resource Development*, 1998-2019, https://www.iaea.org/topics/human-resource-development; IAEA, *Human Resource Development for Nuclear Power Programmes: Meeting Challenges to Ensure the Future Nuclear Workforce Capability*, Proceedings of an International Conference, Gyeongju, Republic of Korea, 28–31 May 2018, https://www-pub.iaea.org/MTCD/Publications/PDF/PUB1898web.pdf.

[100] ANSTO, *Our History*, ANSTO, 2019, https://www.ansto.gov.au/about/what-we-do/our-history.

The decommissioning of HIFAR and most facilities at ANSTO's Lucas Heights' campus are on hold pending the availability of funding and a waste disposal pathway, the plans and procedures for which are established in the *Australian Radioactive Waste Management Framework*.[101]

Consequential upon the establishment of a nuclear power program in Australia, it would be necessary to institute a framework to continue to develop and train the required decommissioning workforce. However, given the long lifetimes of power reactors, this workforce would not be required immediately.

[101] Department of Industry, Innovation and Science, *Australian Radioactive Waste Management Framework*, Australian Government, Department of Industry, Innovation and Science, April 2018.

9. Security Implications

While nuclear security and nuclear safeguards matters, and Australia's international obligations thereunder, predominantly fall within the purview of the Australian Safeguards and Non-proliferation Office—which ANSTO understands is making a separate submission, ANSTO is responsible for the security of its facilities, principally at its Lucas Heights campus. ANSTO also has facilities in Camperdown (Sydney) and Clayton (Victoria), for which it maintains security.

As part of the exercise of its responsibilities, ANSTO adheres to Australian regulations and legislative requirements regarding nuclear security and nuclear safeguards. ANSTO recognises that there is no room for complacency with nuclear security, and that a mature security culture contributes directly to a safe and secure workplace, which is a pre-requisite for any nuclear industry activity, including nuclear power.

More broadly, ANSTO contributes to the promotion of nuclear security in Australia, the Asia-Pacific region, and around the world. ANSTO strongly supports Australia's non-proliferation efforts, and provides international leadership in nuclear security operations. The organisation also undertakes research in selected areas, such as nuclear forensics and border security technology development.

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 independent Nuclear Threat Initiative[102], a non-government organisation that works to reduce global threats from nuclear, biological, and chemical weapons. Australia has maintained its top ranking through steps such as reducing the quantities of highly enriched uranium it holds and its leadership role in the Global Initiative to Combat Nuclear Terrorism (GICNT).

On Australia's behalf, ANSTO participates in the GICNT steering group, the Implementation and Assessment Group, has chaired the Nuclear Forensics Working Group, and participates in two other working groups.

ANSTO has established a nuclear forensics facility staffed with experts in radiochemistry and forensic science. The functions of the facility and its staff are:

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

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

Due to our experience in managing the security of our facilities, ANSTO has provided expert advice to the Department of Industry, Innovation and Science's National Radioactive Waste Management Facility Taskforce regarding security arrangements for a future Facility. ANSTO also provides expert and technical advice to the Foreign Affairs and Trade portfolio in the areas of the peaceful uses of nuclear energy and science, nuclear safety, nuclear security, and nuclear-non-proliferation.

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[102] 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.

10. National Consensus

A key prerequisite for a nuclear power program in Australia would be to secure bipartisan political support for that program. ANSTO notes that it enjoys bipartisan support for its activities at the Federal level, which most recently was demonstrated during the process to enable Australia's accession to the Generation IV International Forum. ANSTO acknowledges, and is grateful for, this ongoing support.

ANSTO also enjoys bipartisan support in New South Wales and Victoria—both jurisdictions in which it operates facilities. Similarly, as one of the major employers in the Sutherland Shire, ANSTO has deep and congenial connections with its local community. ANSTO maintains a strong relationship with key stakeholders, including the Sutherland Shire Council, local education and community groups, and business and industry associations.

International research has found that public support for, and positive sentiment toward, nuclear activities is higher in communities that are located in close proximity to nuclear facilities. Public support also has been found to be higher when the public is aware of the role that nuclear power plays in combatting climate change.

As previously noted, there are established methods for successfully engaging with communities to develop understanding of, and assess support for, nuclear power programs.

11. Other Relevant Matters

Legislative and Regulatory Pre-requisites

Legislative changes would be required in order to establish a nuclear power industry in Australia. At present, nuclear power is prohibited in Australia. 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. In addition, the *Australian Radiation Protection and Nuclear Safety Act 1998* (Cth) prevents the Chief Executive Officer of ARPANSA from licensing the siting, construction, or operation of nuclear facilities by Australian Government entities. There are also various State-based prohibitions, such as the *Uranium Mining and Nuclear Facilities (Prohibitions) Act 1986* (NSW) or the *Nuclear Activities (Prohibitions) Act 1983* (VIC). ANSTO notes that the potential repeal of these particular State acts are the subject of extant or planned inquiries, respectively, in New South Wales and Victoria.

In addition to the removal of the legislative impediments, legislation would also likely be required to upgrade the existing regulatory structure so that it is capable of performing the functions required for the licensing of nuclear power reactors. In addition, there would need to be legislation governing nuclear liability in order to bring Australia into line with international legal norms (see below).

Liability Regime

Introduction

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. This section provides an overview of the international nuclear liability regime and its application to the various steps in the nuclear fuel cycle. It also discusses the role of the IAEA International Expert Group on Nuclear Liability (INLEX) in advising on the application of, and promoting adherence to, the international conventions in this area, and the current position under Australian law.

The principles of the international nuclear liability regime

Although there are a number of international conventions covering nuclear liability, these reflect the same general principles. The first set of Conventions (the Paris Convention and the Vienna Convention) were adopted in the 1960s; they were modernised, respectively, in the late 1990s and early 2000s.

The operator of a nuclear installation is exclusively liable for nuclear damage

All liability is channelled onto one legal person, namely, the operator of the nuclear installation where the nuclear incident occurs, or, in the case of an accident during the shipment of material, of the installation from which the shipment originated. Under the aforementioned Conventions, the operator—and only the operator—is liable for nuclear incidents, to the exclusion of any other person. Two primary factors have motivated this exclusive liability of the operator, as distinct from the position under the ordinary law of torts:

- First, it is desirable to avoid difficult and lengthy questions of complicated legal cross-actions to establish in individual cases who is legally liable.
- Second, such exclusive liability obviates the necessity for all those who might be associated with the construction or operation of a nuclear installation other than the operator itself, to also take out insurance, and thus allows a concentration of the insurance capacity available.

The exclusive liability of the operator reflects the general principle of the IAEA that the operator of a nuclear facility bears the primary responsibility for its safety and security.

The issue of liability for an accident in the course of transport of radioactive material requires additional explanation. The basic principle—with limited, rarely used, exceptions—is that the carrier of the material does not carry liability; rather, it is imposed either on the operator of the facility from which the material was sent or on the operator of the facility to which it is being sent. The determination of which of those operators is actually liable is normally done by way of contract; in the absence of any contractual provision, the default position is that liability lies with the operator of the sending facility until it is received at the recipient facility.

Strict (no-fault) liability is imposed on the operator

There is a long-established tradition of legislative action or judicial interpretation that a presumption of liability for hazards created arises when a person (or entity) engages in a dangerous activity. Because of the special dangers involved in the activities within the scope of the Conventions and the difficulty in establishing negligence in particular cases, this presumption has been adopted for nuclear liability. Strict liability, therefore, is the rule; liability results from the risk, irrespective of fault. There are very limited exonerations:

- an Act of War, defined as ‘armed conflict, hostilities, civil war or insurrection’. This exoneration does not apply in the case of a possible release of radiation caused by a terrorist attack, for which the operator of the facility remains liable; and
- under the 1960s Conventions, a grave natural disaster of an exceptional character. The Fukushima incident demonstrates the limited relevance of this exoneration, which exists under Japanese law, but was considered not to apply to the incident.

Liability may be limited in amount

The Conventions provide the ability for states parties to cap the liability of their operators at a specified amount. The quantum of this cap is one area where there are differences between the conventions. All Conventions foresee the possibility of establishing lower amounts for low-risk installations (national governments to make up difference). Notwithstanding the existence of this option, there is an increasing trend towards unlimited liability, as is the case in Japan.

Following the Fukushima incident, INLEX recommended that countries with nuclear installations should ‘Establish compensation and financial security amounts significantly higher than the minimum amounts envisaged under the existing instruments’.

Mandatory financial coverage

While it naturally would be desirable to provide for large—or unlimited—amounts of liability, governments and potential claimants need to be assured that such amounts will actually be available in the case of an accident. The Conventions therefore require the operator to carry financial security of a specified amount. This is the case even in countries where there is unlimited liability. Such financial security generally is obtained by way of insurance, and there are large amounts of nuclear insurance (in the billions of dollars) available in the global market.

However, there are gaps in insurance coverage, in three areas:

- Terrorism—Immediately after the 11 September 2001 terrorist attacks in the United States, it was impossible for any company (whether in the nuclear industry or elsewhere) to obtain insurance coverage against terrorist attacks. That has eased somewhat in recent years, but it still is the case that operators might find it difficult to get as much coverage for terrorist attacks as they can for accidents.

- Coverage of personal injury where claims are lodged more than 10 years after the initiating event—This is a general line in the sand for the insurance industry, which is concerned about how it reasonably could make provision for such claims; and
- Compensation for the new heads of environmental damage introduced in the modernised Conventions—Insurers claim to have no experience in addressing such claims and, therefore, that they have no basis on which to assess risk and premiums.

While these gaps are not peculiar to nuclear insurance, there is a particular issue for the nuclear industry, because the Conventions—and national law that reflects those Conventions—require them to have financial security to cover claims, but insurance is not available. In these circumstances, some governments have stepped into the breach to provide insurance where no commercial insurance is available.

Liability is limited in time

As with any other type of legal claim, the Conventions apply a statute of limitations for the bringing of claims. In the case of nuclear liability, bodily injury may not become manifest for some time after the exposure to radiation has occurred. Operators and their insurers or financial guarantors will be concerned if they have to maintain, over long periods of time, reserves against outstanding or expired policies for possibly large, but unascertainable, amounts of liability. If the available money for compensation is limited, there also is an issue of how—and how much—money should be set aside to compensate possible future claims.

However, it would be unreasonable for victims whose damage manifests later to find no provision has been made for compensation to them. A further complication is the difficulty of proof involved in establishing or denying that delayed damage was, in fact, caused by the nuclear incident. The 1960s Conventions provide that claims only may be made during a period up to 10 years after an incident (accident). Under the more recent amendments to the Conventions, claims for loss of life and personal injury may be made up to 30 years after an accident.

Exclusive jurisdiction is granted to a single court

The general rule is that a court of the Contracting Party in whose territory the nuclear incident occurs has jurisdiction. If law suits arising out of the same incident were to be tried and judgements rendered in the courts of several different countries, the problem of assuring equitable distribution of compensation might be insoluble. Within the country, one single competent forum should deal with all actions (including direct actions against insurers or other guarantors and actions to establish rights to claim compensation) against the operator arising out of the same nuclear incident. So, in the case of transport, jurisdiction goes to the designated court in the country where the majority of the damage is likely to have occurred. Outside the territory of any State Party, jurisdiction falls back to the designated court of the installation state (the country in which the facility of the liable operator is located).

Non-discrimination

Coupled with the principle of exclusive jurisdiction of the court of the incident state is the principle that that court must award compensation to all without discrimination based upon nationality, domicile, or residence, as long as the damage was suffered in areas within the geographical scope of the applicable Convention.

The improvements in the modernised Conventions

The modernised Conventions built on these principles, but enhanced them in three significant ways: higher compensation; broader definition of nuclear damage; and updated jurisdiction rules. In addition, the Vienna and Paris Protocols mandate access to compensation by residents of non-Contracting Parties.

Amounts of compensation

The 1997 Protocol to the Vienna Convention and the Convention on Supplementary Compensation (CSC) establish 300 million special drawing rights (SDRs) as the minimum amount that a country must make available under its national law to compensate for nuclear damage. Under the 2004 Paris Protocol, the minimum amount is €1.2 billion. This represents a significant increase on the minimum amounts required by the 1960 Paris Convention and the 1963 Vienna Convention.

Furthermore, the CSC provides for an international fund to supplement the amount of compensation available under national law. Assuming widespread adherence, the international fund could provide approximately 300 million SDRs more to compensate nuclear damage, meaning a total compensation amount of approximately 600 million SDRs. Contributions to the international fund are based on a formula, under which more than 90 percent of the contributions come from nuclear power generating countries on the basis of their installed nuclear capacity, while the remaining portion comes from all member countries on the basis of their United Nations rate of assessment. Since nuclear power generating countries generally have high United Nations rates of assessment, this formula should result in a very high percentage of the contributions coming from nuclear power generating countries. The CSC provides that half of the international fund must be exclusively allocated to cover any transboundary damage. This recognises the importance that the international community attaches to compensating transboundary damage.

Definition of Damage

The modernised Conventions enhance the definition of ‘nuclear damage’ by explicitly identifying the types of damage that must be compensated. In addition to personal injury and property damage, which were included in the 1960s definition, the enhanced definition includes five categories of damage relating to impairment of the environment, preventive measures, and economic loss. The definition makes it clear that these additional categories are covered to the extent determined by the law of the competent court. The enhanced definition thus provides certainty that the concept of nuclear damage includes costs of reinstatement of impaired environment, preventive measures, and certain economic loss, while recognising that the forms and content of compensation are best left to the national law of the country, the courts of which have jurisdiction over a particular nuclear incident.

The modernised Conventions also revise the definition of ‘nuclear incident’ to make it clear that, in the absence of an actual release of radiation, compensation may be payable for the cost of preventive measures taken in response to a grave and imminent threat of a release of radiation that could cause other types of nuclear damage. The use of the phrase, ‘grave and imminent’, makes it clear that preventive measures can be compensated if, at the time they were taken, there was a credible basis for believing that a release of radiation with severe consequences otherwise may have occurred in the future. The modernised Conventions are explicit that, in order to be compensable, preventive measures, as well as measures of reinstatement relating to impairment of the environment, must be reasonable. The importance of reasonableness is confirmed by the inclusion of a definition of reasonable measures. This definition makes it clear that the competent court is responsible for determining whether a measure is reasonable under its national law, taking into account all relevant factors.

Jurisdiction

The modernised Conventions reaffirm the basic principle of nuclear liability law that exclusive jurisdiction over a nuclear incident lies with the courts of the member country where the incident occurs, or with the courts of the installation state if the incident occurs outside any member country. They also recognise developments in the Law of the Sea in respect of the exclusive economic zone

(EEZ) and the concerns of some coastal countries over compensation for possible accidents in the course of maritime shipments of nuclear material. Specifically, the modernised Conventions provide that the courts of a member country will have exclusive jurisdiction over claims for nuclear damage resulting from a nuclear incident in its EEZ. Exclusive economic zone jurisdiction is only for the purposes of adjudicating claims for nuclear damage and does not create or modify any rights or obligations concerning actual shipments.

The legal arrangements with respect to nuclear liability in Australia

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

The legal arrangements with respect to nuclear liability that would need to be established within Australia were any additional nuclear fuel cycle activities to be introduced

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

12. Conclusion

Nuclear power is a mature technology, which has a proven track record of safe and reliable operation in many countries around the world. Of the major economies in the region, Australia alone has excluded nuclear power from energy policy considerations.

ANSTO maintains strong linkages with the international nuclear community to ensure that, as nuclear energy use expands throughout our region and the rest of the world, Australia is capable of understanding past, present, and future nuclear technologies. Through such linkages, ANSTO is well positioned to further assist the Committee in its Inquiry and to provide ongoing support should a future government consider the introduction of nuclear power in Australia.

13. Useful Reports and Publications

Members of the Committee may find the following reports and publications to be of value:

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

14. Upcoming Meetings and Events

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

Meeting / Event	Location and Date	Further Information
International Framework for Nuclear Energy Cooperation (IFNEC) IDWG Workshop - Nuclear energy beyond electricity	Warsaw, Poland, 24 – 25 September 2019	https://www.ifnec.org/ifnec/
OECD–NEA workshop on Stakeholder Involvement: Risk Communication - Dialogues Towards a Shared Understanding of Radiological Risks	OECD Conference Centre, Paris, 24 – 26 September 2019	https://www.oecd-nea.org/civil/workshops/2019/stakeholder/
Third Research Coordination Meeting on Assessments of the Potential Role of Nuclear Energy in National Climate Change Mitigation Strategies	International Atomic Energy Agency, Vienna, 24 – 27 September 2019	https://www.iaea.org/events/evt1804665
6th World Nuclear Industry Congress 2019	London, 25 – 26 September 2019	http://szwgroup.com/nuclear-industry-congress-uk-2019/?hmsr=COMS&hmpl=&hmcu=&hmkw=&hmci=
19th Meeting of the Working Party on Nuclear Energy Economics of the OECD–NEA	OECD Boulogne Building, Paris, 27 September 2019	Available from ANSTO
International Workshop on Developments in Safety Assessment Approaches and Safety Management Practices of Fuel Cycle Facilities	OECD Conference Centre, Paris, 7 – 9 October 2019	https://www.oecd-nea.org/nsd/workshops/fcssafe-2019/
International Conference on Climate Change and the Role of Nuclear Power	International Atomic Energy Agency, Vienna, 7 – 11 October 2019	https://www.iaea.org/atoms4climate
Applications for SMRs and Advanced Reactors to promote clean growth	Dubai, 29 – 30 October 2019	http://www.stratcoms.com/SMRsARs2019/
5th International	Adelaide, 17 – 21	https://icrp2019.com/

Symposium on the System of Radiological Protection South Australia	November 2019	
International Conference on Research Reactors: Addressing Challenges and Opportunities to Ensure Effectiveness and Sustainability	Buenos Aires, 25 – 29 November 2019	https://www.iaea.org/events/conference-on-research-reactors-2019
International Youth Nuclear Congress	Sydney, 8 – 13 March 2020	https://iync2020.org/
International Nuclear Supply Chain Symposium	Munich, 12 – 13 May 2020	https://www.tuev-sued.de/academy/conference-management/plant-engineering-industrial-safety/nuclear-supply-chain-symposium?utm_medium=cooperation&utm_source=nti&utm_campaign=supply-chain-2020-nti-eng
World Nuclear Exhibition 2020	Paris Nord Villepinte, 23 – 25 June 2020	https://www.world-nuclear-exhibition.com/en-gb.html

Response to Question on Notice

House of Representatives Standing Committee on the Environment and Energy

Prerequisites for Nuclear Energy in Australia

Thursday, 29 August 2019

Sydney

Mr Burns asked:

> ‘The big differences between ANSTO’s current capabilities and what it would look like on the scale to generate nuclear energy are obviously around the use of water and the waste et cetera. Perhaps, Dr Paterson, you could give the committee an overview of the use of water currently by the OPAL reactor—how much water is being used, how much more water would be required. I understand that obviously some of the SMRs have different designs, but given it's a little bit off, using current technology, what sort of usage of water would that mean?’

Answer:

> As an average, water use for the OPAL Cooling Towers with the reactor operating at 20 MWth is 30 m^3 per hour.
>
> Water use in nuclear power plants is addressed in the body of the submission.