Senator CANAVAN: I'll stick with ANSTO and Dr Applerley, just to your submission where you talk about technological developments. There's been an undue focus, I think, on SMRs. The bill before us is simply to remove the ban completely. I'd be particularly interested to know about generation IV technologies. Where are they up to, and what are the advancements in gen IV that go above and beyond previous generations of nuclear technologies?

Dr Apperley: ANSTO would be happy to provide you with a much fuller briefing beyond the scope that's in this submission around gen IV technologies. There are a number of advances. Australia is connecting into some parts of that and have a watching brief over all the technologies included. I'd prefer to provide you, on notice, with more information.

Generation IV Nuclear Reactor Systems

'Generation IV reactors' is an umbrella term for a number of advanced reactor technologies. The Generation IV International Forum (GIF) is a cooperative international endeavour bringing together 14 countries, including Australia, seeking to develop the research necessary to test the feasibility and performance of fourth generation nuclear systems. In the early 2000s, the GIF selected six reactor concepts as the most promising reactor technologies for the future: (1) Sodium-cooled Fast Reactors (SFR); (2) Gas-cooled Fast Reactors (GFR); (3) Lead-cooled Fast Reactors (LFR); (4) Molten Salt Reactors (MSR); (5) High or Very High-Temperature Reactors (VHTR); (6) SuperCritical-Water-cooled Reactors (SCWR).

These Gen IV reactors could offer several advantages over the current generation (III and III+) reactor systems:

1) Improved Safety: Gen IV reactors are designed with advanced safety systems and passive safety features which kick-in without human intervention.
2) Efficient Use of Fuel: Gen IV reactors aim to capitalise on advances in fuel technology to use fuel much more efficiently than existing reactors, extracting more energy from a given amount of material and thus also reducing the amount of waste generated. New forms of fuels such as TRISO (Tri-structural Isotropic) for VHTR and GFR, offer higher performance, increased safety characteristics, and retention of fission products from each individual fuel kernel.
3) Waste Minimisation: Gen IV designs aim to reduce the radiotoxicity of spent nuclear fuel by producing waste with shorter half-lives. Some designs (MSR, SFR, LFR) utilise as fuel, the spent fuel from Gen 3 and 3+ conventional reactors.
4) High-Temperature Operations: Gen IV reactors operate at higher temperatures, which makes them useful beyond electricity generation including for industrial processes which require high-temperature heat, including steel, fertiliser, hydrogen, cement and synthetic fuel production.
5) Non-Proliferation: Gen IV reactors include features that make the fuel cycle resistant to the proliferation of weapons.

6) Economic Competitiveness: the overall lifecycle cost of Gen IV reactors may be lower than the current generation due to better fuel efficiency, less waste management, and the potential for revenue from heat sales for industrial processes.
7) Integrated Energy Systems: Gen IV reactors are being designed to provide a high degree of compatibility with intermittent renewable energy sources like wind and solar, ensuring an efficient and reliable power supply.
8) Scale: Gen IV reactor designs come in different sizes and are intended for use in a wide range of conditions, from large-scale reactors (> 300MW, small modular reactors (SMRs) (20 - 300 MW) to microreactors (< 20MW). Larger systems are intended for on-grid production of dispatchable electricity and industrial heat. Microreactors are being designed for off-grid locations such as mining sites, rural communities, research stations, military bases, island communities, off-shore platforms, which require reliable electricity and heat supply, or for space travel. Smaller reactor systems are being designed to be factory fabricated, rapidly deployed, easily exchanged or removed, and straightforward to operate without requiring a large number of specialised personnel.

Current Status

Over the past two decades, progress in Gen IV reactor technologies has been uneven, with some designs advancing more rapidly than others. The Very High-Temperature Reactor (VHTR) demonstration reactors are the only ones to have reached the construction and operational stages. There are two examples in operation: the High-Temperature Engineering Test Reactor (HTTR) in Japan and the High-Temperature Pebble-bed Module (HTR-PM) in China. The former, run by the Japan Atomic Energy Agency (JAEA), first achieved criticality in 1998, and the latter, operated by the China National Nuclear Corporation, reached criticality in 2021.

The U.S. Department of Energy (DOE) is working on the Microreactor Applications Research Validation and EvaLuation (MARVEL) reactor, which is being built at Idaho National Laboratory (INL) and is expected to go critical in 2024. MARVEL is a liquid-metal-cooled microreactor designed to demonstrate the technology readiness of various microreactor designs. Additionally, the U.S. Department of Defence (DoD) is working on Project PELE, a mobile nuclear microreactor that will be the first high-temperature gas-cooled electricity-generating Generation-IV reactor in the U.S. It is developed by BWX Technologies LLC, and it will be assembled and operated at INL when it goes critical in 2024.

Commercial entities are primarily focusing their efforts on SMRs and microreactors:

- X-Energy LLC is developing the Xe-100 reactor, which is based on the high-temperature Helium-cooled thermal reactor design utilising TRISO fuel, which allows the reactor to run without fuel interruption for up to 60 years. Xe-100 is designed to produce high-temperature industrial heat of up to 750 °C and generate an electrical power output of 80 MWe. X-Energy LLC is engaged in pre-application activities with the U.S. Nuclear Regulatory Commission (NRC).
- Terrestrial Energy Inc. is working on the Integrated Molten Salt Reactor (IMSR), which can produce high-temperature industrial heat of up to 680°C and 195 MWe of power output. IMSR is designed to operate in load-following mode, which is ideal for hybrid electric girds with various renewable energy sources.

- General Atomics Inc. is developing the Energy Multiplier Module (EM2), which is a high-temperature Helium-cooled reactor design, however, unlike X-Energy's Xe-100, it operates with fast neutron spectra. Hence, the EM2 can recycle its used fuel while producing high-temperature industrial heat of up to 850 °C with a net unit power output of 265 MWe.
- Kairos Power LLC is developing the KP-FHR reactor, which is a fluoride salt-cooled high-temperature reactor leveraging TRISO fuel combined with a low-pressure fluoride salt coolant. KP-FHR can produce very high-temperature industrial heat of up to 650°C while providing a power output of 140 MWe.
- Moltex Energy Canada Inc. is working on the development of the Wasteburner Stable Salt Reactor (SSR-W 300), which utilises recycled nuclear waste as a fuel. The SSR-W 300 operates with a fast neutron spectrum and can generate industrial heat of up to 630°C and electricity of up to 300 MWe.
- ARC Clean Energy Inc. is developing the sodium-cooled fast reactor (ARC 100) utilising metallic uranium alloy fuel, which can produce industrial heat up to 510°C while providing 100 MWe electricity power output. The ARC-100 consumes its waste and recycles its fuel, leaving almost no long-term waste while also recycling waste from traditional reactors.
- BWX Technologies LLC was selected by the U.S. Department of Defence (DoD) to develop the high-temperature gas-cooled (HTGR) mobile microreactor under Project Pele. BWXT's microreactor will use TRISO reactor fuel, while it can produce 1 MWe to 5 MWe.
- Westinghouse Inc. is developing its eVinci microreactor for decentralised, remote applications. eVinci microreactor will deliver combined heat and power of up to 5 MWe for up to 8 years of full power operation before refuelling. It targets less than 30 days of onsite installation and will be capable of autonomous operation.

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