Federal Ministry
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Climate Action, Environment,
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Generation IV reactors

Generation IV reactors – also known as "innovative" reactor concepts – have been researched and, in some cases, developed ever since the early days of nuclear power use in the 1950s and 1960s. However, it was the light-water reactors that are common nowadays that won out. Rather than specific reactor designs, the term "Generation IV" refers much more to various technological strands and concepts. Generation IV reactors have so far failed to gain a foothold in the market.

The term "generation"

To an extent, the term "generation" that is often used to categorise reactors is misleading because the concept of "generations" – in the sense of continuous further development – is only applicable to light-water reactors. Specifically, Generation I light-water reactors were early prototypes, Generation II were commercial reactors, and Generation III were advanced commercial reactors. Following the classification used for light-water reactors, Generation IV rectors are, in a way, early prototypes of Generation I. The designation "Generation IV" refers to technologies that are deemed to be "advanced" irrespective of their actual level of technical development. To some extent, Generation IV reactors are based on concepts underpinned by fundamentally different principles of physics but fall some way short of the level of technical development or maturity achieved by Generation II light-water reactors.[1, 2]

Authors such as Pistner, et al. (2024) call Generation IV reactors "so-called innovative reactor concepts" because the concepts and basic principles of nuclear physics underlying them have long been known about but not yet put into practice. Amongst other things, the difference between Generation IV reactors – or so-called "innovative" reactor

[1] Goldberg, S.M., Rosner R. (2011), "Nuclear Reactors: Generation to Generation".
[2] Pistner, C., et al. (2024), "Analyse und Bewertung des Entwicklungsstands, der Sicherheit und des regulatorischen Rahmens für sogenannte neuartige Reaktorkonzepte", BASE.

concepts – and conventional commercial light-water reactors lies in the nuclear fuels used, the neutron spectrum, the temperature, how fissile and, if applicable breeding material, is introduced and removal of fissioned and bred material, as well as the choice of coolant and, if required, moderator.[3]

The Generation IV International Forum (GIF), an international research alliance that helped to coin the term "generation" in the context of the nuclear industry, describes Generation IV as a revolutionary or innovative design. The fundamental goals made by and requirements made of Generation IV include enhanced safety, sustainability, economic competitiveness, less radioactive waste, and proliferation resistance (measures to prevent military use) and physical protection.[4, 5, 6] No evidence that these requirements have been met in technical terms has yet been produced.

Strands of technology

The GIF has identified the following strands of technology that make up Generation IV:[7]

- The very-high-temperature reactor (VHTR)
- The molten-salt reactor (MSR)
- The supercritical-water-cooled reactor (SCWR)
- The gas-cooled fast[8] reactor (GFR)
- The sodium-cooled fast reactor (SFR)
- The lead-cooled fast reactor (LFR)

Although work on researching the initial concepts behind these various strands of technology began shortly after nuclear fission was discovered, it was the light-water

[3] Pistner, C., et al. (2024), "Analyse und Bewertung des Entwicklungsstands, der Sicherheit und des regulatorischen Rahmens für sogenannte neuartige Reaktorkonzepte", BASE.
[4] Generation IV International Forum (2002), "A Technology Roadmap for Generation IV Nuclear Energy Systems", gen-4.org/gif/upload/docs/application/pdf/2013-09/genivroadmap2002.pdf.
[5] Generation IV International Forum (2022), "Annual Report 2021", gen-4.org/gif/jcms/c_203440/gif-2021-ar.
[6] Generation IV International Forum (2014), "Technology Roadmap Update for Generation IV Nuclear Energy Systems", gen-4.org/gif/jcms/c_60729/technology-roadmap-update-2013.
[7] Generation IV International Forum (2002), "A Technology Roadmap for Generation IV Nuclear Energy Systems", gen-4.org/gif/upload/docs/application/pdf/2013-09/genivroadmap2002.pdf.
[8] "Fast" relates to the dominant neutron spectrum inside the reactor (in contrast to "thermal").

reactors that came to dominate the industry. To date, none of the Generation IV technologies listed above have been able to establish themselves on the market in a competitive way.[9]

Practical experience with Generation IV

Some 14 experimental and demonstration reactors that can be classified as Generation IV based on the technology used were put into operation around the world (in Germany, France, the US, the USSR, Japan, and the UK) between the 1950s and 2010. All of them have since been shut down and have been or are being decommissioned.[10]

By early 2024, there were three commercially operated reactors that can be classified as Generation IV based on the technology that they use. All three (two in Russia, one in China – built by Russia) are sodium-cooled fast reactors from the Soviet-era BN series. However, they do not uphold any or all of the four goals of Generation IV. As of 2024, there are also six demonstration reactors being operated for research purposes – four in China, one in India, and one in Russia – with a further prototype currently under construction in Russia.[11, 12, 13]

The claim versus the reality

In no way can the key goals that Generation IV defines – safety, sustainability (reduced waste production), economic competitiveness, and proliferation resistance – be said to have been upheld based on experience to date.

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[9] Pistner, C., et al. (2024), "Analyse und Bewertung des Entwicklungsstands, der Sicherheit und des regulatorischen Rahmens für sogenannte neuartige Reaktorkonzepte", BASE.
[10] Pistner, C., et al. (2024), "Analyse und Bewertung des Entwicklungsstands, der Sicherheit und des regulatorischen Rahmens für sogenannte neuartige Reaktorkonzepte", BASE.
[11] IAEA (2024), "Advanced Reactor Information System (ARIS)", aris.iaea.org/sites/overview.html.
[12] IAEA (2024), "Power Reactor Information Service", pris.iaea.org/PRIS/home.aspx.
[13] IAEA (2024), "Research Reactor Database", nucleus.iaea.org/rrdb/#/home.

Below are a number of generic points by way of example:

- Not enough data and information is available to make a conclusive assessment of reactor safety. The much-cited argument that severe accidents that can happen in light-water reactors are practically excluded in Generation IV reactors is misleading, because the design and characteristics of the various strands of Generation IV technology cause them to have different accident sequences to light-water reactors. Whilst Generation IV plants are held to offer certain safety benefits, they also have a number of drawbacks compared to standard Generation II and III/III+ light-water reactors.[14, 15, 16]
- The goal to deliver sustainability relates mostly to making use of a higher proportion of uranium and/or to the “closed fuel cycle”, which relies on using more plutonium and on reprocessing the fuel. Plutonium also plays a role in building nuclear weapons and thus poses a challenge from a non-proliferation perspective.[17]
- As things stand, Generation IV-type reactors are most definitely a subject for research and development and are not yet ready to generate electricity and heat on a commercial scale. Past experience in building and running different Generation IV plants shows that putting these concepts into practice poses numerous technical challenges and problems, some of which remain unresolved. Whether Generation IV-type reactors will ever be able to hold their own or be commercially competitive on the market remains to be seen.[18]

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[14] Pistner, C., et al. (2024), “Analyse und Bewertung des Entwicklungsstands, der Sicherheit und des regulatorischen Rahmens für sogenannte neuartige Reaktorkonzepte”, BASE.
[15] IRSN (2012), “Overview of Generation IV Reactor Designs, Safety and Radiological Protection Considerations”.
[16] Bertrand, F., et al. (2021) “Simplified criteria for a comparison of the accidental behaviour of Gen IV nuclear reactors and of PWRS”, “Nuclear Engineering and Design Volume 372”, February 2021, 110962.
[17] Pistner, C., et al. (2024), “Analyse und Bewertung des Entwicklungsstands, der Sicherheit und des regulatorischen Rahmens für sogenannte neuartige Reaktorkonzepte”, BASE.
[18] Pistner, C., et al. (2024), “Analyse und Bewertung des Entwicklungsstands, der Sicherheit und des regulatorischen Rahmens für sogenannte neuartige Reaktorkonzepte”, BASE.