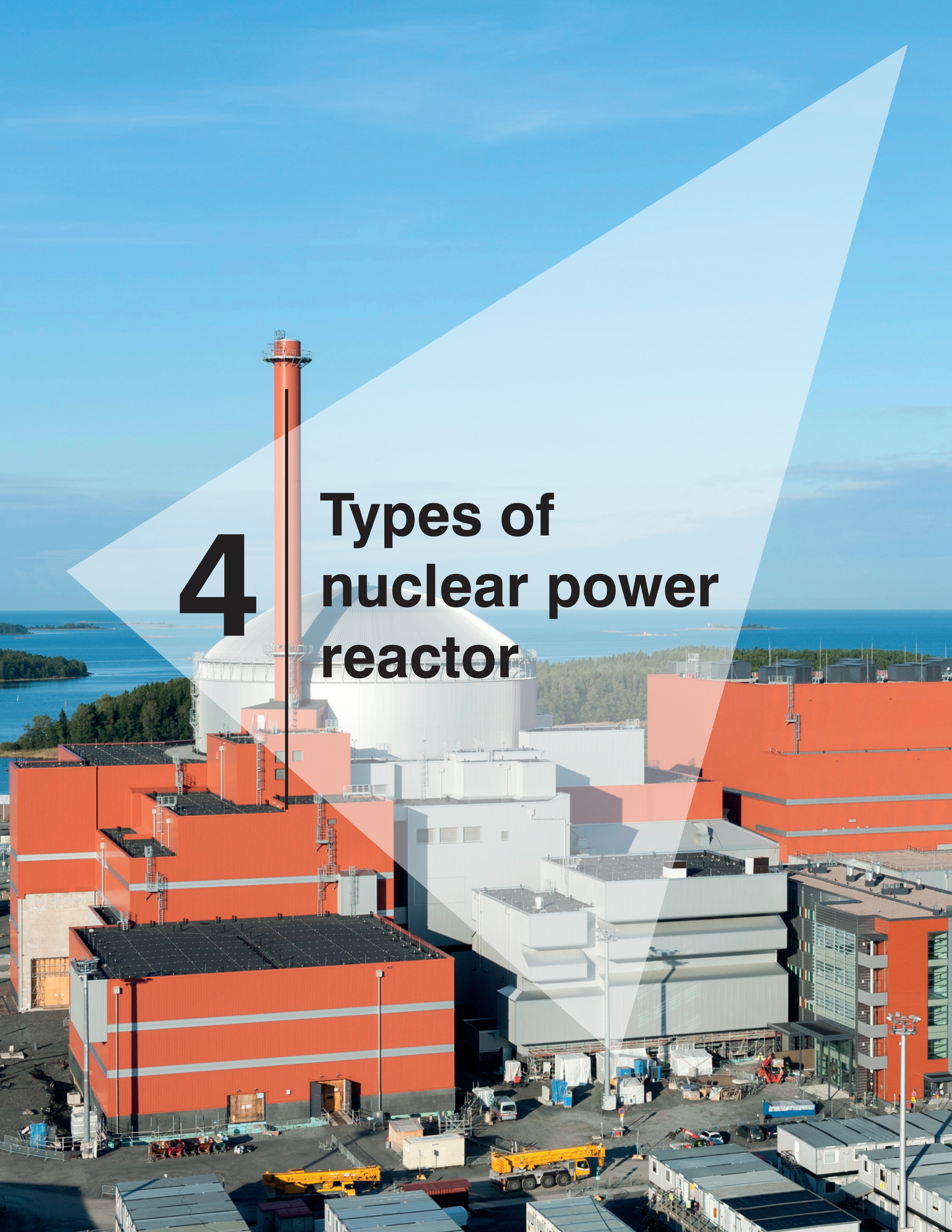


4

Types of nuclear power reactor

4.1 | Today's power reactors

The first generation of nuclear reactors was developed in the 1950s-'60s and none of them are still running. The next generation of power reactors is typified by the present US fleet and throughout Europe, as well as most of those in operation elsewhere. Nearly all of the approximately 450 nuclear power reactors currently operable around the world are second-generation designs, which have proved to be safe and reliable, but they are being superseded by more advanced designs.

4.2 | Advanced power reactors

The first few advanced reactors which are a distinct step forward from most of the 400+ operating today have been operating in Japan and South Korea, and others are under construction or ready to be ordered. These are sometimes called Generation III types, and are improved versions of those which have delivered power for half a century, though there is no clear consensus on the exact generational transition point. Generation IV designs are still on the drawing board and are not likely to be commercialised before the 2030s.

Reactor suppliers in North America, Japan, South Korea, Europe, Russia and elsewhere have several new nuclear reactor designs either approved or at advanced stages of planning, and others at a research and development stage. These incorporate safety improvements and should also be simpler to build, operate, inspect and maintain, thus increasing their overall reliability and economy.

In general, the new generation of reactors have the following characteristics:

- Greater standardisation of design for each type to expedite licensing, reduce capital cost and reduce construction time.
- A simpler and more rugged design, making them easier to operate and less vulnerable to operational issues.
- Higher availability and longer operating lifetimes – typically 60 years, as against 40 or so for earlier designs (though extendable with capital investment).
- Reduced possibility of accidents in which the reactor's core melts, particularly through coping with decay heat following shutdown (the essential problem at Fukushima).
- Resistance of the structure to the serious damage that would allow radiological release from an aircraft impact.
- Higher burn-up of fuel, to use it more fully and efficiently and to reduce the amount of radioactive waste created.

The greatest change from most designs now operating is that many new nuclear plants will rely more on 'passive' safety features such as gravity and natural convection, requiring no active controls or operational intervention to avoid accidents in the event of malfunction. They will allow operators more time to remedy problems, and provide greater assurance regarding containment of radioactivity in all circumstances.

Table 8. Nuclear power plants commercially operable

Reactor type	Main countries	Number	Capacity (GWe)	Fuel	Coolant	Moderator
Pressurised water reactor (PWR)	USA, France, Japan, Russia, China	290	273	Enriched UO_2	Light water	Light water
Boiling water reactor (BWR)	USA, Japan, Sweden	78	75	Enriched UO_2	Light water	Light water
Pressurised heavy water reactor (PHWR)	Canada, India	49	25	Natural UO_2	Heavy water	Heavy water
Gas-cooled/advanced gas-cooled reactor (GCR/AGR)	UK	14	7.7	Natural U (metal), enriched UO_2	Carbon dioxide	Graphite
Light water graphite reactor (RBMK & EGP)	Russia	11+4	10.2	Enriched UO_2	Light water	Graphite
Fast neutron reactor (FNR)	Russia	3	1.4	PuO_2 and UO_2	Liquid sodium	None
	TOTAL	449	392			

Source: IAEA

A separate line of development epitomising this is of small high-temperature reactors with fuel capable of withstanding very high temperatures, and cooled by helium. These are put forward as intrinsically safe, in that no emergency cooling system is needed, and in the event of a problem the units can be left unattended. Being relatively small, the high surface to volume ratio of the fuel enables dissipation of heat naturally (see also Section 4.5).

Certification of designs is on a national basis, and is safety-based. In Europe, and to some extent more widely, there are moves towards harmonised requirements for licensing reactor designs, and the Fukushima accident has sharpened the focus on this need. In the USA there is a design certification process which has approved five advanced reactor designs and is processing more.

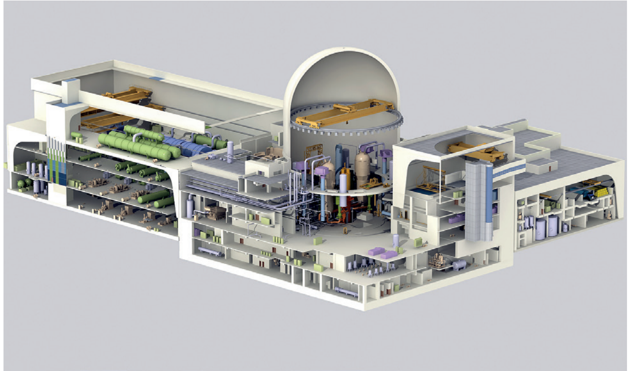
These US Nuclear Regulatory Commission (NRC) approvals mean that as a result of an exhaustive public process, safety issues within the scope of the certified designs have been fully resolved and hence will not be open to legal challenge during licensing for particular plants. Furthermore, utilities are able to obtain a single NRC licence to both construct and operate a reactor in the USA before construction begins.

Table 9. Main new-generation reactors

GE Hitachi/Toshiba ABWR	1350 MWe – operating, Japan, planned UK
KHNP APR1400	1450 MWe – operating, South Korea, building there and UAE
Gidropress AES-2006	1200 MWe – operating, Russia, building there, Belarus and Bangladesh
Westinghouse AP1000	1200 MWe – building, USA, China, planned China, UK
Framatome EPR	1700 MWe – building, Finland, France, China, UK
China Hualong One	1150 MWe – building, China & Pakistan, planned UK
Mitsubishi APWR	1500 MWe – planned, Japan
GE Hitachi ESBWR	1600 MWe – licensed, USA
Candu EC6	750 MWe – licensed, Canada
CNEC HTR-PM	2 x 105 MWe – building, China

ABWR

The first new-generation design, approved in 1997, was the 1350 MWe advanced boiling water reactor (ABWR), examples of which are in commercial operation in Japan, with more under construction there and in Taiwan. More are planned for the UK, and two were proposed for South Texas, USA. It has been marketed by both Toshiba and GE Hitachi.



APR1400 (KEPCO)

APR1400

In South Korea, the APR1400 advanced PWR design has evolved from US origins. Korean design certification was awarded in 2003, and the first of these 1450 MWe reactors is operating at Shin-Kori, with a total of six planned at two sites. Four are under construction in the United Arab Emirates, with the first one due online in 2018.

VVER-1200

From Russia, Gidropress late models of the well-proven VVER-1000 units with enhanced safety have been built in China and India. Developed from these is a new-generation VVER-1200 reactor (in AES-2006 plants) with a longer operational lifetime, more power and greater efficiency. The lead unit is operating at Novovoronezh II with others under construction at Leningrad II, in Belarus and Bangladesh. Others are planned for Hungary, Finland, Turkey and Egypt.

AP1000

In 2005, the NRC gave design certification to the 1100 MWe Westinghouse AP1000, which was the first late third-generation design. It is capable of running on a full mixed oxide fuel (MOX) core if required, and its modular design potentially reduces construction time. The first ones are under construction at Sanmen and Haiyang in China, where many more are planned (as CAP1000). Two are being built in the USA to come online from 2021. China is developing the CAP1400 based on it.

EPR

Framatome (formerly Areva NP) has developed the large (1600 and up to 1750 MWe) European Pressurized Water Reactor (EPR), which is the new standard design for France and received French design approval in 2004. It has the capability to operate flexibly to follow loads, and is capable of using a full core load of MOX. The first EPR units are being built at Olkiluoto in Finland, at Flamanville in France, and two at Taishan in China. Several are planned for the UK. A simpler version is planned for multiple replacement units in France.

APWR

Mitsubishi's large 1600 MWe APWR – advanced PWR – was developed in collaboration with four utilities and the first two are planned for Tsuruga in Japan. It is expected to be the basis for the next generation of Japanese PWRs.

ESBWR

GE Hitachi has developed the ESBWR of 1550 MWe with passive safety systems, from its ABWR design. It received US design certification in 2014 and is proposed for construction in the USA.

Hualong One

This is the first Chinese design based on French predecessors and able to be sold worldwide as the HPR-1000. The first 1150 MWe units are being built in China and Pakistan. The design has been submitted for certification of compliance with European standards.

Atmea1

The Atmea joint venture was established by Framatome (formerly Areva NP) and Mitsubishi Heavy Industries to produce an evolutionary 1150 MWe reactor with 60-year operating lifetime, and the capacity to use mixed-oxide fuel only. It has load-following capability. The French regulator approved the general design in 2012. It will be marketed primarily to countries embarking upon nuclear power programs.

EC6

The Canadian Enhanced CANDU-6 (EC6) is a development of earlier CANDU reactors with power increased to 750 MWe gross and flexible fuel options, plus a 60-year plant operating lifetime (with mid-life pressure tube replacement). This is under consideration for new build in Ontario and Argentina.

4.3 | Floating nuclear power plants

Russia's floating nuclear power plant concept employs a pair of pressurised water reactors similar to those used in icebreakers. China's has one reactor per vessel.

The first of these floating nuclear power plants is under construction in the Baltic shipyard at St Petersburg. The *Akademik Lomonosov* will be located near Vilyuchinsk, in Russia's far east, from about 2019. The two KLT-40S reactors well proven in icebreakers and now using low-enriched fuel (less than 20% U-235) are from OKBM Afrikantov and are mounted on a 21,500 tonne barge. Each reactor has a capacity of 150 MW thermal, or about 35 MWe as well as up to 35 MW of heat for desalination or district heating. The refuelling interval is 3-4 years onsite, and at the end of a 12-year operating cycle the whole plant will be returned to a shipyard for a two-year overhaul and storage of used fuel, before being returned to service.

China General Nuclear Group (CGN) has a floating nuclear power plant under construction at the Bohai shipyard, with a single ACPR50s reactor. This is 200 MW thermal, or 60 MWe, and will supply both power and heat. The Nuclear Power Institute of China (NPIC), under China National Nuclear Corporation (CNNC), has designed a multi-purpose small modular reactor for marine use, the ACP100s. Its 310 MW thermal produces about 100 MWe.

4.4 | Small light water reactors

Some of the following are small modular reactors (SMRs), generally 300 MWe or less, designed to be built in factories, shipped to the site and usually installed below ground level. They pursue economies of series production and are intended to be set up as independent components of a power plant which has several of them operating together. They may also be stand-alone units, for either power or heat. (Modular construction refers to large elements of a power plant being prefabricated and then assembled onsite.) Some of these have integral steam generators (*i.e.* inside the pressure vessel). None is yet operating. Licensing reactor designs is very costly and for small organisations it represents a major hurdle. In most cases construction is delayed pending licensing and financing.

Table 10. Some small reactors

Type	Capacity MWe	Source	Comments
CNP-300	300	China	One operating in China and four in Pakistan
KLT-40S	35	Russia	Under construction for floating nuclear power plant
CAREM-25	27	Argentina	Under construction
HTR-PM	210 (two reactors)	China	Under construction
ACPR50S	60	China	Under construction for floating nuclear power plant
ACP100	100	China	Planned
NuScale SMR	50	USA	Planned
Holtec SMR-160	160	USA	Planned
SVBR-100	100	Russia	Planned
PRISM	311	USA	Planned