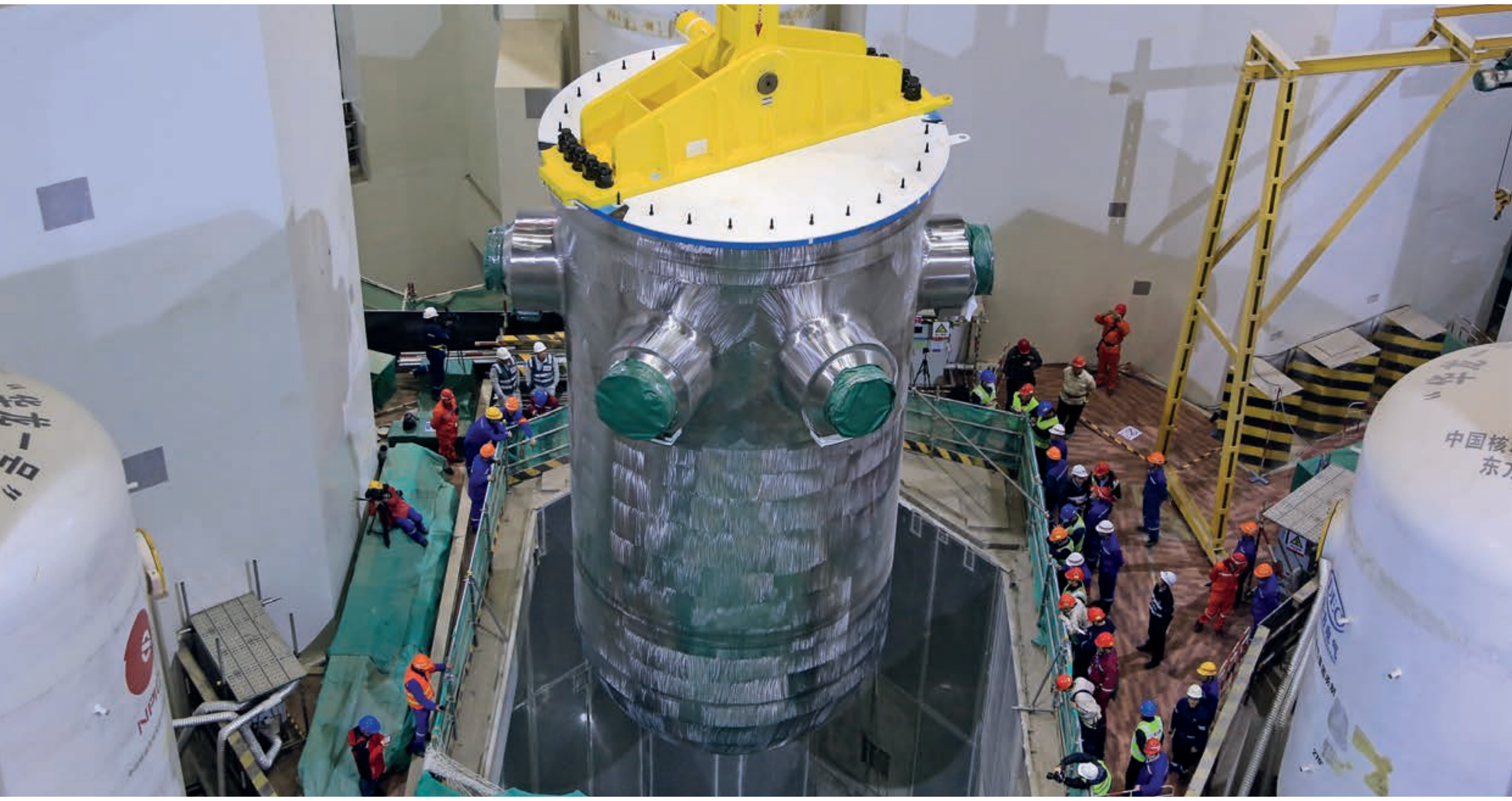
WORLD NUCLEAR ASSOCIATION



World Nuclear Performance Report 2018

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Preface

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The world's nuclear reactors performed excellently in 2017. Global nuclear electricity output was 2506 TWh, an increase of 29 TWh compared to 2016. This marked the fifth successive year that nuclear output has increased, with generation 160 TWh higher than in 2012.

At the end of 2017 the global nuclear capacity of the 448 operable reactors stood at 392 GWe, up 2 GWe on the end of 2016 total. Four new reactors were connected to the grid, with a combined capacity of 3373 MWe. Five reactors were shut down, with a combined capacity of 3025 MWe. However two of those reactors, Monju and Santa Maria de Garoña, had not generated for some years previously.

The number of reactors under construction at the end of 2017 was 59. The median average construction time for the four reactors grid connected last year was 58 months. In addition to the four grid connections, there were four construction starts and two construction projects halted. Both 2015 and 2016 had more grid connections, with ten each, and we have already had more grid connections in 2018 than in the whole of 2017.

The capacity factor for the global fleet stood at 81%, maintaining the high availability of around 80% that has been maintained since 2000, up from the 60% average capacity factor at the start of the 1980s.

In Asia, construction started on the first nuclear power reactor to be built in Bangladesh. Nuclear generation was boosted by the return to service of the fifth Japanese reactor, with further restarts taking place in 2018. In South Korea, a public vote lead to the resumption of construction of Shin-Kori 5. Construction was completed on the first unit at Barakah, in the United Arab Emirates (UAE).

In Canada, plans are progressing to support the development of small modular reactor (SMR) technology, as well as to ensure the continued operation of its existing Candu reactors. In the US, construction was halted on the two VC Summer reactors. Agreement was reached on the completion of the two sister reactors at Vogtle, and construction since this agreement is progressing well. However, market conditions are proving challenging, resulting in announcements of planned closures of some reactors. In some states, measures have been introduced to correct those market distortions to support the continued operation of nuclear plants as they are providing reliable and clean electricity.

Turkey has become the latest country to start a new build programme. Construction on-site at Akkuyu formally started in December 2017, with construction of the first reactor starting in April 2018.

With construction on more than 25 reactors scheduled to be completed in 2018 and 2019 strong progress is being made. New reactor projects are needed to maintain and accelerate global nuclear build so that nuclear generation can meet the Harmony goal of supplying 25% of the world's global electricity by 2050.

1 Recent Industry Highlights

A number of factors – both internal and external – are combining to create profound challenges for nuclear power in some of its most mature markets. Despite this, the need for the reliable, predictable and clean electricity provided by nuclear has never been greater, and that is reflected in the growing number of new build programmes underway in several parts of the world. Of the 448 reactors that were operable at the end of 2017, over half were in the USA and Europe where, despite the importance of nuclear, reactor retirements continue to outpace capacity additions.

Asia

At the beginning of 2018, China had 38 operable nuclear reactors, representing about 9% of the world's nuclear capacity. The country continues to dominate the new-build market, accounting for three of the four grid connections in 2017, and 18 of the 59 reactors under construction at the start of 2018. During 2017, reactors were connected to the grid at Yangjiang, Fuqing and Tianwan, adding 3 GWe of capacity.

In April 2018, the Chinese regulator granted permission for fuel to be loaded into both Sanmen 1, an AP1000 unit, and Taishan 1, one of two EPRs under construction in China. Both reactors achieved first criticality in June 2018. Sanmen 1 and Taishan 1 became the first of their respective designs to enter commercial operation worldwide. A total of six reactors are expected to be brought online in China in 2018, with construction of a further six-to-eight to commence.

China's continued innovation in nuclear science was evident in 2017 through advancements in its fast neutron reactor (FNR) and high-temperature gas-cooled reactor (HTR) programmes. In December, China National Nuclear Corporation (CNNC) commenced construction of its demonstration CFR600 fast reactor at Xiapu. CNNC expects the FNR technology to predominate in China by mid-century, enabling the country to close the nuclear fuel cycle. In April 2018, loading of the moderator elements took place at China's Shidaowan demonstration HTR-PM (HTR Pebble-bed Modular, a twin-reactor unit (2x250MWt with pebble bed fuel and helium coolant driving a single 210 MWe steam turbine.

The growing strength of China's domestic nuclear industry is supporting active promotion of its technology and services overseas. In May 2017, China signed a contract for the construction of two reactors (one Candu and one Hualong One) in Argentina, and in November, a cooperation agreement was signed with Pakistan for a Hualong One unit at the Chashma nuclear plant. In addition, over the course of 2017, China signed cooperation agreements with France, Kenya, Thailand, Uganda, Saudi Arabia, Brazil, Cambodia and Vietnam.

In July 2017 the fourth unit was connected at the Chashma nuclear power plant in Pakistan. The reactor, a 313 MWe CNP-300 unit, is the fourth Chinese-supplied reactor to enter operation at the Chashma site.

At the end of 2016, just three of Japan's operable reactors were online; by June 2018, a further six reactors had restarted, and applications for the restart of 19 more reactors were being assessed. The Japan Institute of Energy Economics expects a total of 10 nuclear power reactors to have restarted by March 2019, stating that the restarts "improve the country's economy, energy security and environment." The rate of restarts has so far been heavily influenced by judicial rulings and local consent.

In South Korea, President Moon Jae-in, elected in May 2017, made an election pledge to phase out the country's use of nuclear energy. Following his issuance of an administrative order to halt construction of units 5&6 at Shin Kori, Korea Hydro & Nuclear Power took the decision to halt construction. However in October 2017, a government-convened citizens' jury voted 59.5% in favour of completing the units. President Moon accepted the decision, but has said that no more new plants will be built. South Korea currently generates about one-third of its electricity from 24 nuclear power reactors.

South Korea's export business continues to grow, with the APR1400 design gaining European Utility Requirements (EUR) approval in October 2017. The country has signed multiple cooperation agreements with the UAE, where it is constructing four APR1400 reactors. The agreements cover reactor operations, nuclear fuel and overseas business development. In addition, the UAE has agreed to work with South Korea in its efforts to win orders for the construction of units in Saudi Arabia.

The Russian-built second unit of India's Kudankulam power plant entered commercial operation in April 2017. In the same month, responsibility for unit 1 was formerly transferred from Russia's ASE Group to the Nuclear Power Corporation of India Limited (NPCIL). Following the completion of the first phase of the Kudankulam project, construction of the second, comprising units 3&4, officially began in June 2017. Earlier in the year, a framework agreement was signed between the two countries on the construction of the third stage, units 5&6.

At the beginning of 2018, India had seven reactors under construction, with a combined capacity of 4.8 GWe, including the country's indigenously designed 700 MWe units. The country retains plans to significantly expand its nuclear power sector: in May 2017, the prime minister approved the construction of ten PHWRs; and in March 2018, France's EDF and NPCIL signed an agreement setting out the framework for the construction of six EPRs.

Europe (East) & Russia

Rostov 4 and Leningrad II-1 were connected to the grid in February and March 2018. The two units were the first to be connected in Russia since Novovoronezh II-1 in August 2016. In May 2018, Russia marked a significant milestone in the completion of construction of its first floating nuclear power plant, *Academik Lomonosov*, with the power ship leaving Saint Petersburg to be towed to Murmansk for fuelling.

The strength of Russia's nuclear industry is reflected in its dominance of export markets for new reactors. The country's national nuclear industry is currently involved in new reactor projects in Bangladesh, Belarus, China, Hungary, India, Iran and Turkey, and to varying degrees as a potential investor in Algeria, Bolivia, Brazil, Congo, Egypt, Indonesia, Jordan, Kazakhstan, Nigeria, Philippines, Saudi Arabia, South Africa, Sri Lanka and Tajikistan.

In Ukraine, ambitious plans are in place to start supplying electricity to the European Union by 2019 via its planned 'energy bridge'. In August 2017, the country's new energy strategy was approved, confirming that nuclear power would continue to provide about 50% of the country's electricity to 2035. In October 2017 Energoatom signed a cooperation agreement with Japan's Toshiba Energy Systems & Solutions for the proposed uprating of its 15 nuclear reactors. A significant number of other European countries are looking to build new nuclear reactors, including Bulgaria, Czech Republic, Hungary, Poland and Romania.

Yangjiang 5 control room (Image: Yangjiang Nuclear Power Co)

Europe (West & Central)

In France, the government has so far retained its policy to reduce nuclear power's relative share of electricity production to 50%, but has reneged on its commitment to do so by 2025. President Emmanuel Macron, in an address to the European Parliament in April 2018, stated that France's energy strategy had one top priority: to reduce emissions. The construction of the Flamanville 3 EPR unit continued through 2017, although further delays to the start-up have since been announced.

The Spanish government denied the renewal of Garoña nuclear power plant's operating licence in August 2017, despite the regulator granting approval for its restart earlier in the year. The plant was the country's oldest and smallest, and had been offline since December 2012. It was formally shutdown in August 2017.

Seven nuclear reactors remain in operation in Germany, and in 2017 they generated about 10% of the country's electricity. Some frequently operate in load-following mode, accommodating the country's push for variable renewable sources and coping with the negative pricing that often results. Germany's greenhouse gas emissions rose in 2016 – although they fell slightly in 2017 – and in January 2018, discussions between German parties involved in forming a coalition government suggested the country's greenhouse gas emissions goal for 2020 would be missed.

In May 2017, Switzerland voted to approve a revision to the country's energy policy that prohibits the construction of new nuclear power plants. The change to the country's energy policy in May 2017 does not impact the country's existing nuclear power reactors. In March 2018, the regulator granted approval to bring unit 1 of Beznau nuclear power plant back into service following a three-year outage, taking the number of operating reactors in the country to five.

Finnish utility Teollisuuden Voima Oyj (TVO) reached an agreement with French Areva and German Siemens in the long-running dispute over cost overruns and delays to the Olkiluoto 3 EPR project. TVO now expects fuel loading in 2019.

Middle East and Africa

Work on the Middle East's first nuclear power plant, Barakah, in the UAE, continued to make good progress during 2017 and into 2018. Construction of unit 1 was officially completed in March 2018, at which point units 2-4 were 80% completed. However, start-up of Unit 1 has been deferred to 2019/2020 to complete operator training and obtain regulatory approvals.

Turkey began construction of its first nuclear reactor in April 2018. It is the first of four VVER-1200 units planned for the Akkuyu nuclear plant.

Saudi Arabia is planning to build its first nuclear power plant and is expected to award a construction contract for a 2800 MWe facility by the end of 2018. The country has solicited information from five vendors from China, France, Russia, South Korea and the USA.

Egypt plans to host four VVER-1200 units at El Dabaa. In December 2017 notices to proceed with contracts for the construction of the nuclear power plant were signed in the presence of President Abdel Fattah El Sisi of Egypt and President Vladimir Putin of Russia.

North America

The number of operable reactors in the USA stood at 99 at the end of 2017, unchanged from a year earlier, but down from a high of 104 in 2012.

The year 2017 was a challenging one for the US nuclear power industry. The combination of sustained low natural gas prices, market liberalization and subsidization of renewables continued to impart significant economic pressure. That, combined with well-documented construction problems, resulted in the two AP1000 units at VC Summer, South Carolina, being halted in July, leaving just two units under construction in the country at Vogtle, Georgia. Entergy announced in January 2018 its agreement to close Indian Point in 2020-2021; Exelon warned in May of premature retirement of Three Mile Island 1; and FirstEnergy announced in March 2018 its intention to deactivate its three units in Ohio and Pennsylvania.

The significance of the challenges faced by the nuclear sector in the USA has had the positive effect of highlighting its unique value to state- and national-level decision-makers. In April 2018, New Jersey established a zero emissions certificate (ZEC) programme that will compensate nuclear power plants for their zero-carbon attributes and contribution to fuel diversity. A similar scheme established in late-2016 in New York enabled Exelon to invest in refuelling and maintenance work at three of the state's nuclear plants (Fitzpatrick, Ginna and Nine Mile Point during 2017).

At national level, the current administration has been vocal in its support of the country's nuclear industry. The US Department of Energy (DOE) has called for market reforms to protect the attributes of resiliency and reliability provided by those technologies able to supply baseload electricity. In addition, the

DOE has provided support to the owners of the Vogtle plant under construction, in the form of loan guarantees.

In Canada, all but one of 19 power reactors are in Ontario. Six of those units – those at the Bruce power station – are to undergo refurbishment, extending operating lifetimes by 30-35 years. In March 2018, the first of the six units to undergo refurbishment, Darlington 2, reached an important milestone with removal of the final calandria tube from the reactor's core. A month earlier, on 15 February, the refurbishment of unit 2 officially passed the halfway mark.

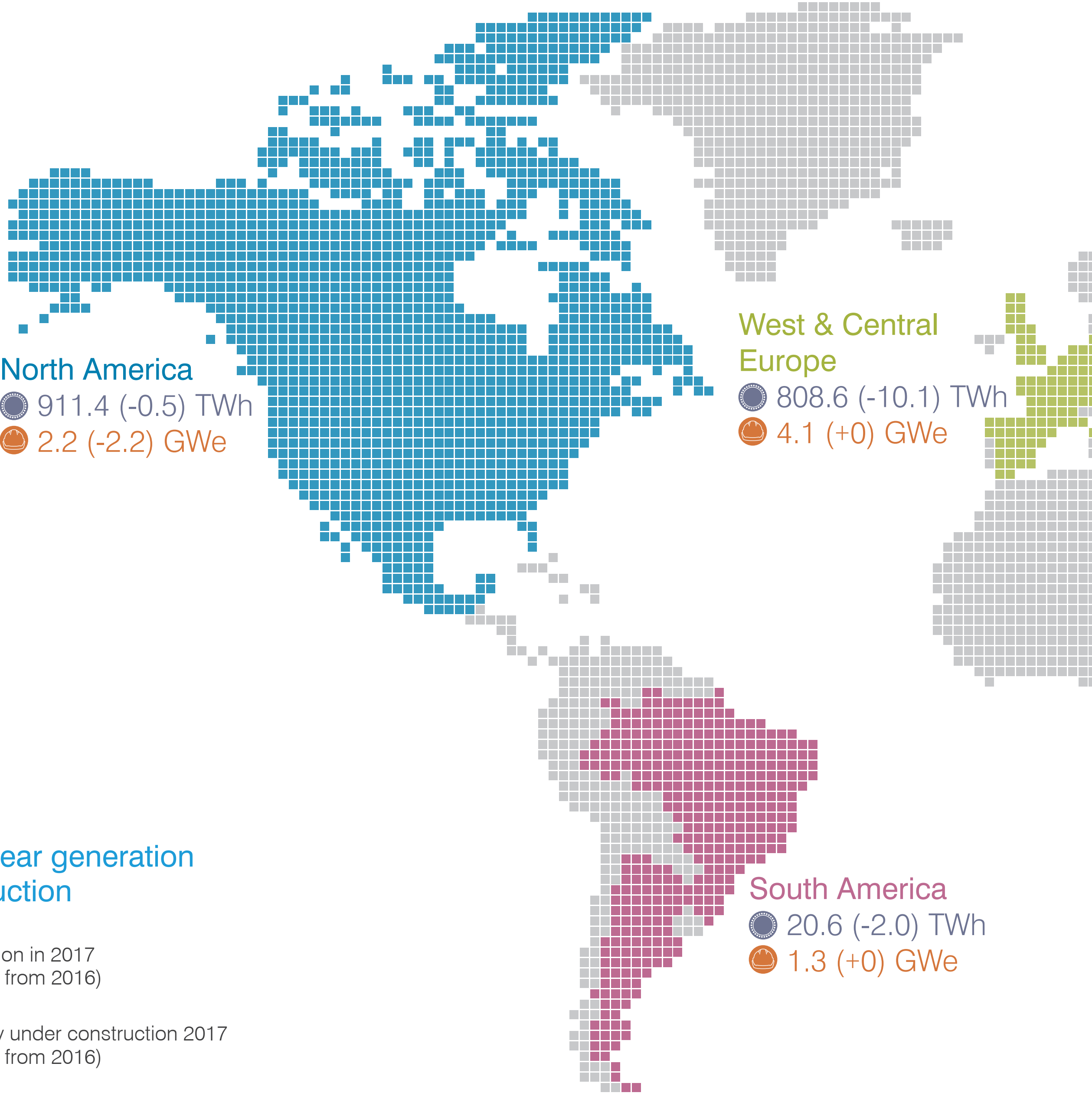
Interest in the on- and off-grid applications of SMR technology in Canada is notable. Early in 2017 Canadian Nuclear Laboratories set a goal of siting an SMR on its Chalk River site by 2026, and in February 2018, Natural Resources Canada launched a process to prepare a roadmap to explore the potential of SMR technologies. At the start of 2018 the Canadian Nuclear Safety Commission was involved in pre-licencing vendor design reviews of ten small reactors.

South America

Argentina signed further agreements with both China and Russia, reaffirming its intention to increase electricity generation from nuclear. In May 2017, a general contract with China for the supply of two reactors – one Candu and one Hualong One –commencing construction in 2018 and 2020, respectively, was signed. In January 2018, a memorandum of understanding was signed with Russia to promote cooperation in uranium mining.

Turkey began construction of its first nuclear reactor in April 2018.

2 | Nuclear Industry Performance



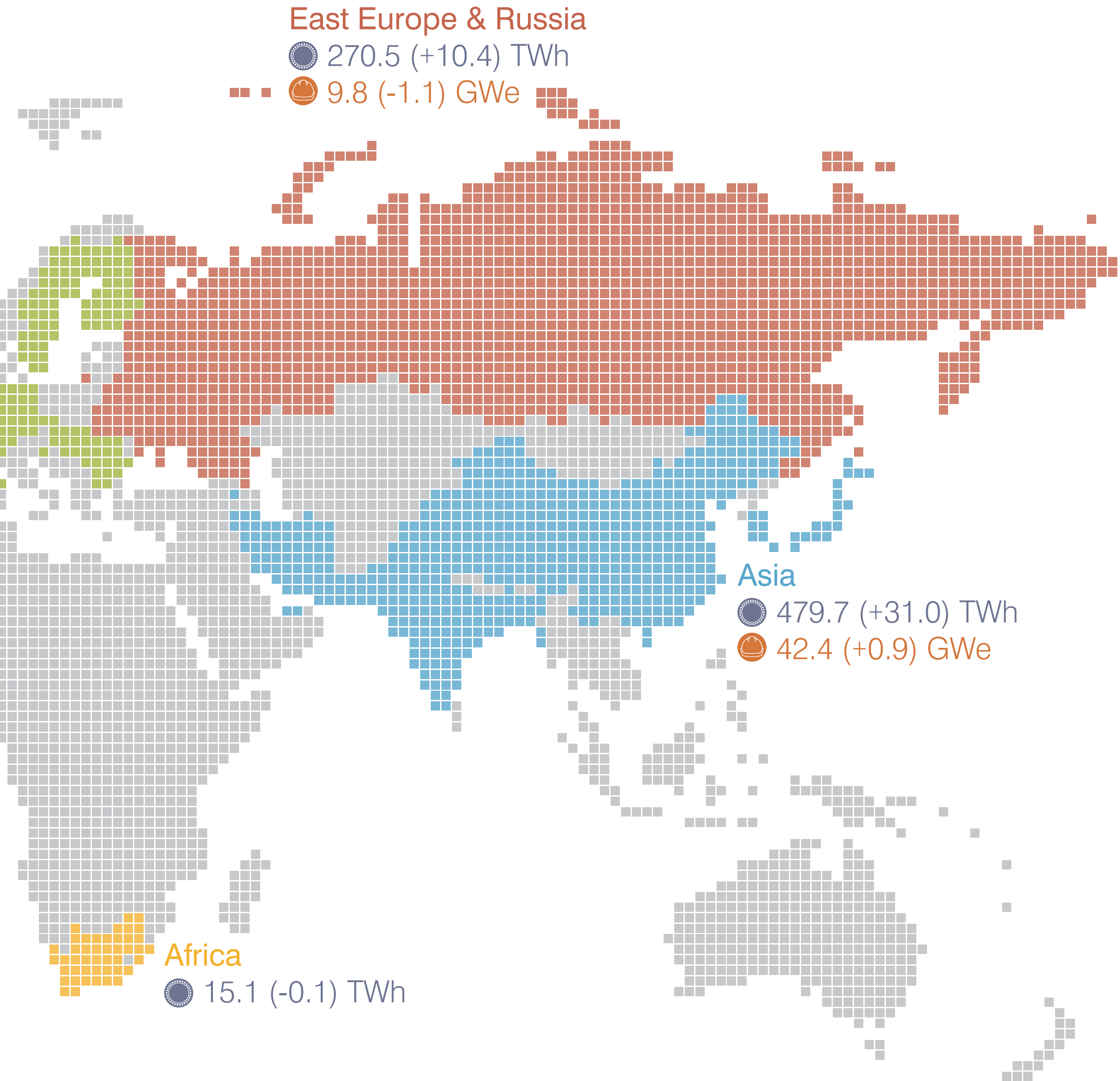
Global nuclear generation and construction

Generation in 2017 (change from 2016)

Capacity under construction 2017 (change from 2016)

Nuclear industry performance indicators 2017

81.1%	2506 TWh	4
Global mean average capacity factor	Electricity generated in 2017	New reactors brought online



2 GWe

Net increase in generation capacity

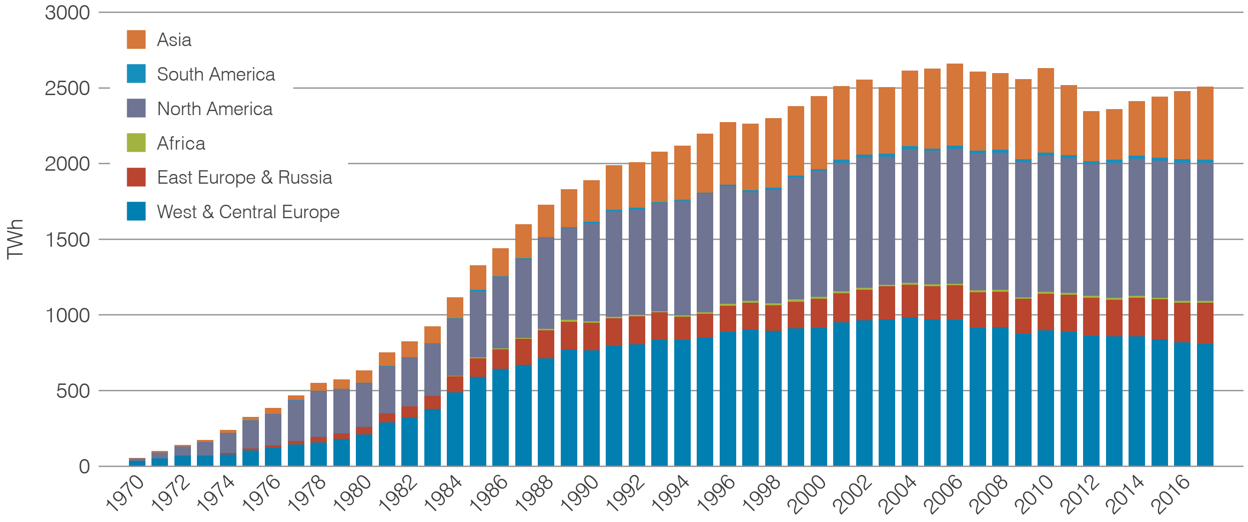
58 months

Median average construction period for new reactors starting in 2017

2.1 Global highlights

Nuclear reactors generated a total of 2506 TWh of electricity in 2017, up from 2477 TWh in 2016. This is the fifth successive year that nuclear generation has risen, with output 160 TWh higher than in 2012.

Figure 1. Nuclear electricity production

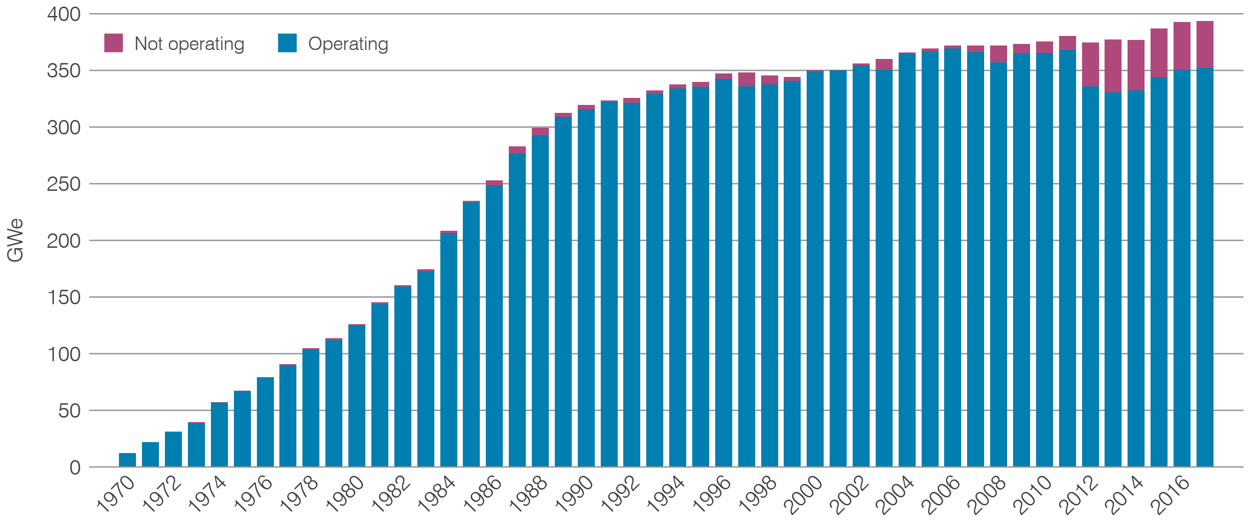


Source: World Nuclear Association and IAEA Power Reactor Information Service (PRIS)

In 2017 the total net capacity of nuclear power in operation was 394 GWe, up from 391 GWe in 2016. These figures are higher than the end of year capacity as they includes those reactors that were closed during each year. The global capacity at the end of 2017 was 392 GWe, up from 390 GW in 2016.

Usually only a small fraction of operable nuclear capacity does not generate electricity in a calendar year. However, since 2011, most of the Japanese reactor fleet has been awaiting restart. Two reactors restarted in 2017 and more are expected in 2018. The net capacity of nuclear plant that generated electricity in 2017 was 352 GWe.

Figure 2. Nuclear generation capacity (net)



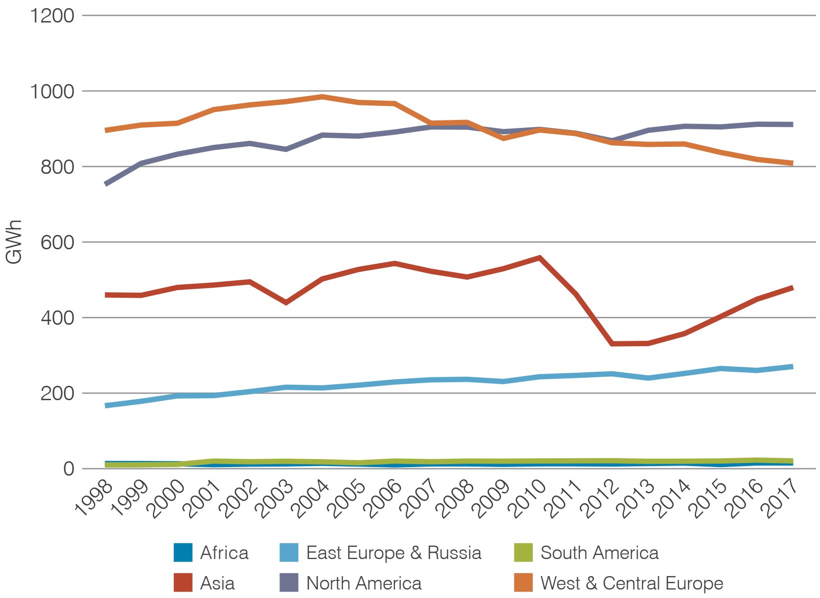
Source: World Nuclear Association, IAEA PRIS

In 2017, nuclear generation rose in Asia and East Europe & Russia. Generation declined in West & Central Europe. These changes continued the trends of recent years.

Generation fell marginally in North America. Generation also declined in South America and Africa, although output in those regions is determined by a relatively small number of reactors and has remained little changed over the past ten years.

Global capacity at the end of 2017 was 392 GWe, up from 390 GWe in 2016.

Figure 3. Regional generation



Source: World Nuclear Association, IAEA PRIS

At the end of 2017 there were a total of 448 operable reactors, up one from the end of year figure for 2016. The PWR continues to be the predominant reactor type in use, with all four reactors connected to the grid and four construction starts being based on PWR technology.

Table 1. Operable nuclear power reactors at year-end 2017

	Africa	Asia	East Europe & Russia	North America	South America	West & Central Europe	Total
BWR		28		36		11 (-2)	75 (-2)
FNR		1	2				3
GCR						14	14
LWGR			15				15
PHWR		25		19	3	2	49
PWR	2	86 (+3)	33	65	2	104	292 (+3)
Total	2	140 (+3)	50	120	5	131 (-2)	448 (+1)

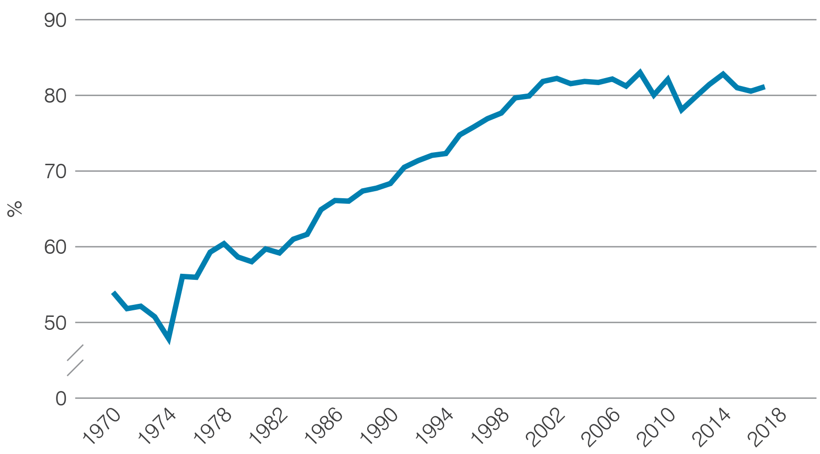
Source: World Nuclear Association, IAEA PRIS

2.2 Operational performance

Capacity factors in this section are based on the performance of those reactors that generated electricity during each calendar year. For reactors that were grid connected or permanently shut down during a calendar year their capacity factor is calculated on the basis of their performance when operational.

In 2017, the global average capacity factor was 81.1%, up from 80.5% for 2016. This maintains the high level of performance seen since 2000 following the substantial improvement seen over the preceding years. In general, a high capacity factor is a reflection of good operation performance. However, there is an increasing trend in some countries for nuclear reactors to operate in a load-following mode.

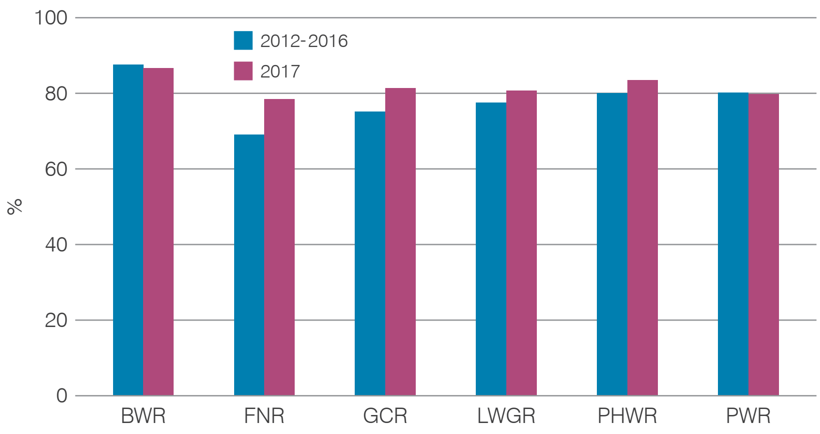
Figure 4. Global average capacity factor



Source: World Nuclear Association, IAEA PRIS

Capacity factors for different types of reactor are broadly consistent with the average achieved in the preceding five years. Greater variation is seen in those reactor types represented by a smaller number of reactors.

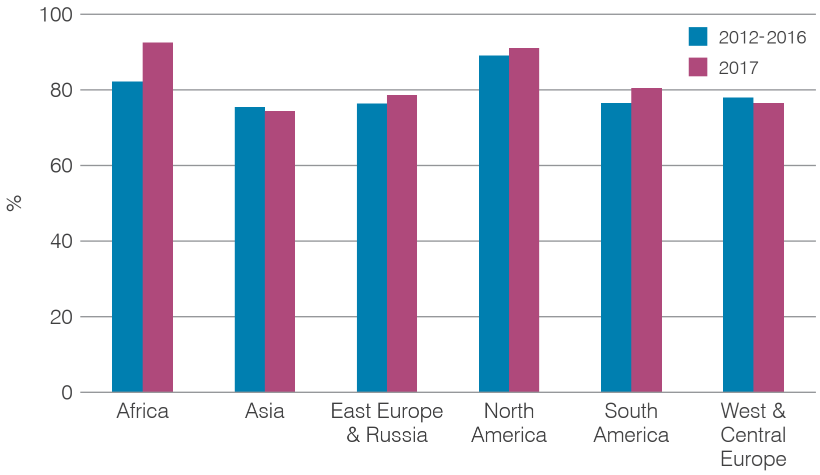
Figure 5. Capacity factor by different reactor type



Source: World Nuclear Association, IAEA PRIS

Capacity factors are also broadly consistent with the average achieved in the preceding five years for reactors in the same regions. The greatest variation is seen in regions represented by a smaller number of reactors.

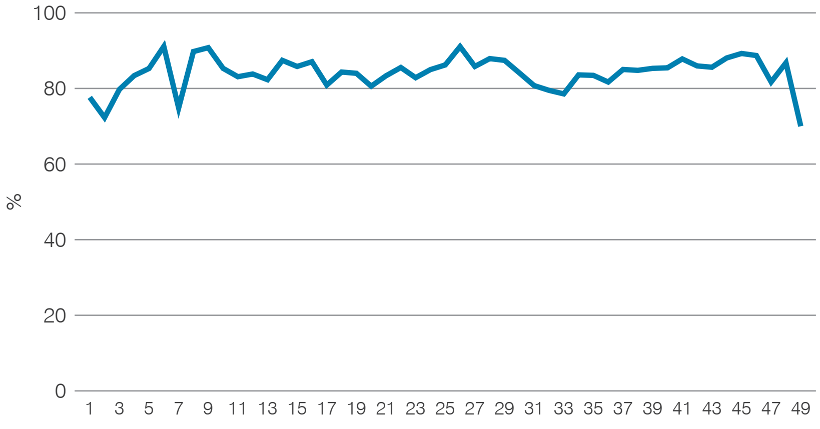
Figure 6. Capacity factor by region



Source: World Nuclear Association, IAEA PRIS

There is no significant age-related trend in nuclear reactor performance. The mean capacity factor for reactors over the last five years shows no significant variation regardless of their age.

Figure 7. Mean capacity factor 2012-2017 by age of reactor

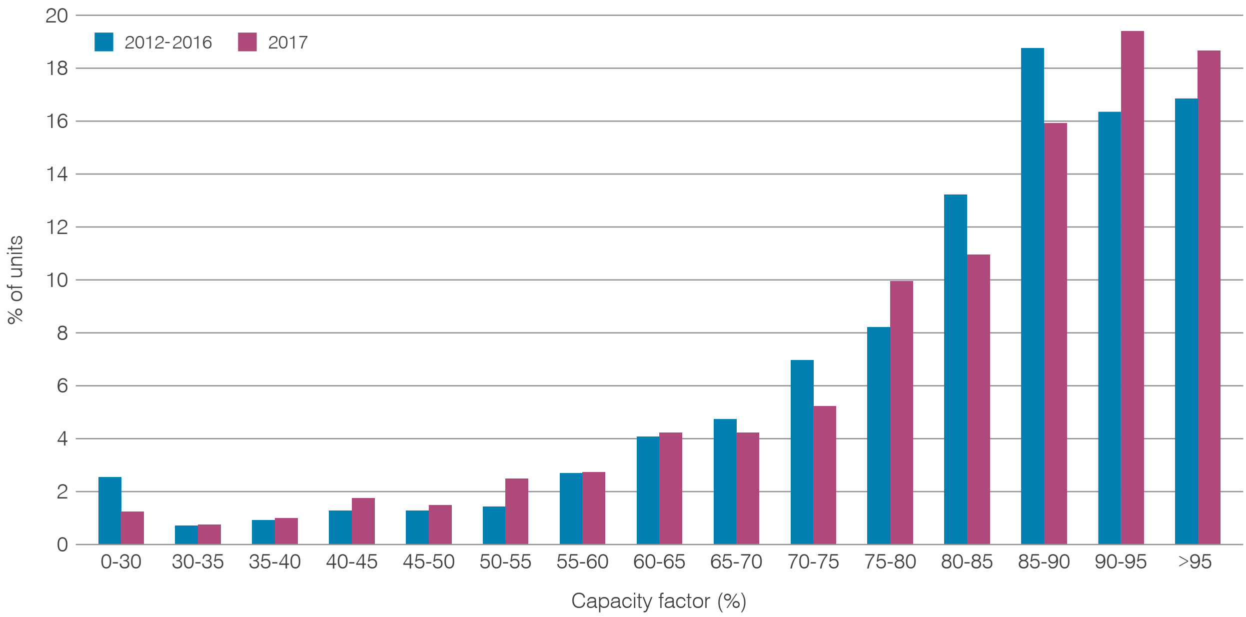


Source: World Nuclear Association, IAEA PRIS

Nuclear reactor performance shows no significant age-related trend.

The global average capacity factor has remained fairly constant over the last 15 years and there has been no significant change to the spread of capacity factors across the fleet either. While the highest capacity factors are usually considered optimal, an increasing number of reactors are operating in a load-following mode, resulting in lower annual capacity factors.

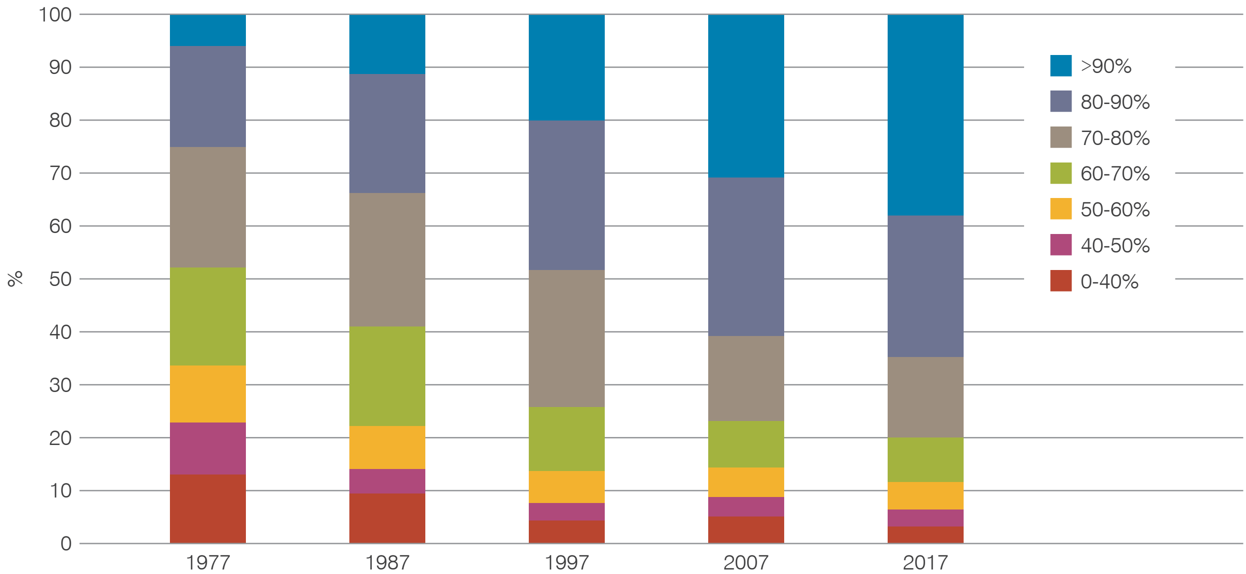
Figure 8. Percentage of units by capacity factor



Source: World Nuclear Association, IAEA PRIS

There has been ongoing improvement in the proportion of reactors reaching higher capacity factors over the last 40 years. For example, 64% of reactors achieved a capacity factor higher than 80% in 2017, compared to 25% in 1977, whereas only 6% of reactors had a capacity factor below 50% in 2017, compared to 23% in 1977.

Figure 9. Long-term trends in capacity factors



Source: World Nuclear Association, IAEA PRIS

Five reactors were shut down in 2017. The reactors in Germany and South Korea closed as a result of the current nuclear policy in those countries. Santa Maria De Garoña, in Spain, and Monju, in Japan, had not been operating for several years and were deemed in long-term shutdown prior to their permanent closure, so the number of reactors generating in 2017 that closed down totalled three.

Table 2. Shut down reactors in 2017

	Country	Capacity (net)	First grid connection	Permanent shutdown	Type of reactor
Gundremmingen B	Germany	1284 MWe	1 December 1966	31 December 2017	BWR
Kori 1	South Korea	576 MWe	26 June 1977	18 June 2017	PWR
Monju	Japan	246 MWe	29 August 1995	5 December 2017	FNR
Oskarsham 1	Germany	473 MWe	19 August 1971	19 June 2017	BWR
Santa Maria De Garoña	Spain	446 MWe	2 March 1971	2 August 2017	BWR

Source: World Nuclear Association, IAEA PRIS

2.3 New construction

With four construction starts, two reactor construction cancellations and four reactors being grid connected, the total number of reactors under construction fell by two to 59 over the course of 2017.

Table 3. Reactors under construction by region year-end 2017 (change since 2016)

	BWR	FNR	HTR	PHWR	PWR	Total
Asia	4	1	1	4	30	40
East Europe & Russia					11	11
North America					2 (-2)	2 (-2)
South America					2	2
West & Central Europe					4	4
Total	4	1	1	4	49 (-2)	59 (-2)

Source: World Nuclear Association, IAEA PRIS

The four construction starts in 2017 are listed in Table 4.

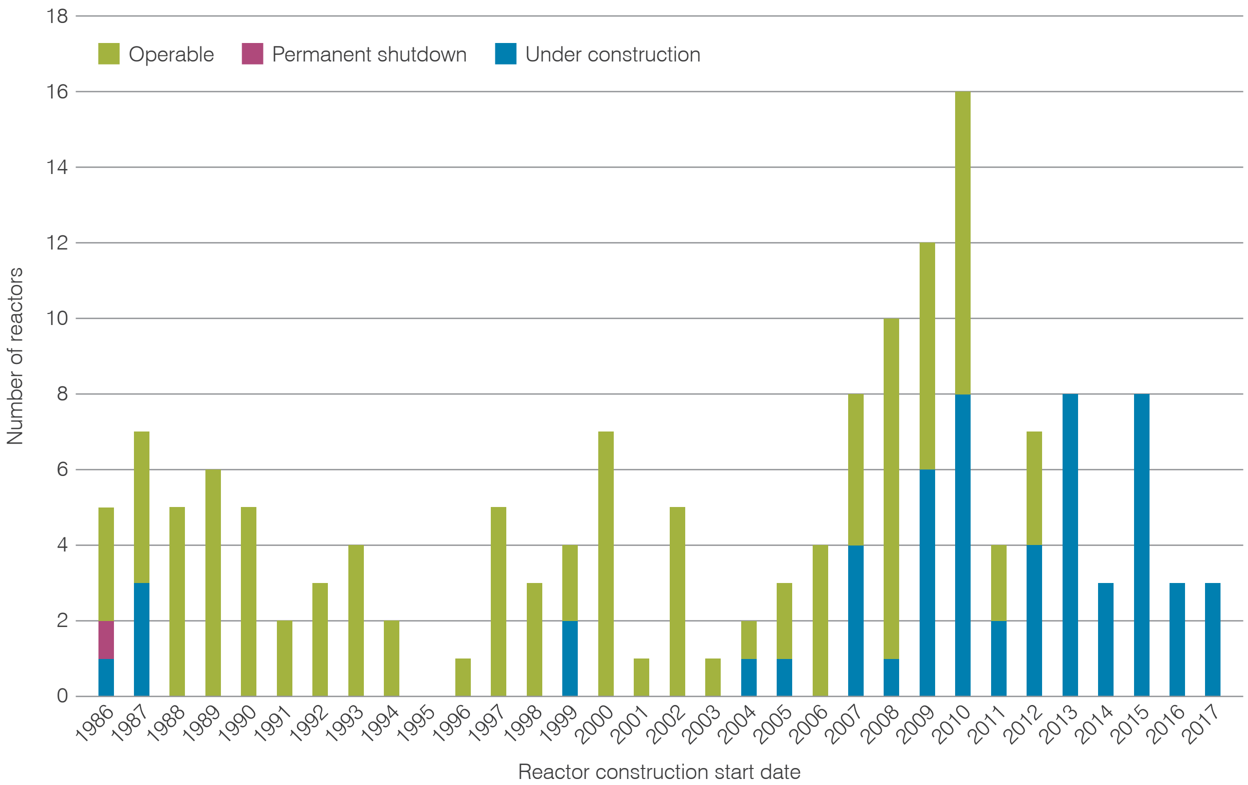
Table 4. Reactor construction starts 2017

Reactor	Country	Capacity (MWe)	Start of construction	Type of reactor
Kudankulam 3	India	917	29 June 2017	PWR (VVER)
Kudankulam 4	India	917	23 October 2017	PWR (VVER)
Rooppur 1	Bangladesh	1080	30 November 2017	PWR (VVER)
Shin-Kori 5	South Korea	1340	1 April 2017	PWR

Source: World Nuclear Association, IAEA PRIS

Most reactors currently under construction started construction within the last ten years. A small number of reactors have been formally under construction for a longer period. For example, Mochovce 3&4 in Slovakia started construction in 1987, but work was suspended in 1991. The project was restarted in 2008 and is expected to be completed before 2020. The shutdown reactor in Figure 10 that started construction in 1986 is the Japanese Monju FNR, which closed in 2017.

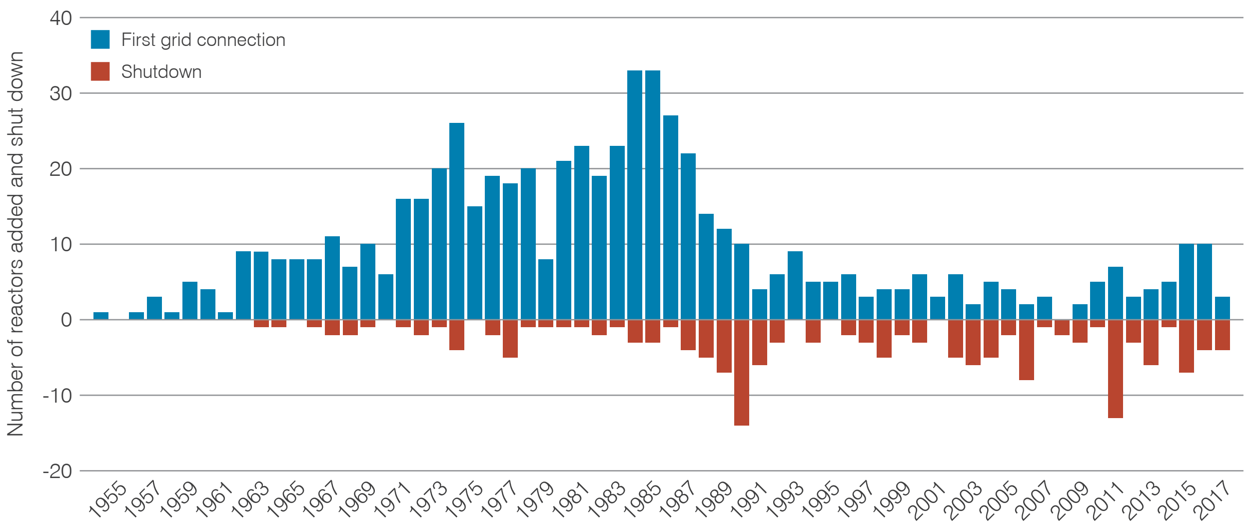
Figure 10. Operational status of reactors with construction starts after 1985



Source: World Nuclear Association, IAEA PRIS

In 2017 four reactors were grid connected and five were permanently shut down, although two of these were previously in long-term shutdown.

Figure 11. Reactor grid connection and shutdown 1954-2016



Source: World Nuclear Association, IAEA PRIS

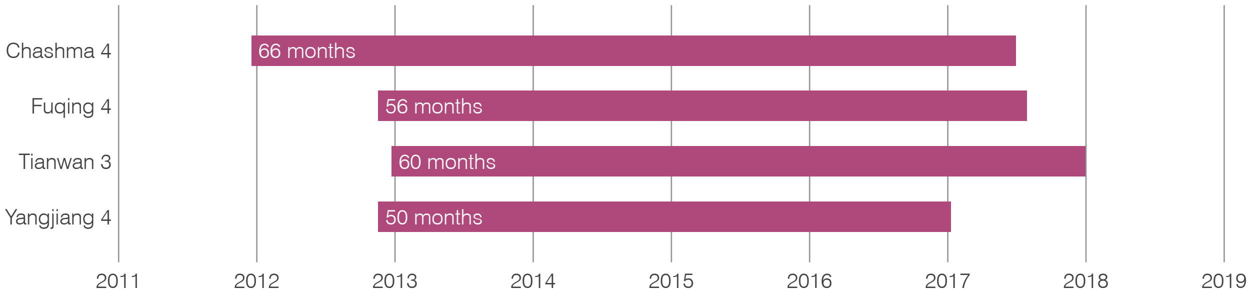
Table 5. Reactor grid connections in 2017

Reactor	Country	Capacity (net)	Construction start	Grid connection	Type of reactor
Chashma 4	India	313 MWe	18 December 2011	1 July 2017	PWR
Fuqing 4	China	1000 MWe	17 November 2012	29 July 2017	PWR
Tianwan 3	China	1060 MWe	27 December 2012	30 December 2017	PWR
Yangjiang 4	China	1340 MWe	17 November 2012	8 January 2017	PWR

Source: World Nuclear Association, IAEA PRIS

Three of the four reactors connected to the grid in 2017 were constructed in China, with the other reactor, Chashma unit 4, a reactor supplied by China and constructed and grid connected in Pakistan.

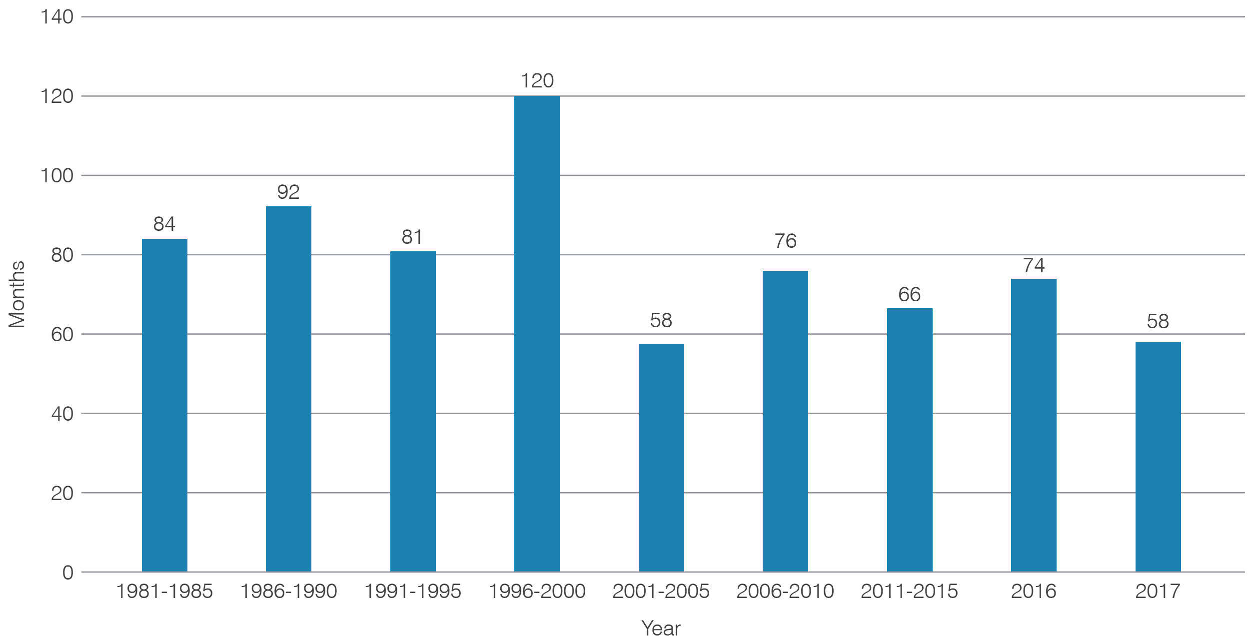
Figure 12. Construction times of new units connected to the grid in 2017



Source: World Nuclear Association, IAEA PRIS

The median construction time was 58 months, down from 74 months in 2016, and equalling the lowest five-year median construction time achieved in 2001-2005.

Figure 13. Median construction times for reactors since 1981



Source: World Nuclear Association, IAEA PRIS

3 | Case Studies

Restart of Takahama Power Station Units 3 and 4

Takahama 3 and 4 (Image: Kansai Electric Power Co)

Details (unit 3)

Reactor type	Pressurized water reactor (PWR)
Owner	Kansai Electric Power Co
Operator	Kansai Electric Power Co
Net capacity	830 MWe
Gross capacity	870 MWe
Construction start	12 December 1980
First grid connection	9 May 1984
Commercial operation	17 January 1985

After the accident of March 2011 at Fukushima, regulatory requirements in Japan were revised to a great extent, based on a thorough adoption of the defence-in-depth concept.

New nuclear regulation by the Nuclear Regulation Authority (NRA) takes into account various natural and other hazards, such as earthquake, tsunami, tornado, wildfire, internal fire and internal flooding, that can expose safety systems to risk of common cause failure.

Operators implemented several countermeasures against the postulated accidents. For example, to protect against an earthquake with 700 Gal of ground acceleration, they reinforced safety-significant structures, 830 reinforced or newly installed snubbers and supports for units 3 and 4.

An 8.5 m-high flood control gate in the seawater intake was constructed and an 8.0 m-high flood barrier along the water discharge side for a 6.2-6.7 m-high tsunami above sea level, respectively.

The seawater pump area was covered with an anti-tornado structure made of steel plates and multi-layered wire net to protect seawater facilities against tornadoes with a maximum wind speed of 100 m/s, while an 18 m-wide firebreak was prepared based on the postulated intensity of wildfire around Takahama power station.

Additionally a quake-resistant fire service water system was installed with 300 m^3 of water source for each reactor to reduce the risk of damaging safety-significant systems through fire induced by a severe earthquake.

Kansai Electric Power Co also reinforced mitigation measures. The capacity of DC power supplies were doubled and air-cooled emergency power generators were deployed for station blackout and diversified water injection measures to the reactor, the containment vessel, the steam generators, the component cooling water system and the seawater system.

Thirteen igniters and five passive autocatalytic recombiners were installed for each unit to reduce the buildup of hydrogen in the containment vessel after core damage.

Water cannons and silt fences were installed to reduce atmospheric and marine diffusion of radioactive materials in case of failure of the containment vessel.

These measures might be thought as extremes but the operator considers it is their responsibility to achieve the highest level of safety as one of the Japanese nuclear operators which experienced the Fukushima Daiichi accident. Kansai hopes these efforts eventually result in recovering nations' confidence.

Interview

Tai Furuta, Deputy Plant Manager, Nuclear Safety, Takahama Power Station

Can you summarise the process taken to allow Takahama 3 to restart?

In Japan, the safety review consists of reactor installation licence, construction permit (CP) and technical specifications (T-specs). The CP is followed by the pre-service inspections (PSIs). After licensees pass all the PSIs, reactors can be restarted.

After the accident at the Fukushima Daiichi plant in March 2011, the NRA performed the safety reviews based on the new regulations, which require robust countermeasures for natural and other hazards, as well as severe accidents.

As for emergency preparedness for a nuclear disaster, a detailed plan for the evacuation of local residents was established by the government of Japan. Apart from the NRA's safety review process, the effectiveness of the emergency plan is verified through emergency drills with participation of local residents.

In addition to the regulatory process in Japan, the understanding of local communities is necessary for restart, taking into account the status of the safety review and emergency preparedness.

Have the countermeasures taken meant major changes to the day-to-day operations of the reactor once it restarted?

Maintenance work increased due to the increase of new equipment and components for safety measures, while we have strengthened our response systems for emergencies by increasing the number of initial response personnel in the power plant on a 24-hour/365-day basis, who engage in activities to secure power and water supply and other functions.

Emergency response drills also increased dramatically because we have to keep skilled responders sufficiently prepared. Each responder performs functional drills based on their roles and responsibilities repeatedly on a yearly basis.

Even during the periodical inspection (refuelling outage), we have to keep the configuration according to the T-specs. After the Fukushima Daiichi accident, T-specs were totally revised and safety requirements during outages were increased, especially in the equipment and systems, and the operation mode, which leads to a longer outage.

What advice would you give to operators of other reactors seeking to restart?

We have to consider various issues to restart. Japanese PWR utilities and plant vendors have been exchanging information on NRA safety reviews. We considered the NRA's specific requirements for preceding reviews to decide the adequate level of safety measures for our own plants.

Takahama 3 and 4 took four-to-six years to restart from shutdown after the Fukushima Daiichi accident. We kept operators' performance maintained with simulator drills and visits to one of our fossil power plant in service. We repeated maintenance work even in the shutdown mode, considering usage of the systems and components from year-to-year in order to keep plant in a good condition. We also received a restart review by WANO.

We meticulously and carefully took all kinds of measures to minimize the chance of inconvenience during restart.

The media had a great interest in the restart, and we were concerned excessive media coverage would affect the smooth restart, especially for minor events. So we prepared a list to categorize assumed announcements and other possible events from the point of view of safety and shared the list with the media in advance.

Upon the restart, site leadership eagerly requested each member of the personnel to achieve their own roles without regret.

It is important for any power station to reflect on the preceding experiences of utilities for their own coming restarts.

As for Takahama Power Station, we expect to restart units 1 and 2 in a couple of years, which are the first units in Japan to have been approved by the NRA for extended operation up to 60 years from the initial commercial operation.

I believe it will be a monumental step towards the revival of nuclear energy in Japan to restart all four units of Takahama Power Station after resolving any challenges that we will face.

Dresden Unit 3: Achieving 100% Energy Availability Factor

Dresden 3 (Image: Exelon)

Details

Reactor type	Boiling water reactor (BWR)
Owner	Exelon Corporation
Operator	Exelon Generation Co
Net capacity	895 MWe
Gross capacity	935 MWe
Construction start	14 October 1966
First grid connection	22 July 1971
Commercial operation	16 November 1971

Dresden Unit 3, along with its sister reactor, Unit 2, supplied more than 15 TWh of electricity in 2017. The plant's owner, Exelon Corporation, estimates this is enough to supply more than 2 million homes with clean electricity.

The plant provides more than 800 jobs and provides millions of dollars, including the $24.8 million paid annually in taxes, to support school, roads and other public services.

Since 1971 Dresden 3 has supplied more than 240 TWh of electricity, which is almost as much as the annual production of electricity in Indonesia.

In 2017 Dresden 3 operated continuously, for a total of 8760 hours, meaning it had an energy availability factor of 100%. The unit supplied 8.38 TWh of electricity, giving a capacity factor of 102.5%.

This places Dresden Unit 3 among the top performing reactors in 2017, demonstrating the potential for reactors to operate at high levels throughout their operational lifetimes. Figure 7 (page 13) in this report shows that there is no age-related trend in reactor capacity factors. The absence of any such trend is a positive indication of the potential for nuclear reactors to perform well if their operating licence is extended. Dresden 3 is licensed to operate until 2031.

Sarah Coady, Design Engineer, examines the Instrument Air System at Dresden 3 (Image: Exelon)

Interview

Peter J. Karaba, Site Vice President, Dresden Generating Station, Exelon Generation

Dresden 3 had a 100% energy availability factor in 2017 and has shown consistently high performance, particularly over the last 20 years. What do you think are the most important factors in achieving this?

Dresden's record capacity factor in 2017 has its roots in Exelon's Nuclear Management Model, which is widely regarded as the gold standard for US nuclear plant operations. The model sets high expectations and provides the staffing and procedural guidance our stations need to reach their safety, reliability and human performance targets. Together with seasonal readiness campaigns, significant investments in technology and new equipment, Dresden is home to a network of highly-skilled nuclear professionals who operate the plant with the highest standards and a commitment to safety and precision: every task, every shift, every day error free. This level of ownership and accountability is sustained through continuous human performance assessment and talent development at all levels of the organization.

Are there any particular issues in maintaining high performance in an older plant?

Dresden has made significant investments in state of the art equipment and innovative technologies to identify and address equipment issues and operational risks before they impact operations. The station also has a robust long-term asset management plan and we continuously design, build and test equipment in excess of regulatory requirements and technical specifications. At older plants, unanticipated failures of passive or infrequently operated components, particularly within steam-sensitive areas or containment, can challenge a continuous run. Failure of these components can lead to down powers and outages that take time and resources to resolve. Dresden, like all Exelon Generation nuclear stations, constantly focus on mitigating and eliminating risk. This is accomplished through proactive removal of unused systems and extending the frequency of tests and inspections.

Dresden 3 has seen a number of uprates to its reference unit power. What were the drivers for these uprates and were there any particular challenges to carrying them out?

Power uprates were performed on both Dresden units during the 2000s, including low-pressure turbine retrofits, generator rewinds, alterex replacements, switchyard upgrades, and transformer replacements. This allowed the reactor to increase its output from 820 MWe to around 980 MWe, which was great news for the plant, the environment, the local economy and regional customers. Across the Exelon Generation nuclear fleet, power uprates generated between 1,300 and 1,500 new megawatts – roughly the equivalent of a new reactor – without the potential risk of construction delays and high costs of new construction. Power uprates, where they make financial sense, are an important part of Exelon Generation's growth strategy, providing clean, safe and reliable electricity.

What is required to ensure that Dresden 3 can continue to supply electricity in the longer term?

Despite Dresden's legacy of safe and effective operations, like many merchant nuclear power plants, it is financially challenged due to the lack of state and federal policies that value nuclear power plants for their zero emissions, resiliency, fuel security, and economic attributes. Prices in the energy market are at historic lows due to a variety of factors, including the way in which energy prices are set, flat and negative demand, a plethora of domestic natural gas, and various subsidies for other clean energy sources. In addition, in PJM, where Dresden is located, the capacity auctions set clearing prices without regard for environmental, fuel security, or resiliency benefits. PJM has acknowledged that long-standing energy market flaws put nuclear energy at risk but have failed to move forward to correct these known flaws.

Now, more than ever, we need federal, regional and state policymakers to act to preserve the benefits of our nation's largest and most resilient source of emissions-free energy. Current state and federal policies place a value on the environmental benefits of wind, solar and more than a dozen other clean energy technologies, but they exclude nuclear, even though it accounts for more than 60% of the nation's zero-carbon energy. In the meantime, we will continue to support the adoption of state-level policy solutions – such as the zero emissions credit/certificate programmes adopted in Illinois, New York and recently in New Jersey – that fairly compensate nuclear and renewable energy for their environmental attributes.

Start-up of Novovoronezh II-1, the first Generation III+ reactor

Novovoronezh NPP (Image: Rosatom)

Comparison of VVER-1000/1200 reactors

Parameters	VVER-1000 (Generation III)	VVER-1200 (Generation III+)
Rated capacity (MW)	1,000	1,198 (+20%)
Service life of the reactor equipment	30 years	60 years (twice longer)
Staffing requirements/ MWe		Less by 30-40%

Novovoronezh II-1, also known as Novovoronezh unit 6, is the first Generation III+ reactor to enter commercial operation. Generation III+ reactor designs are evolutions building on experience with previous generations of reactors. Developments include a more standardised design for each type (to expedite licensing, reduce capital cost and reduce construction time), enhanced safety features, higher availability and longer operating life – typically 60 years – with the potential for extended operation beyond that.

In comparison to the previous generation of reactor, the VVER-1000, the capacity of the VVER-1200 has been increased by 20% and the staffing requirements have been reduced by 30-40%, in terms of staff per megawatt capacity. The economics have been improved through extensive automation and centralization of functions and processes, as well as by doubling the design life of the main equipment up to 60 years.

The VVER-1200 has two variations, the E and M models and several reactor modifications are being used in current projects. The power units that will be in operation at Novovoronezh and Leningrad have identical nuclear and turbine islands, but have a number of distinguishing features in their safety systems and layouts. In particular, an air-type passive heat removal system (PHRS) is used at Novovoronezh, while a water-type one is used at Leningrad. Also, at Novovoronezh the active safety systems have two channels with internal redundancy, while at Leningrad NPP these are four-channel systems. Nevertheless, commonality of VVER-1200 projects amounts to 80% or more.

Interview

Alexander Shutikov, RosEnergoAtom Concern's First Deputy Director, Nuclear Operation

Novovoronezh II-1 is the first Generation III+ reactor to be completed – what developments does this new design bring?

The main feature of the VVER-1200 project is a unique combination of active and passive safety systems. A power unit has two containments with a ventilated space between them. The inner containment ensures the integrity of the reactor installation. The outer containment provides protection against natural (tornadoes, hurricanes, earthquakes, floods, etc.), man-triggered and anthropogenic (explosions, aircraft crashes, etc.) effects.

Passive safety systems remain functional even in the event of a blackout and without any operator intervention.

Novovoronezh is the first nuclear power plant in Russia with the passive heat removal system (PHRS). The PHRS ensures long-term heat removal from the reactor core in the absence of any sources of electricity. In the lower part of the containment, a core catcher is installed in order to constrain the corium in the event of an accident. The core catcher prevents release of radioactivity into the environment even in the case of hypothetical severe accidents.

What learning from the construction of Novovoronezh II-1 can be carried through to VVER-1200 reactors under construction or planned?

Novovoronezh-II is the reference plant for Rosatom's projects abroad, as well as the first plant with Gen III+ units. The project was taken as the basis for constructions in Bangladesh and Turkey. Operational excellence and single information space technologies, as well as e-document management and other tools were actively used at the design, equipment manufacturing and supply, and construction stages. All best practices will be applied for other VVER-1200-based units.

Were there any particular challenges with the construction of this plant and how were they resolved?

In the early hours of 10 November 2016 the electric generator failed during the tests of Novovoronezh II-1, which resulted in disconnection of the unit. The reactor's protection systems functioned in a routine mode. The event was preliminary assessed as zero (not significant) according to the International Nuclear Event Scale (INES). The failed generator was the flagship in the series designed for 1200 MW capacity. Before that, Russia only constructed power units with 1000 MW capacity. The failure was due to the features of the generator design (detachment of the outlet bars on the turbine side). Following the event, these flaws were eliminated at all the generators planned for delivery to the power units of AES-2006 project. Novovoronezh II-1 was put into commercial operation in February 2017. By mid-2018 it has generated about 10 TWh of electricity.

Sprinkling pool, part of the plant's cooling system (Image: Rosatom)

Shin-Kori Unit 3, the first APR1400

Shin Kori 3&4 APR1400 reactors (Image: KHNP)

Details

Reactor type	Pressurized water reactor
Owner	Korea Hydro and Nuclear Power Company
Operator	Korea Hydro and Nuclear Power Company
Construction start	16 October 2008
First grid connection	15 January 2016
Commercial operation	20 December 2016
Capacity net	1416 MWe
Capacity gross	1455 MWe
Capacity thermal	3983 MWt

The first APR1400 (Advanced Pressurized Reactor-1400), Shin-Kori Unit 3, recorded uninterrupted operation on its first cycle of commercial operation. During the first cycle of operation, Shin Kori 3 generated 13.7 TWh, which is equivalent to 67% of the annual power use of the Korean city of Busan, significantly contributing to the country's power supply.

The operators consider the continuous operation of Shin-Kori 3 a milestone, as newly-developed nuclear reactors can experience halts in operation, prior to achieving operational stability.

The Korean-designed APR1400 is based on proven technology and experience accumulated through the development, construction, and operation of the 1000MWe Optimized Power Reactor (OPR-1000), the first standard pressurized water reactor plant in South Korea.

During the 1980s, South Korea launched a technology self-reliance programme on all aspects of nuclear power plant construction. Based on the self-reliant technology and experience accumulated through the design, construction, operation and maintenance of the OPR-1000, Korea launched the APR1400 development project in 1992 and completed its standard design in 2002.

The APR1400 has several advanced features such as direct vessel injection from the safety injection system, a passive flow regulation device in the safety injection tank, an in-containment refuelling water supply system, an advanced safety depressurization system, and systems for severe accident mitigation and management. The main control room was designed with consideration of human factors and fully-digital instrumentation and control (I&C) systems. Additionally, the general plant arrangement has been improved taking into account operation and construction experience of the OPR-1000 series.

Shin-Kori 3 is currently in operation in South Korea and nine units are under construction worldwide. In addition, APR1400 obtained European Utility Requirements certification in November 2017. And, its US design certification is also progressing smoothly as planned for next year.

Shin Kori 3&4 (Image: KHNP)

Interview

Park, Byoung-kweon, Director General, Plant Manager of Shin-Kori Unit 3&4, Korea Hydro & Nuclear Power Company

Were there any particular challenges to the start-up of this first-of-a-kind APR1400?

Shin-kori Unit 3 is the first APR1400 and therefore literally everything was done for the first time. Since we didn't have any operating experience from preceding reference plants, when an event occurred we had to conduct a technical root cause analysis (RCA) more thoroughly than we would usually need to do.

What contributed to the excellent performance of Shin-Kori 3 in its first year of commercial operation?

Most of all, I see the key success factor was facilitating quick responsiveness of the organization by inducing trust and a sense of accomplishment among the workforce. Meetings were kept short and simple, improving their effectiveness. We also organized motivational out-of-office team activities.

I believe the excellent performance of the plant is attributable to our endeavors dedicated to predicting and reducing risk factors, which can occur during the first cycle. To give some examples, we put great emphasis on three activities.

First, shifting our mindset from construction-oriented to operation-oriented. Most of staff who worked during the construction phase stayed and carried on their career at the commercially operating plant, and they tended to have a construction-centered perspective. So we changed such a mindset and put the plant with the technical specifications in the center of our focus to secure safe operation.

Second, field-centered management; we paid great attention to local conditions so that we could correctly understand the actual status of equipment, even just by listening to the sound of it and we closely monitored what is happening in the field to identify issues and then look for solutions applying RCA and the feedback principle. All these efforts aimed at maintaining plant components and equipment in their best condition.

Last but not least, support from experts and continuous learning. Since each individual does not have all the experience required, in order to fill in the gaps, we often invited experts to share their knowledge and expertise, and based on such opportunities we never stopped learning to make the best decisions. As a result, not only could we have zero forced outages but also we received the highest scores in all 11 WANO Performance Indicator indexes. Moreover, I believe we can consecutively accomplish another zero-failure operation in the second cycle as well.

Will the experience of starting up this first APR-1400 be helpful for the start-up of subsequent reactors of the same type, for example Shin-Kori 4 and the reactors at Barakah?

Since Shin-Kori Unit 3 is the reference plant for subsequent APR1400 based plants, I believe the next reactors will certainly benefit from the event & issue (E&I) experience we gained.

To serve as a leader of APR1400 plants, we are operating a separate technical support team, providing various technical information, assisting procedures for visits or admittance, and conducting benchmarking activities. In addition, two employees from UAE's Nawah Energy are stationed at the Shin-Kori Unit 3 site. And we are providing more systematic, swift and accurate technical support by sharing daily operation logs and design changes as well as organizing presentations on Barakah and holding video conferences.

In Shin-Kori Unit 4, we have already incorporated all design changes and E&I of the power ascension test (PAT) that were identified from Shin-Kori Unit 3. Consequently, Shin-Kori Unit 4 is fully ready, with an operating licence targeted in 2018 and commercial operation planned in 2019.

Furthermore, since Shin-Kori Unit 3 is the very first APR1400 we have already had a number of visits from other countries who are planning to introduce nuclear power plants and made presentations for them to share information. As such, other plants are continuously benefiting from the first APR1400 and all of our employees feel proud of what we are doing in Shin-Kori Unit 3.

Construction of Fuqing Unit 5, demonstration HPR1000 reactor

Fuqing power plant (Image: CNNC)

Details

Reactor type	Pressurised water reactor (PWR)
Model	HPR1000
Owner	China National Nuclear Corporation
Operator	CNNC Fujian Fuqing Nuclear Power Company
Construction start	7 May 2015
Capacity net	1000 MWe
Capacity gross	1150 MWe

The Fuqing nuclear power project is planned to eventually consist of six 1 GWe nuclear power plants, with units 1-4 adopting mature generation II technology, and units 5-6 adopting generation III technology with China's own intellectual property.

Units 1-4 have already been put into commercial operation. On May 7, 2015 construction started on Fuqing Unit 5, the first demonstration project of the HPR1000 reactor, also known as the Hualong One reactor. On 22 December of the same year, construction of Unit 6 officially started.

When all six reactors are in full operation the total installed capacity of the Fuqing nuclear power plant will be 6,656 MWe, with an annual power generation of 50 TWh. The Fuqing plant will be one of the largest in China, and will contribute to optimizing the energy mix of the Fujian province, promoting energy diversity, and injecting impetus into the economic growth of the Fujian region.

Interview

Zhou Saijun, Deputy Chief Engineer, CNNC Fujian Fuqing Nuclear Power Company

What particular challenges and lessons learned have there been in the construction of the first HPR 1000 reactor?

The first reactor is often the biggest challenge of a nuclear power project. The application of new technologies and new equipment, major adjustment of technical solution and other uncertainties are the factors that make the whole project a daunting task.

The biggest design challenge is finalizing the drawings. The designers are dispatched to the project site to review the print-out sequence and priority level of over 4,000 drawings, identify the problems, and put forward a solution. The issuance punctuality rate of design drawings is over 99%, which meets the on-site construction needs.

The biggest challenge in construction is the application of new construction techniques. Some of the construction requirements and processes of the Hualong One reactor have been greatly improved. For example, the construction of double-layer containment is a new process, and the external water tank is the first of a kind in a domestic Chinese nuclear power project. The lack of mature experience makes the construction difficulty increase.

The lack of referential experience makes the construction extremely difficult. We invited experienced designers and on-site engineers to plan, simulate and test the construction process. Several scenarios were proposed. Experts were invited to review the complex process and solution and then put forward their opinions. We worked with the installation company to create a three-dimensional simulation model and verify it. All these efforts are intended for the avoidance of risks related with new technologies and new processes in the construction.

Has the experience gained in the construction of Unit 5 been useful in the construction of Unit 6, and the HPR1000 at Fanchenggang?

The National Nuclear Safety Administration (NNSA) and China Nuclear Energy Association (CNEA) have established an experience sharing platform, which is open to all domestic nuclear power plants. Experiences and feedback of Fuqing generator units 5 and 6 are shared on the platform. The project team of Fangchenggang can retrieve the experiences of Fuqing NPP and other nuclear power projects on the platform at any time.

The overall volume of Fuqing 5 is bigger than any of the neighbouring Fuqing 1-4 units. How did you manage this and what is the impact on construction time and cost compared to CPR-1000?

The Generation III technology adopted by Fuqing 5 means that the building arrangement, construction process and project management of Fuqing generator unit 5 are slightly different from that of units 1-4. The overall size is bigger, and the quantity of concrete and steel has increased. As a demonstration project of Hualong One, Fuqing generator unit 5 has a longer project schedule and the planned cost is higher in comparison with units 1-4. But the overall safety level and economy of unit 5 will be better.

To guarantee project progress, the project team of Fuqing has implemented the following coordination and management:

First, we have prepared a scientific work plan. To guarantee the quality of the massive concrete placement, the placement procedure is broken down into detailed stages, and then the responsible person and schedule of each stage are clearly defined. Before commencement of the concrete placement, a 1:1 simulation drill is implemented to identify and eliminate any problem. 3-D simulation technology is used in measurement and design. On-site post-job review is organized on a daily basis to identify and eliminate any problem.

Second, we improve the construction management and determine the scientific construction plan. The construction plan is prepared, verified, documented and implemented. Each stage of construction is managed and controlled. Simulation is organized to identify and eliminate any possible risk of key construction stages.

Third, we reinforce quality control. Quality control is implemented in each stage of construction to avoid rework that gives rise to progress delay. The construction and installation experiences of units 1-4 are summarized as preventive measures for units 5 and 6, so as to avoid re-occurrence of similar problems. Key areas are simulated using digital modeling software. The construction challenges such as the rebar of equipment hatch, embedded part, pre-stressed tube and template are identified, and relevant measures are taken.

4 Director General's Concluding Remarks

There is no sustainable energy future without nuclear energy. To meet the growing demand for reliable, affordable and clean electricity, we will need all low-carbon energy sources to work together.

Nuclear capacity must expand to achieve this. The nuclear industry's Harmony goal is for 25% of the world's electricity to be supplied from nuclear energy by 2050 as part of a low-carbon mix.

Much needs to be done to deliver the Harmony goal, but good progress has been made, both in terms of global reactor performance and new nuclear capacity additions. In 2017 the average global capacity factor was 81.1%, up from 80.5% in 2016. This continues a trend of more than 20 years of high capacity factors of around 80%. Global nuclear generation also increased to 2506 TWh, up 29 TWh from 2016 and up more than 160 TWh over the last five years.

The nuclear industry's Harmony goal requires 1000 GW of new nuclear build by 2050. A path to that target is for 10 GW of nuclear capacity to be added each year between 2016-2020.

After 2015 and 2016 each saw nearly 10 GWe of new nuclear capacity start up, a more modest 3.3 GWe was connected to the grid in 2017. However, in 2018 and 2019 more than 26 GWe of new nuclear capacity is scheduled to come online, meeting the overall target for this first five-year period.

The pace of capacity additions required to meet the Harmony goal needs to accelerate in the next decade, eventually reaching an average of 33 GWe of new nuclear capacity added each year. Action is needed to enable this acceleration to happen.

Action is needed in three key areas to allow nuclear generation to grow at its full potential. There needs to be a level playing field in energy markets, where nuclear energy is treated on equal opportunity with other low-carbon technologies and recognized for its value in a reliable, resilient low-carbon energy mix that optimizes existing low-carbon energy resources already in-place and drives investment in future clean energy

Harmonized regulatory processes are required in order to provide a more internationally consistent, efficient and predictable nuclear licensing regime, to facilitate significant growth of nuclear capacity, without compromising safety and security.

And there needs to be an effective safety paradigm focusing on genuine public wellbeing, where the health, environmental and safety benefits of nuclear are better understood and valued when compared with other energy sources.

Governments are now renewing their recognition of the importance of nuclear energy in achieving a sustainable low carbon energy supply. The launch of the Nuclear Innovation: Clean Energy Future (NICE Future) initiative at the Clean Energy Ministerial in May 2018 put nuclear energy back on an even footing with other low-carbon solutions already discussed within the Clean Energy Ministerial process. The NICE Future initiative will play a crucial role in multilateral dialogue and engagement of policymakers on the role of nuclear energy as part of a low-carbon mix contributing to sustainable development.

This worldwide political recognition needs to apply to our existing reactors, as well as supporting new build. In the USA measures have been taken to maintain operation of reactors facing challenging market conditions. While efforts to maintain the country's nuclear generation are welcome they fail to address fundamental inequities in the US electricity markets. More wide-ranging reforms are needed to ensure all forms of generation in the USA can compete fairly on their merits, with appropriate recognition of the clean and reliable generation from nuclear reactors.

Japan reaffirmed its target for nuclear energy to supply 20-22% of the country's electricity by 2030. There continues to be steady progress in the restart of reactors in Japan. In 2017 Takahama 3&4 became the fourth and fifth reactors to restart and a further four reactors have also restarted. In addition, the next steps are being taken towards completing the construction of the first new reactors, at the Shimane nuclear power plant, since the Fukushima accident. These developments are welcome, but the pace of restarts needs to increase if Japan is going to achieve its goal for nuclear generation. Failing to meet this objective could jeopardize Japan's ability to meet its climate change targets.

The Harmony goal is to have 1000 GWe of new nuclear build by 2050.

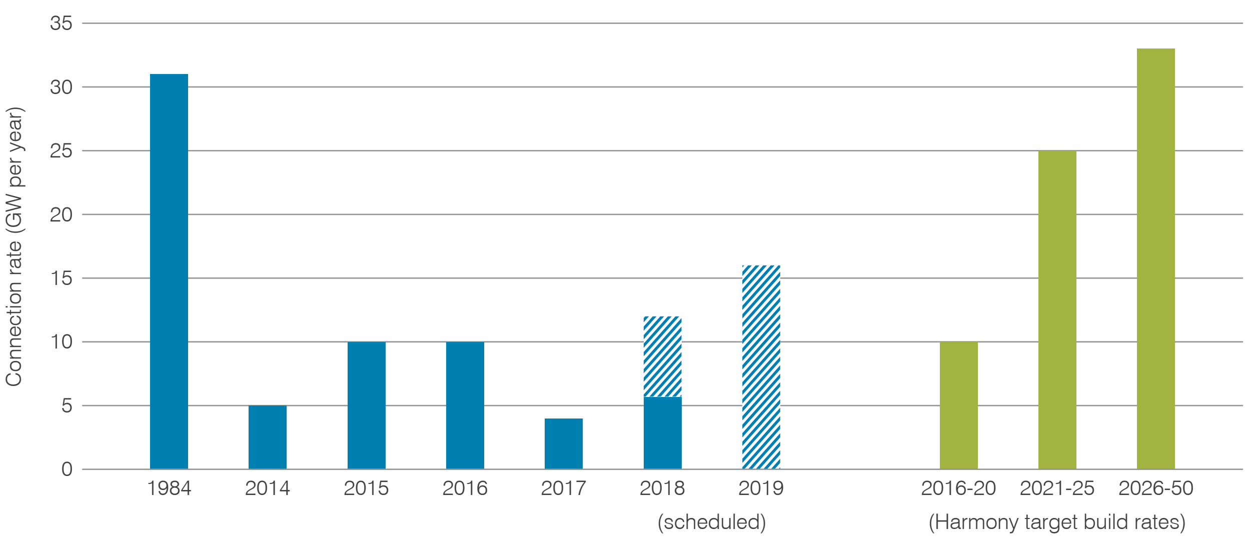
With more than 40 reactors in operation and 15 under construction, China continues to play a key role in the development of nuclear energy. This year has seen the grid connection of the first EPR and AP1000 reactors, as well as the ongoing construction of the first of its own Hualong One reactors. China recently committed to start construction of six-to-eight new reactors in 2018. Nuclear energy will have a vital role to play in China's efforts to improve air quality and meet the needs of its growing economy.

New countries are choosing nuclear energy to meet their future energy needs because of the many benefits that it will bring. Nuclear new build will offer opportunities for host country supply chain businesses to participate in the construction of the reactors. Host regions can benefit from investment in local infrastructure. Many jobs will be created, both during construction and operation of the plant.

Construction started in 2017 on the first nuclear power plant to be built in Bangladesh. Building works also began at Akkuyu in Turkey on its first nuclear power plant, with construction of the first reactor beginning in April 2018. We also saw progress made in Egypt with an agreement signed in December for the construction of four VVER-1200 reactors at El Dabaa.

In 2017 nuclear plants brought benefits to local communities, supported national economies and helped meet our growing global need for clean and reliable electricity. Through our Harmony programme we are outlining the steps needed to allow nuclear generation to make its full contribution to our sustainable energy future.

Figure 14. Historic and predicted new grid connection rates, and future requirements for the Harmony target



5 Status Update to 31 July 2018

Operable Reactors

397 GWe

Reactors Under Construction

57 GWe

New connections to the grid

	Capacity (net)	Location	Grid connection
Rostov 4	1011 MWe	Russia	2 February 2018
Leningrad II-1	1085 MWe	Russia	9 March 2018
Yangjiang 5	1000 MWe	China	23 May 2018
Taishan 1	1660 MWe	China	29 June 2018
Sanmen 1	1000 MWe	China	30 June 2018

Construction starts

	Capacity (net)	Location	First concrete
Akkuyu 1	1114 MWe	Turkey	3 April 2018
Kursk II-1	1115 MWe	Russia	29 April 2018
Rooppur 2	1080 MWe	Bangladesh	14 July 2018

Abbreviations

AGR	Advanced gas-cooled reactor
BWR	Boiling water reactor
FNR	Fast neutron reactor
GCR	Gas-cooled reactor
GWe	Gigawatt (one billion watts of electric power)
HTGR	High temperature gas-cooled reactor
IAEA	International Atomic Energy Agency
LWGR	Light water gas-cooled reactor
LWR	Light water reactor (a BWR or PWR)
MOX	Mixed uranium and plutonium oxide fuel
MWe	Megawatt (one million watts of electric power)
MWh	Megawatt hour (one million watt hours of electricity)
PHWR	Pressurized heavy water reactor
PRIS	Power Reactor Information System database (IAEA)
PWR	Pressurized water reactor
TWh	Terawatt hour (one trillion watt hours of electricity)
VVER	Vodo-Vodyanoi Energetichesky Reactor (a PWR)

Geographical Categories

Africa
South Africa, Egypt

Asia
Armenia, Bangladesh, China mainland and Taiwan, India, Iran, Japan, Kazakhstan, Pakistan, South Korea, Turkey, United Arab Emirates

East Europe & Russia
Belarus, Russia, Ukraine

North America
Canada, Mexico, United States of America

South America
Argentina, Brazil

West & Central Europe
Belgium, Bulgaria, Czech Republic, Finland, France, Germany, Hungary, Italy, Lithuania, Netherlands, Romania, Slovakia, Slovenia, Spain, Sweden, Switzerland, United Kingdom

Further Reading

World Nuclear Association Information Library
http://world-nuclear.org/information-library.aspx

The Nuclear Fuel Report: Global Scenarios for Demand and Supply Availability 2017-2035
http://world-nuclear.org/shop.aspx

The World Nuclear Supply Chain: Outlook 2035
http://world-nuclear.org/shop.aspx

World Nuclear News
http://world-nuclear-news.org

The Harmony programme
http://world-nuclear.org/our-association/what-we-do/the-harmony-programme.aspx

International Atomic Energy Agency Power Reactor Information System
https://www.iaea.org/PRIS/home.aspx

We are grateful for access to IAEA PRIS data used in the preparation of this report.

Additional plant performance data Nuclear Power Corporation of India Limited

World Nuclear Association is the industry organization that represents the global nuclear industry. Its mission is to promote a wider understanding of nuclear energy among key international influencers by producing authoritative information, developing common industry positions, and contributing to the energy debate, as well as to pave the way for expanding nuclear business.

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