WORLD NUCLEAR ASSOCIATION

World Nuclear Performance Report 2019

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Cover image: Beznau nuclear power plant
(Image: Axpo)

World Nuclear Association is grateful to the
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Preface

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The world's nuclear reactors made a growing contribution to supplying clean and reliable electricity in 2018. Global nuclear generation was 2563 TWh, up 61 TWh on the previous year.

At the end of 2018 the capacity of the world's 449 operable reactors was 397 GWe, up 4 GWe on the previous year. Nine new reactors were connected to the grid, with a combined capacity of 10.4 GWe. Seven reactors were closed down in 2018, with a combined capacity of 5.4 GWe. Of these, four are Japanese reactors that had not generated since 2011, and a fifth, Chinshan 1, had not generated since 2015, so these closures had minimal impact on overall electricity generation in 2018. Four reactors in Japan, with a combined capacity of 5.6 GWe, were given approval to restart.

The number of reactors under construction at the end of 2018 was 55, with construction starts on five reactors, compared to the nine that have been connected to the grid following completion of construction.

In Asia, nuclear generation rose by more than 10%, to reach 533 TWh, now more than one-fifth of global generation. In China, the first AP1000 and EPR reactors began commercial operation, alongside Russian VVER V-428M and Chinese ACPR-1000 reactors. Although the four reactors gaining approval to restart in Japan brought the total number to nine, the pace of progress to restarting more reactors remains slow, continuing Japan's reliance on fossil fuels.

The median construction time in 2018 was eight-and-a-half years; this was primarily due to the start-up of reactors utilizing new designs. The average construction time for reactors in recent years has been around five-to-six years. We should see construction times return to more typical recent durations in 2019.

Construction started on the first of four planned units at Akkuyu, in Turkey and the first formal start of construction in West & Central Europe since 2007 began at Hinkley Point C, with first concrete poured for the first of two EPR units.

In Russia preparations on the first floating nuclear power plant continued, with both reactors on board the Akademik Lomonosov reaching first criticality. The vessel should be installed at Pevek later this year.

Reactors in the USA produced more electricity in 2018 than in any previous year, with 808 TWh generated. One reactor retired, Oyster Creek, despite being licensed for an additional ten years of operation, because revised water use rules would require construction of cooling towers. While some US states have introduced schemes that support nuclear generation by recognizing the value of its clean, low-carbon generation, elsewhere other reactors are under threat from distorted and challenging market conditions.

The world's nuclear plants continue to perform excellently. Growth is strong, with more than 20 new reactors scheduled to be connected before the end of 2020. For the industry to reach the Harmony goal of supplying at least 25% of the world's electricity before 2050, much greater commitment from policy-makers will be required.

1 Recent Industry Highlights

In 2018, construction started on new reactors in Turkey and the UK, strengthening the trend of an increasing number of countries choosing nuclear energy to help meet their future energy needs.

The need for the reliable, predictable and clean electricity generated by nuclear has never been greater and, worldwide, that is reflected in the growing number of new build programmes underway. In the emerging, industrial and high-growth markets of China and India, demand for reliable electricity that does not pollute the air necessitates continued growth in investment in nuclear power.

However, a number of factors – both internal and external – are creating profound challenges for nuclear power in some of its most mature markets. Of the 449 reactors that were operable at the end of 2018, over half were in the USA and Europe where, despite the vital importance of nuclear to achieving sustainable energy goals, reactor retirements continue to outpace capacity additions.

Asia

At the beginning of 2019, **China** had 46 operable nuclear reactors, representing about 11% of the world's nuclear capacity. In 2018, the country connected a record 8.3 GWe of new nuclear capacity – the second largest annual increase achieved by any country since the advent of civil nuclear power. Of the nine reactors connected to the grid worldwide in 2018, seven were in China. Reactors were connected at Tianwan, Haiyang, Sanmen, Taishan and Yangjiang.

In June 2018, Taishan 1 became the world's first operating EPR, followed in July by Sanmen 1, the first AP1000 to supply electricity to a grid. Earlier in the year, China connected Yangjiang 5, its first ACPR-1000.

Despite the impressive growth of its nuclear sector, a study from China's National Development and Reform Commission's Energy Research Institute in October 2018 concluded that a huge expansion in capacity – to 554 GWe by 2050 – will be needed for the country to fulfil its climate obligations.

At the end of 2017, just four of **Japan's** operable reactors were online; by June 2018 nine were operating. Applications for the restart of more than half of the remaining operable reactors have been submitted and are being assessed.

Prime Minister Shinzo Abe wants nuclear power to provide at least 20 percent of the country's energy by 2030, but the rate of restarts continues to be slowed by judicial rulings and local consent issues. Most recently, in May 2019, Japan's Nuclear Regulatory Authority (NRA) ordered Kansai Electric Power Company (Kepco) to "backfit" seven of its reactors based on a new analysis of the potential eruption of a dormant volcano, Mt. Daisen. All of the affected reactors had previously cleared compatibility examinations based on new regulatory standards. A month earlier, the NRA announced it would not extend deadlines for utilities building facilities to meet new anti-terrorism guidelines. The ruling could potentially see restarted reactors temporarily shutdown.

The restart of five reactors in 2018 demonstrated the economic, security and environmental value of nuclear power for Japan. Following the restart of its Ohi 3&4 reactors, reduced fuel costs allowed Kepco to cut its electricity prices for customers by more than 5% on average. The United States Energy Information Administration estimates that the additional electricity generated by the five reactors restarted in 2018 will allow the country to reduce its imports of LNG for the power sector by up to 10% in 2019.

In **South Korea**, Korea Hydro and Nuclear Power (KHNP) connected the country's second APR1400, Shin Kori 4, to the grid in April 2019. Shin Hanul 1 is expected to follow later this year, which will see the country's operable nuclear capacity rise to a record 24 GWe.

South Korea currently generates about one-quarter of its electricity from nuclear power, with a mixture of imported coal and gas used to generate the balance. Despite the importance of nuclear 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, KHNP 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. Construction restarted on unit 5 in October 2017, and commenced on unit 6 in September 2018.

Despite the domestic challenges, South Korea's nuclear industry continues to export successfully, completing the construction of the first of four APR1400 reactors in United Arab Emirates (UAE), in March 2018. UAE has agreed to work with South Korea in its efforts to win orders for the construction of units in Saudi Arabia.

At the beginning of 2019, **India** had seven reactors under construction, with a combined capacity of 4.8 GWe. The country retains plans to significantly expand its nuclear power sector; in January 2019 the country's minister of state for the Department of Atomic Energy and the Prime Minister's Office told parliament that the country planned to bring 21 more reactors online by 2031. The 21 units will be a mix of indigenous and imported reactor designs. In July 2018 the country's minister of state informed parliament that talks were ongoing with EDF for the construction of six EPRs at Jaitapur, and with Westinghouse for the construction of six AP1000 units at Kovvada; and in October 2018 Russia and India signed an agreement to build six nuclear units at a new site in the country.

Europe (East) & Russia

Rostov 4 and Leningrad II-1 were connected to the grid in **Russia** in February and March 2018. The two units were the first to be connected since Novovoronezh II-1 in August 2016. In April 2019 first concrete was poured for unit 1 of the Kursk II plant, and in May 2019, the second unit of Novovoronezh II began supplying electricity to Russia's grid.

Earlier in May 2018, Russia marked a significant milestone in the completion of construction of its first floating nuclear power plant, Akademik Lomonosov, with the power ship leaving Saint Petersburg to be towed to Murmansk for fuelling. In March 2019 the plant's two reactors were brought up to 100% capacity. The plant is scheduled to be connected to the grid in December 2019 at the Port of Pevek, where it is replacing the outgoing capacities of the Bilibino nuclear power plant and the Chaunskaya combined heat and power plant.

The strength of Russia's nuclear industry is reflected in its dominance of export markets for new reactors. In April 2018, Russia began building Turkey's first nuclear power plant, and in December 2018, Tianwan 4 was connected to the grid in China – the fourth Russian-designed reactor to be deployed in that country. In June 2018, contracts were signed with China for the construction of four further VVER units in the country. In India at Kudankulam, two

Control panel of Leningrad II-1 (Image: Rosenergoatom/ Dmitry Chubar)

Russian-designed VVER units are in operation, two are under construction and a further two are planned. In October 2018, Russia and India signed an agreement looking towards the serial construction of further units at another site in India. Of the 47 reactors under construction outside of Russia at the end of 2018, nine were Russian-designed.

In **Bulgaria**, following the licence extension of Kozloduy 5 in November 2017, the country's parliament in June 2018 mandated the energy minister to resume the search for investors in the stalled Belene project. Similar progress was made in **Poland** too, where the energy ministry released its draft energy policy in November 2018, outlining 6-9 GWe of nuclear power to be online by 2043. A significant number of other European countries are looking to build new nuclear reactors, including Czech Republic, Hungary and Romania.

Europe (West & Central)

France confirmed it had postponed plans to reduce nuclear power's relative share in its electricity generation mix from 75% to 50%. In November 2018 President Macron stated that the new target date was 2035, and that a total of 14 reactors of 900 MWe capacity will be shut down. Earlier, in April 2018, President Macron stated in an address to the European Parliament that France's energy strategy had one top priority: to reduce emissions. First fuel is now expected to be loaded into France's one reactor under construction, Flamanville 3, in the fourth quarter of 2019.

Seven nuclear reactors remain in operation in **Germany**, and in 2018 they generated about 12% 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 set itself the target of reducing greenhouse gas emissions by 40% by 2020 relative to 1990 levels. As it has become clear that the target will be widely missed, the government has faced increasing calls to postpone its plans to phase out nuclear power.

At the beginning of 2018, 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 in **Finland**. TVO now expects fuel loading in 2019.

In the **UK**, first concrete was poured for unit 1 of Hinkley Point C in December 2018, marking the official start of construction.

Middle East and Africa

Construction of unit 1 of the **UAE's** first nuclear power plant, Barakah, was officially completed in March 2018, however start-up has been deferred to 2020 to complete operator training and obtain regulatory approvals. In May 2018 the Department of Energy issued an electricity generation licence for Barakah 1, and in March 2019, the Federal Authority for Nuclear Regulation stated that it was near finishing its review of licence application documents submitted by ENEC in 2015.

Turkey began construction of its first nuclear reactor in April 2018, and in March 2019 the first significant construction milestone was reached, with the completion of concreting work for the reactor's basemat. It is the first of four VVER-1200 units planned for the Akkuyu nuclear plant.

Saudi Arabia is planning to build two large nuclear power reactors, and has plans for small reactors for desalination. The country has solicited information from five vendors from China, France, Russia, South Korea and the USA. In November 2018 a contract was awarded to Worley Parsons to provide wide-ranging consultancy services for the Saudi National Atomic Energy Project.

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, and in April 2019, Egypt's Nuclear Regulation and Radiological Authority granted site approval.

North America

The number of operable reactors in the **USA** stood at 98 at the end of 2018, one lower than a year earlier following the closure of Oyster Creek. Whilst the total number of operable reactors has fallen from a high of 104 in 2012, exceptional operational performance saw the USA's nuclear sector supply a record 808 TWh of clean, low-carbon electricity in 2018.

Despite its laudable operational performance, the challenges faced by the nuclear sector in the USA – related primarily to low natural gas prices, as well as market liberalization and subsidization of renewables – persist. However, that has had the positive effect of highlighting the sector's unique value to both 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. In April 2019, the New Jersey Board of Public Utilities awarded the state's first ZECs to the Halem and Hope Creek nuclear power plants. 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). In Ohio, in July 2019, lawmakers introduced a draft clean energy bill that will provide credits to zero emission producers, including the state's at-risk nuclear power plants.

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. Ten of those units – six units at Bruce, and four units at Darlington – are to undergo refurbishment, extending operating lifetimes by 30-35 years. In March 2018, the first of the four units to undergo refurbishment at Darlington, unit 2, reached an important milestone with removal of the final calandria tube from the reactor's core. The rebuilding work on the core began in June 2018, and was completed, on schedule, in April 2019.

Interest in the on- and off-grid applications of SMR technology in Canada is notable. Canadian Nuclear Laboratories has set a goal of siting an SMR on its Chalk River site by 2026, and in April 2018 invited proponents to evaluate the construction and operation of a demonstration SMR at the site it manages. In March 2019, the Canadian Nuclear Safety Commission received the first licence application – submitted by Global First Power, with support from OPG and Ultra Safe Nuclear Corporation – for an SMR at the Chalk River site.

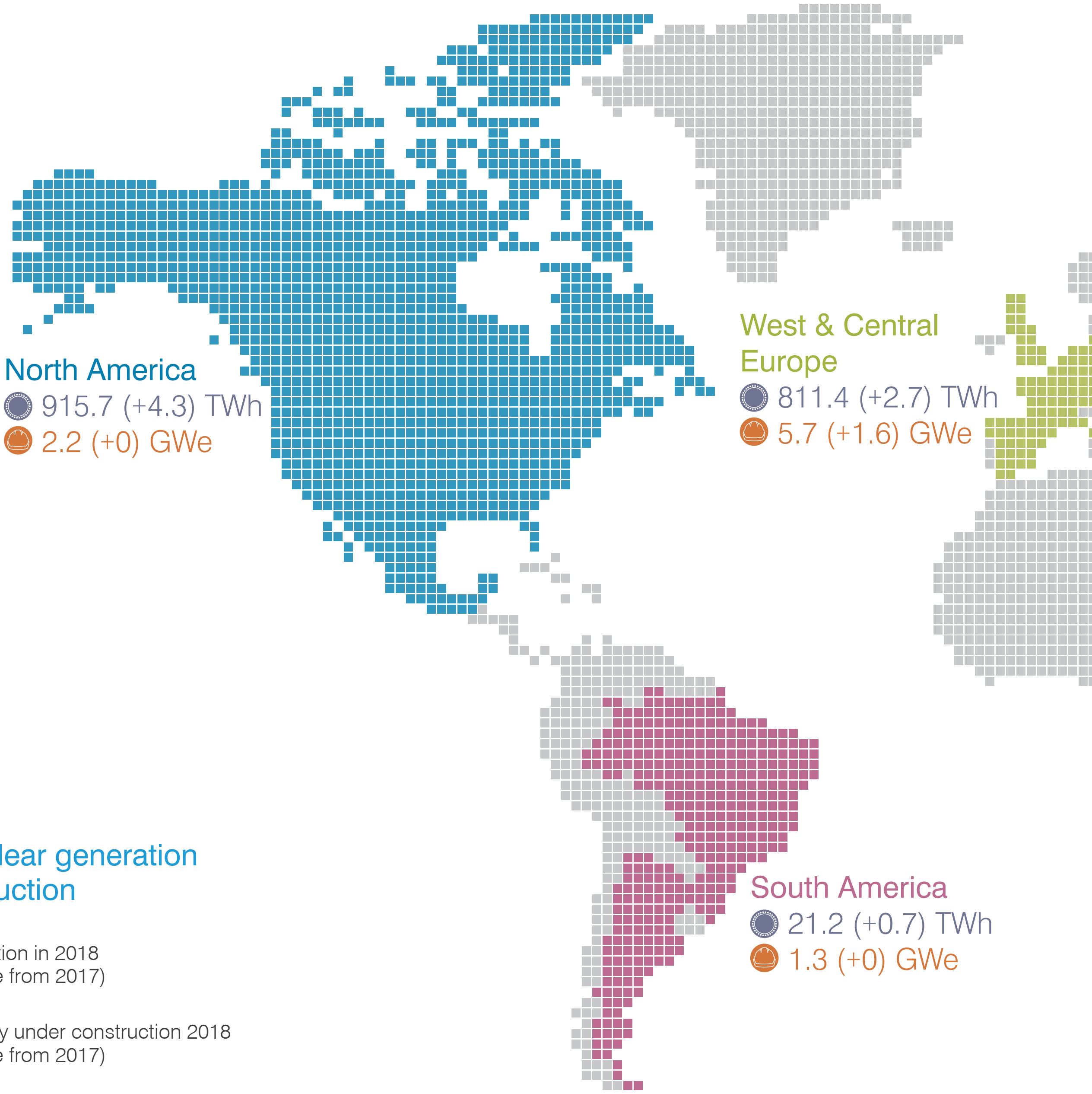
South America

In **Argentina**, the Embalse nuclear power plant resumed commercial operation in June 2019 following a three-year upgrade programme. The work will allow the plant to continue operating for another 30 years.

In **Brazil**, the IAEA concluded a long-term operational safety review of Angra 1 in May 2018 as operator Electrobras Eletronuclear continues preparations to extend the reactor's lifetime to 60 years. In June 2018, a MoU was signed with EDF with an eye to resuming construction at Angra 3 – and in April 2019, the Minister for Mines and Energy, Bento Albuquerque, reiterated the country's commitment to the project.

Exceptional operational performance saw the USA's nuclear sector supply a record 808 TWh of clean, low-carbon electricity in 2018

2 | Nuclear Industry Performance



Global nuclear generation and construction

Generation in 2018 (change from 2017)

Capacity under construction 2018 (change from 2017)

Nuclear industry performance indicators 2018 (change from 2017)

79.8% (-1.3%)
Global mean capacity factor

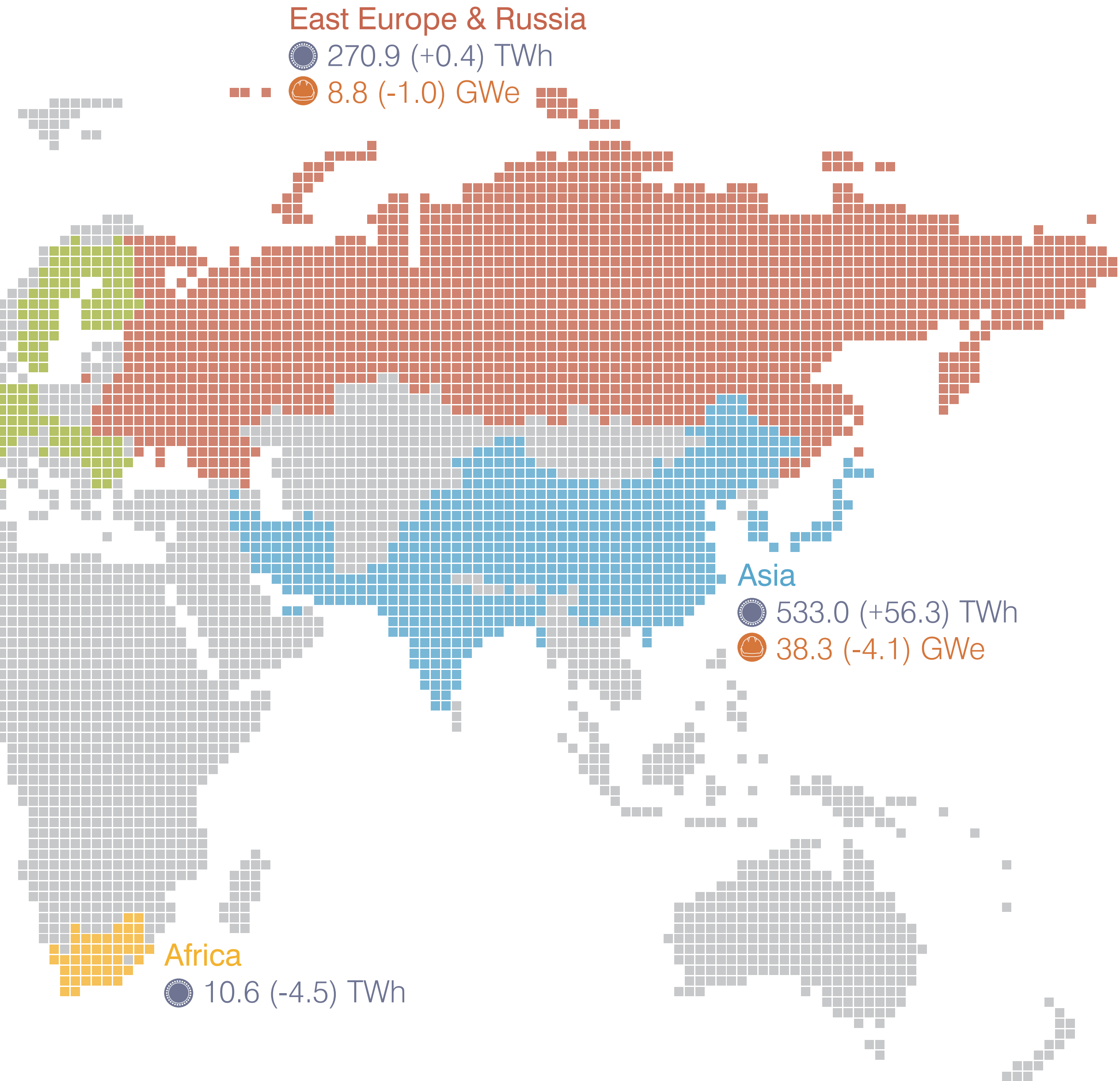
Capacity factor consistently high, between 78-83% over the last 20 years

2563 TWh (+61 TWh)
Electricity generated in 2018

Sixth consecutive year output has increased

9 (+5)
New reactors

10.4 GWe addition is highest since 1990



4 GWe (+2 GWe)

Net increase in operable capacity

397 GWe total operable capacity highest ever global total

103 months (+55 months)

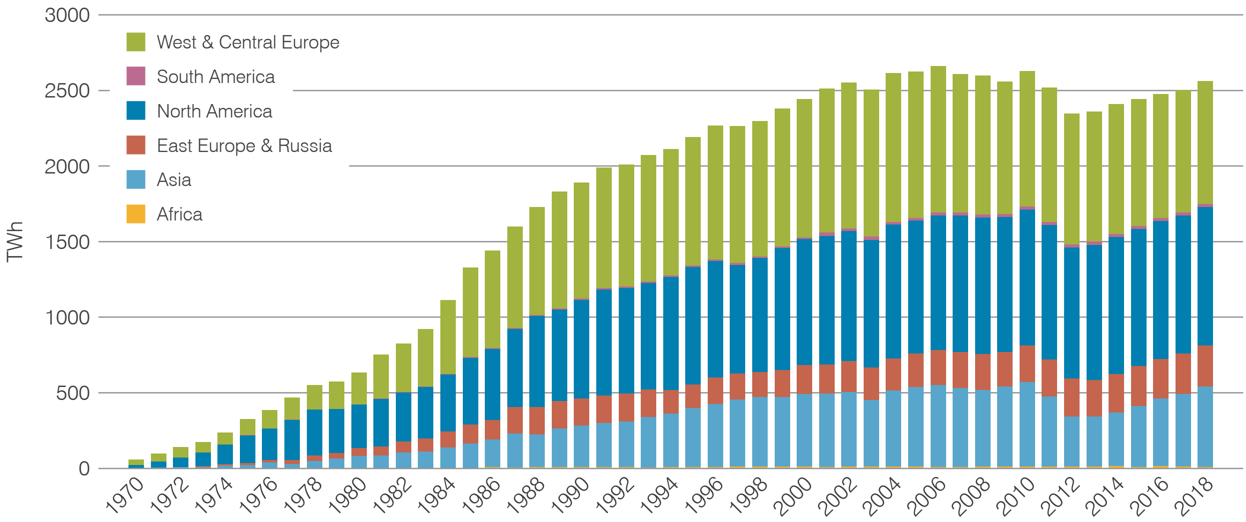
Median construction period for new reactors starting in 2018

Increase due to high proportion of new reactor designs entering service

2.1 Global highlights

Nuclear reactors generated a total of 2563 TWh of electricity in 2018, up from 2502 TWh in 2017. This is the sixth successive year that nuclear generation has risen, with output 217 TWh higher than in 2012.

Figure 1. Nuclear electricity production

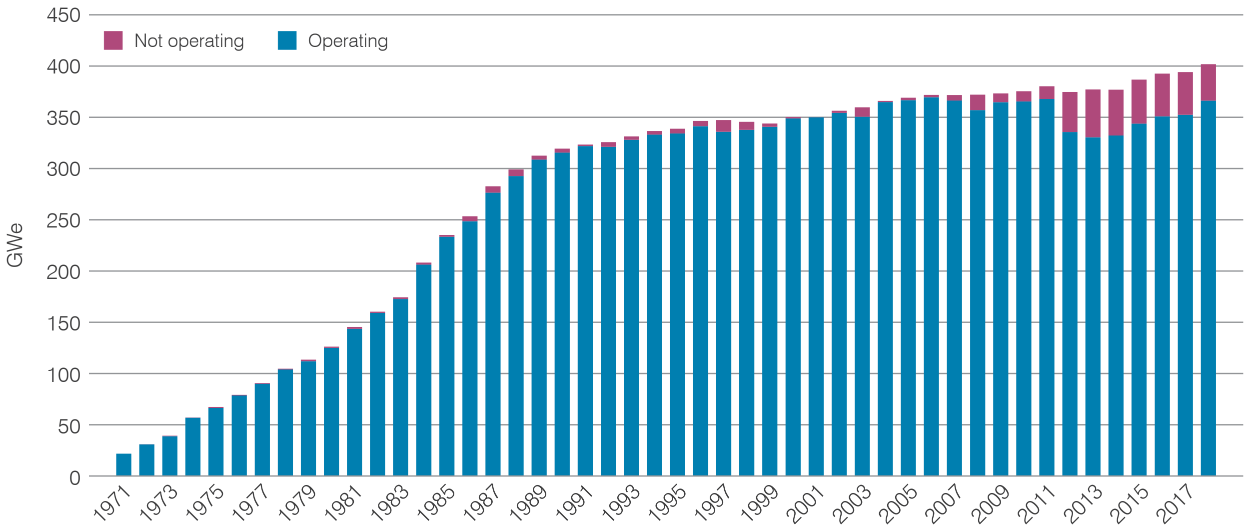


Source: World Nuclear Association and IAEA Power Reactor Information Service (PRIS)

In 2018 the peak total net capacity of nuclear power in operation reached 402 GWe, up from 394 GWe in 2017. The end of year capacity for 2018 was 397 GWe, up from 393 GWe in 2017.

Usually only a small fraction of operable nuclear capacity does not generate electricity in a calendar year. However, since 2011, the majority of the Japanese reactor fleet has been awaiting restart. Four Japanese reactors were restarted in 2018, joining the five reactors that had restarted in previous years.

Figure 2. Nuclear generation capacity operable (net)

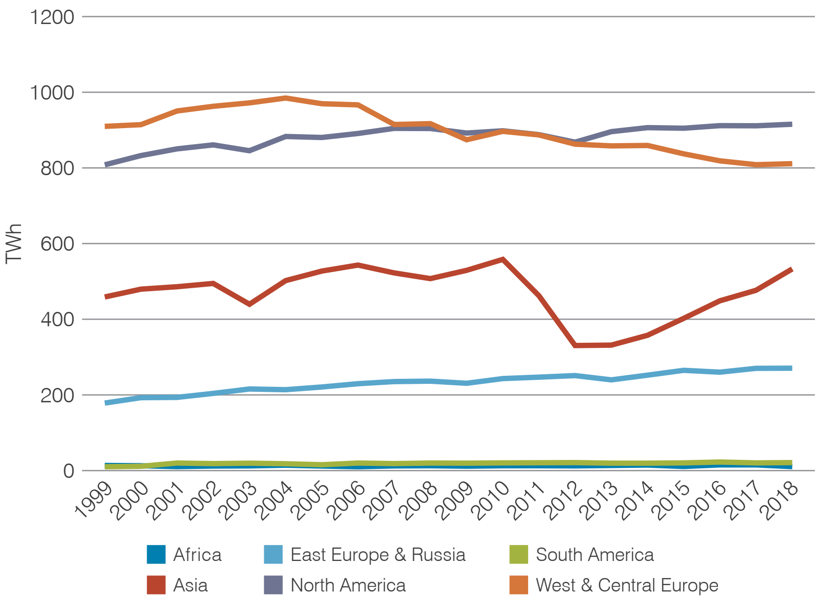


Source: World Nuclear Association, IAEA PRIS

In 2018, nuclear generation rose in Asia, East Europe & Russia, North America, South America and West & Central Europe. Generation fell in Africa, which has only two reactors operating, in South Africa.

Global capacity at the end of 2018 was 397 GWe, up from 393 GWe in 2017

Figure 3. Regional generation



Source: World Nuclear Association, IAEA PRIS

These changes continue the recent trends in these regions.

At the end of 2018 there were a total of 449 operable reactors, up one from 448 in 2017. The PWR continues to be the predominant reactor type in use.

Table 1. Operable nuclear power reactors at year-end 2018

	Africa	Asia	East Europe & Russia	North America	South America	West & Central Europe	Total
BWR		26 (-2)		35 (-1)		11	72 (-3)
FNR		0 (-1)	2				2 (-1)
GCR						14	14
LWGR			14 (-1)				14 (-1)
PHWR		25		19	3	2	49
PWR	2	90 (+4)	35 (+2)	65	2	104	298 (+6)
Total	2	141 (+1)	51 (+1)	119 (-1)	5	131	449

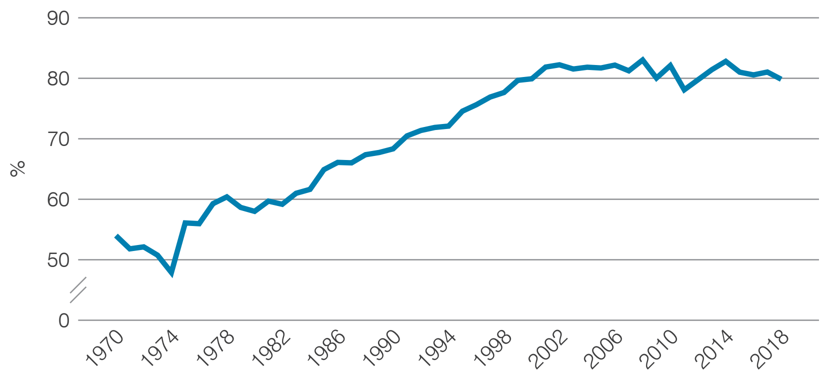
Source: World Nuclear Association, IAEA PRIS

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 2018 the global average capacity factor was 79.8%, down from 81.1% in 2017. Despite this small reduction, this maintains the high level of performance seen since 2000 following the substantial improvement over the preceding years. In general, a high capacity factor is a reflection of good operational performance. However, there is an increasing trend in some countries for nuclear reactors to operate in a load-following mode, which will reduce the overall capacity factor.

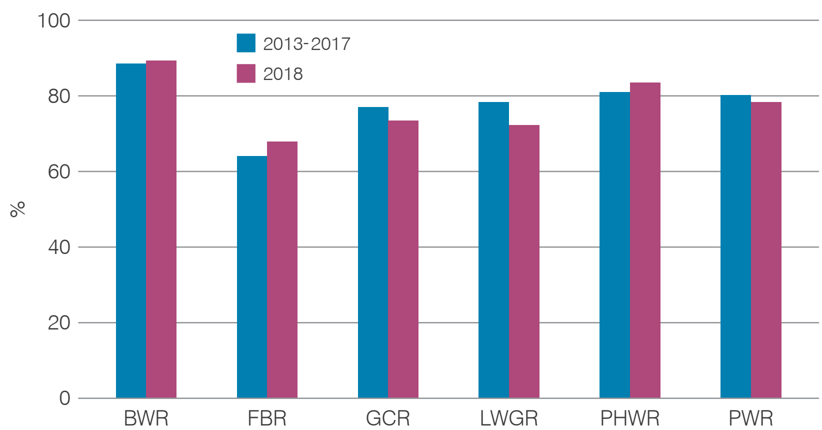
Figure 4. Global average capacity factor



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. With more than half the reactors in the world being PWRs, the slight decline in capacity factor for this category has a major influence on the overall capacity factor figure shown in Figure 4.

Figure 5. Capacity factor by reactor type

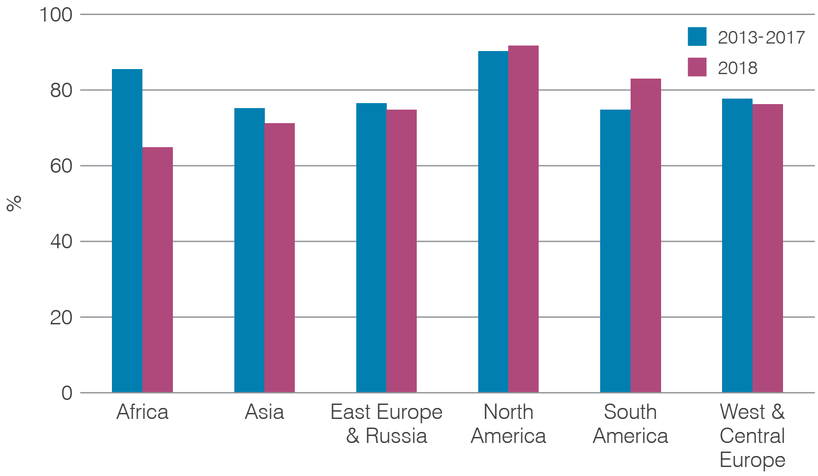


Source: World Nuclear Association, IAEA PRIS

Capacity factors in 2018 are also broadly consistent with the average achieved in the preceding five years for reactors in the same regions. The capacity factor for Africa is dependent on the performance of the Koberg nuclear plant in South Africa and the timing of its outages. The capacity factor is substantially lower for 2018, but consistent with the variation seen over the long term.

Nuclear generation rose for the sixth successive year in 2018

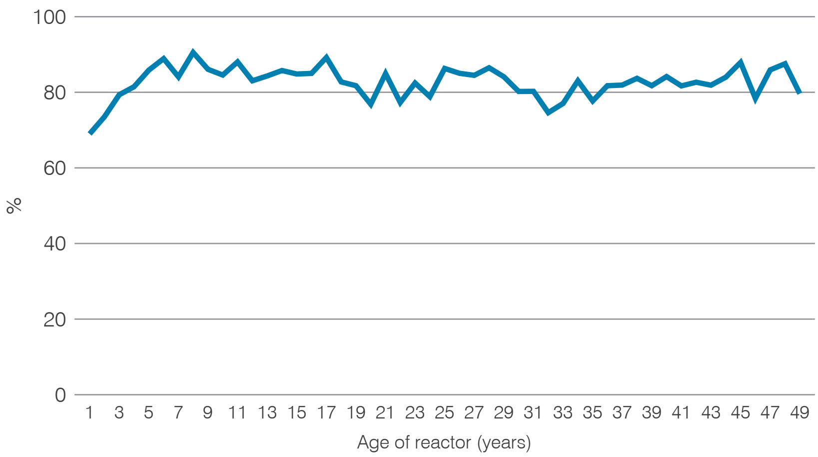
Figure 6. Capacity factor by region



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 little variation with age.

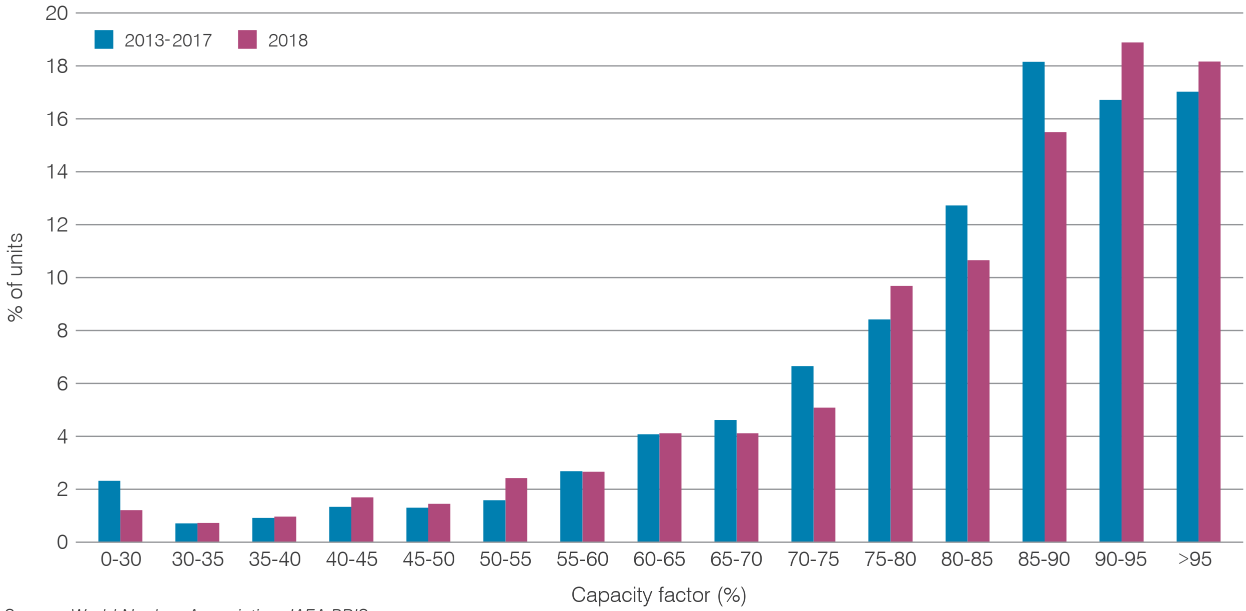
Figure 7. Mean capacity factor 2014-2018 by age of reactor



Source: World Nuclear Association, IAEA PRIS

Capacity factors in 2018 compared to the previous five years are broadly similar, reflecting the consistently high capacity factors seen over the past 20 years. There is a smaller percentage in the 80-85% capacity factor category, and a greater percentage in the categories between 65% and 80%. This may reflect the increasing use of nuclear generation for load following activities.

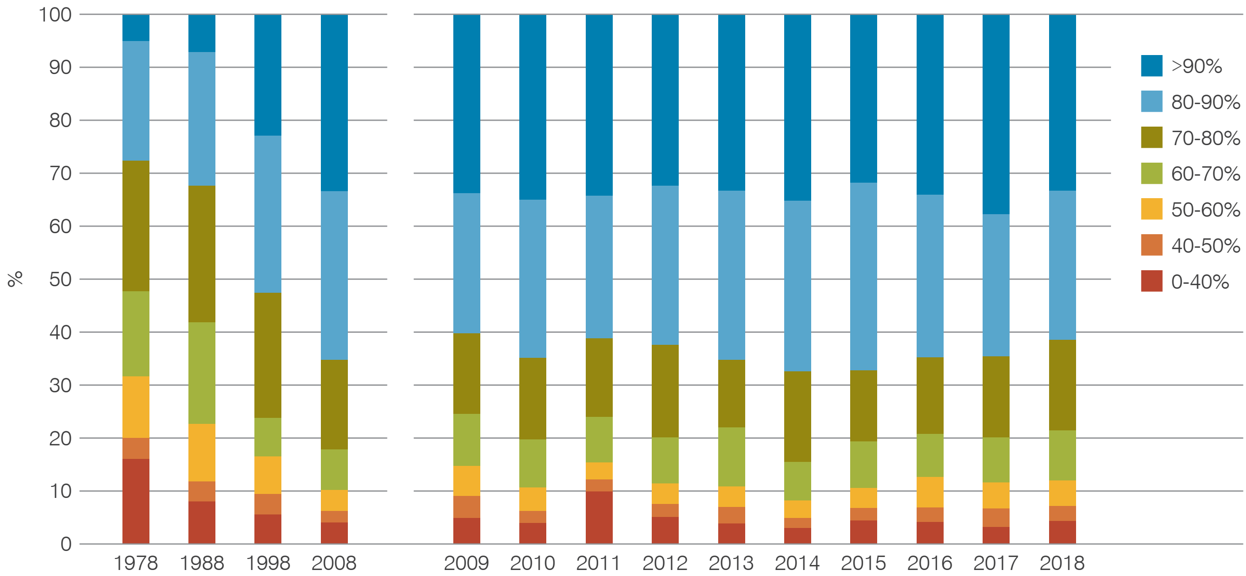
Figure 8. Percentage of units by capacity factor



Source: World Nuclear Association, IAEA PRIS

There was a substantial improvement in capacity factors in the 1970s through to the 1990s, which since has been maintained. Whereas nearly half of all reactors had capacity factors under 70%, the share is now less than one-quarter. In 1978 only 5% of reactors achieved a capacity factor higher than 90%, compared to 33% of reactors in 2018.

Figure 9. Long-term trends in capacity factors



Source: World Nuclear Association, IAEA PRIS

2.3 Permanent shutdowns

Seven reactors shut down in 2018, of which four were in Japan and had not been generating electricity since 2012. The Chinshan 1 reactor of Taiwan shutdown due to a political phase-out decision, despite the fact this was opposed in a public referendum.

Table 2. Shut down reactors in 2018

	Location	Net Capacity (MWe)	First grid connection	Permanent shutdown	Type of reactor
Chinshan 1	Taiwan	604	16 November 1977	6 December 2018	BWR
Ikata 2	Japan	538	19 August 1981	23 May 2018	PWR
Leningrad 1	Russia	925	21 December 1973	21 December 2018	LWGR
Ohi 1	Japan	1120	23 December 1977	1 March 2018	PWR
Ohi 2	Japan	1120	11 October 1978	1 March 2018	PWR
Onagawa 1	Japan	498	18 November 1983	21 December 2018	BWR
Oyster Creek	USA	619	23 September 1969	17 September 2018	BWR

Source: World Nuclear Association, IAEA PRIS

2.4 New construction

With nine reactors being grid connected for the first time in 2018 and five reactors starting construction, the number of reactors under construction fell from 59 to 55 over the course of the year.

Table 3. Reactors under construction by region year-end 2018 (change since 2017)

	BWR	FNR	HTGR	PHWR	PWR	Total
Asia	4	1	1	4	26 (-4)	36 (-4)
East Europe & Russia					10 (-1)	10 (-1)
North America					2	2
South America					2	2
West & Central Europe					5 (+1)	5 (+1)
Total	4	1	1	4	45 (-4)	55 (-4)

Source: World Nuclear Association, IAEA PRIS

With a combined capacity of 6,279 MWe, construction started on five reactors in 2018, including Akkuyu 1, the first reactor in Turkey and Hinkley Point C-1, the first reactor to begin construction in the UK since Sizewell B, 30 years previously. Rooppur 2 is Bangladesh's second nuclear reactor under construction, following its sister unit, which started construction in 2017.

The five construction starts in 2018 are listing in Table 4.

Table 4. Reactor construction starts in 2018

Reactor	Country	Net capacity (MWe)	Start of construction	Type of reactor
Akkuyu 1	Turkey	1114	3 April 2018	PWR (VVER)
Hinkley Point C-1	United Kingdom	1630	11 December 2018	PWR
Kursk II-1	Russia	1115	29 April 2018	PWR (VVER)
Rooppur 2	Bangladesh	1080	14 July 2018	PWR (VVER)
Shin Kori 6	South Korea	1340	20 September 2018	PWR

Source: World Nuclear Association, IAEA PRIS

Table 5. Reactor grid connections in 2018

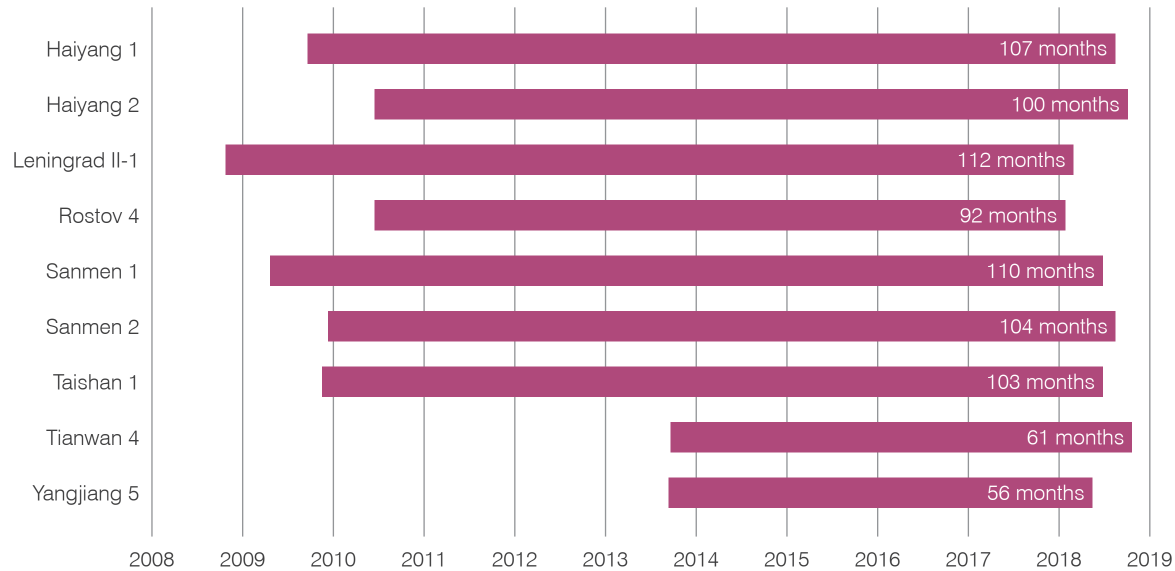
Reactor	Location	Model	Type	Capacity (MWe)	Construction start	First grid connection
Haiyang 1	China	AP1000	PWR	1170	24 September 2009	17 August 2018
Haiyang 2	China	AP1000	PWR	1170	20 June 2010	13 October 2018
Leningrad II-1	Russia	VVER V-491	PWR	1085	25 October 2008	9 March 2018
Rostov 4	Russia	VVER V-320	PWR	950	16 June 2010	2 February 2018
Sanmen 1	China	AP1000	PWR	1157	19 April 2009	30 June 2018
Sanmen 2	China	AP1000	PWR	1157	15 December 2009	24 August 2018
Taishan 1	China	EPR	PWR	1660	18 November 2009	29 June 2018
Tianwan 4	China	VVER V-428M	PWR	1045	27 September 2013	27 October 2018
Yangjiang 5	China	ACPR-1000	PWR	1000	18 September 2013	23 May 2018

Source: World Nuclear Association, IAEA PRIS

Seven of the nine reactors connected to the grid in 2018 were constructed in China. The two others were constructed in Russia. Of the seven reactors built in China, four were US-designed AP1000, one was a French-designed EPR, one was a Russian VVER and one a Chinese ACPR-1000.

One remarkable characteristic of 2018 was the prevalence of new reactors designs amongst the reactor start-ups. Haiyang 1&2 and Sanmen 1&2 were the first four AP1000s to begin operation, Taishan 1 was the first EPR, Leningrad II-1 was the first VVER-1200 and Yangjiang 5 the first ACPR-1000. Notably the second units at Haiyang and Sanmen had significantly shorter construction periods, demonstrating that even second units can benefit from experience of the first unit's construction.

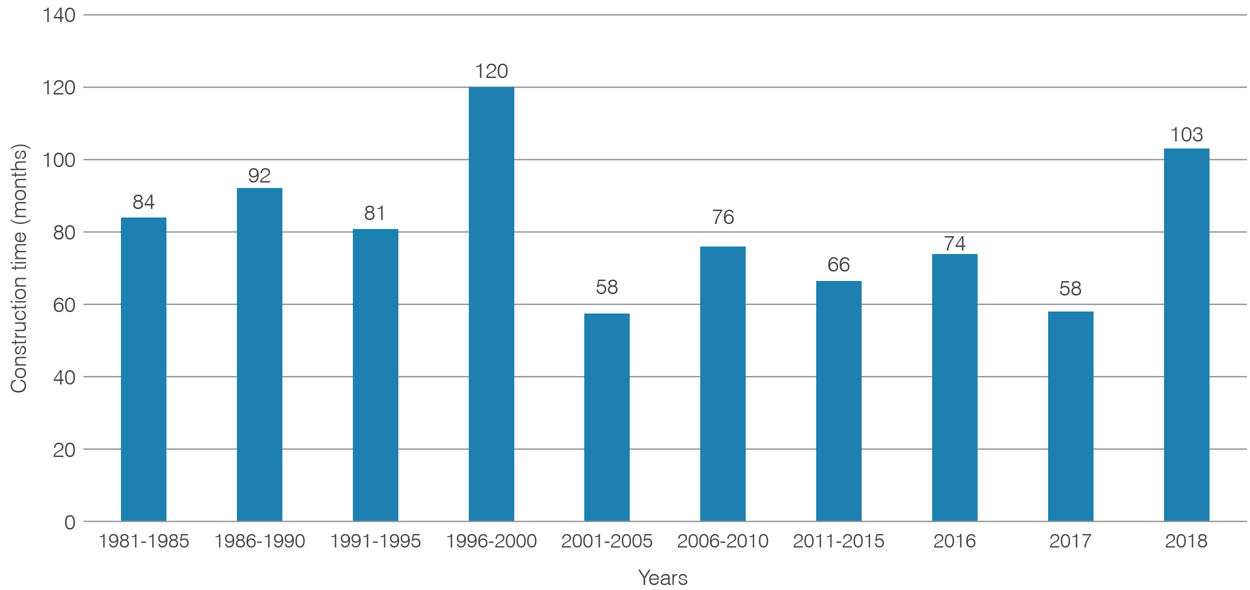
Figure 10. Construction times of new units grid connected in 2018



Source: World Nuclear Association, IAEA PRIS

A consequence of the high proportion of first-of-a-kind units entering service in 2018 is that construction times average longer than those achieved in recent years, with a median construction time of 103 months, and a mean average of 95 months.

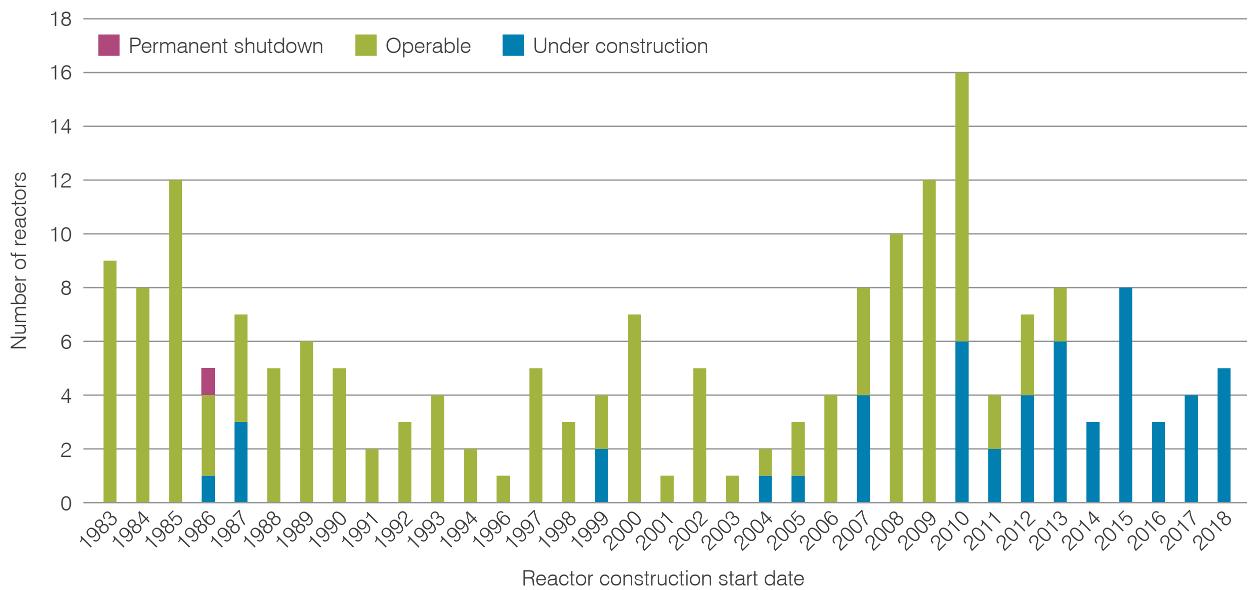
Figure 11. Median construction times for reactors since 1981



Source: World Nuclear Association, IAEA PRIS

Most reactors under construction today started construction in the last nine years. A small number of reactors have been formally under construction for a longer period, but may have had their construction suspended. For Mochovce 3&4 in Slovakia, where first concrete was poured in 1987, construction was suspended between 1991 and 2008. Start-up of the first unit is now expected next year.

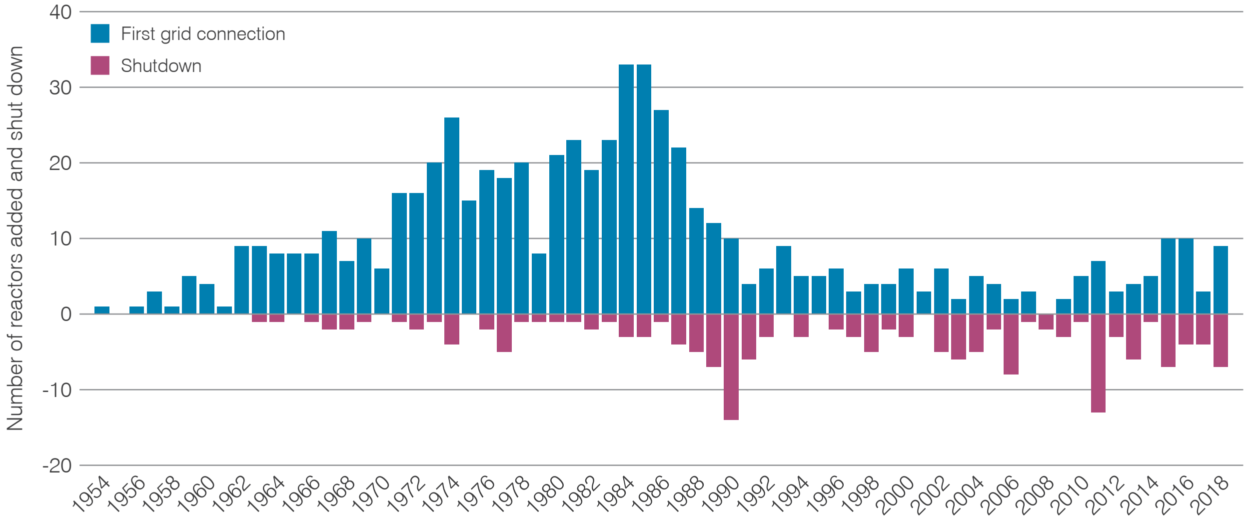
Figure 12. Operational status of reactors with construction starts since 1983



Source: World Nuclear Association, IAEA PRIS

In 2018 nine reactors were grid connected for the first time and seven were permanently shut down.

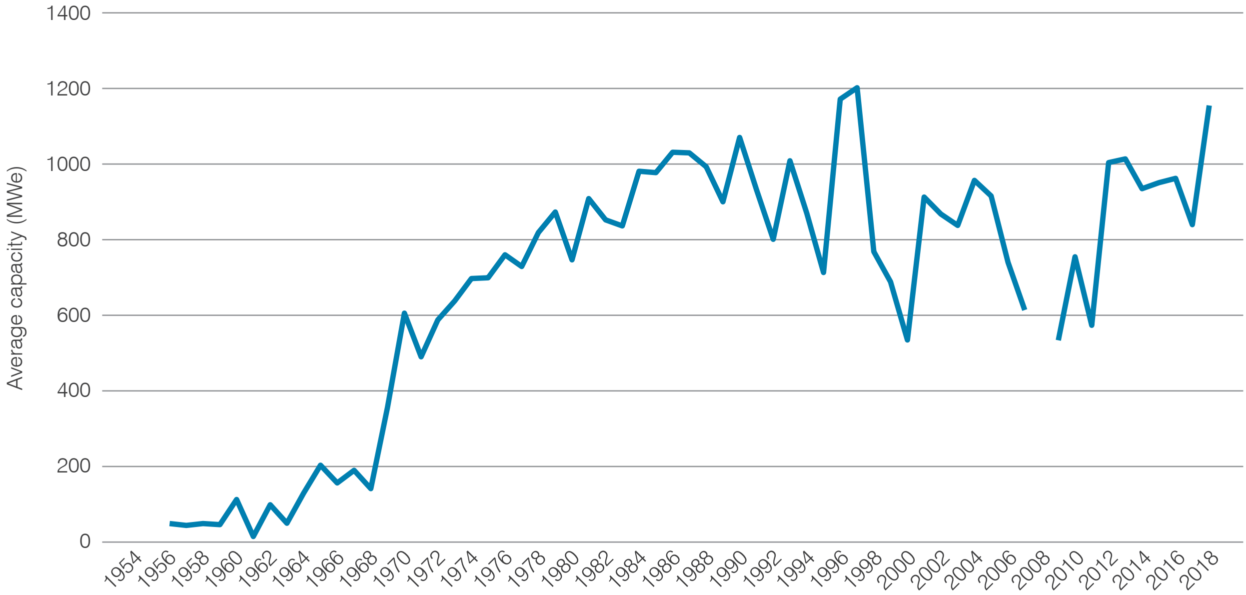
Figure 13. Reactor first grid connection and shutdown 1954-2018



Source: World Nuclear Association, IAEA PRIS

Over the course of nuclear energy's 65 years of operation reactor designs have evolved. One characteristic of that evolution has been an overall increase in reactor capacity, particularly over the first thirty years of reactors development.

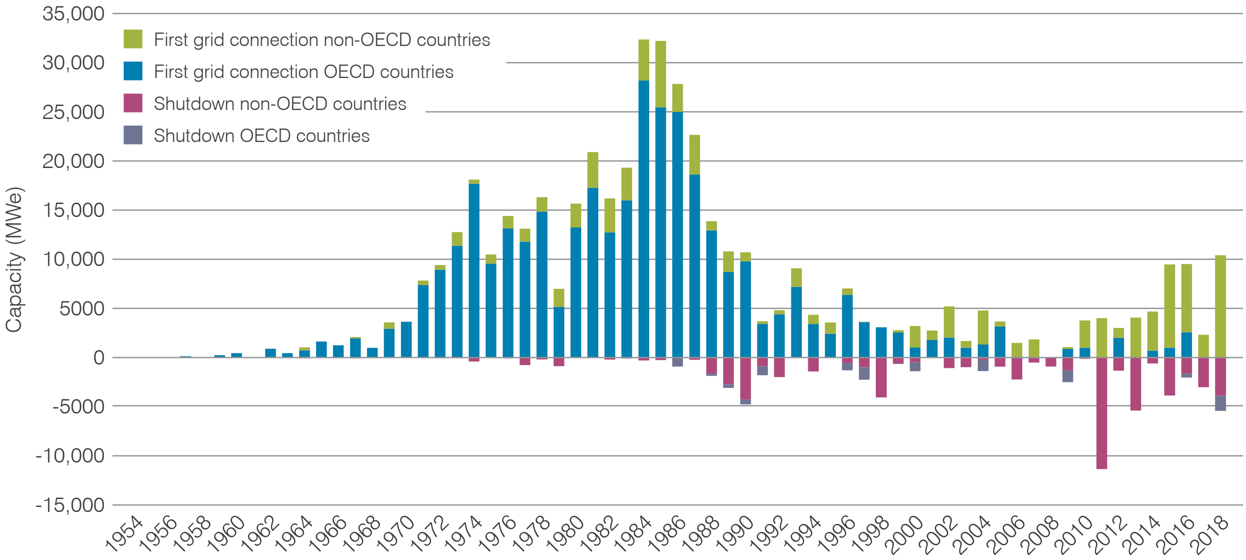
Figure 14. Average capacity of units first grid connected 1954-2018



Source: World Nuclear Association, IAEA PRIS

Increasingly, reactor start-ups are predominantly taking place in non-OECD countries, demonstrating the importance of nuclear energy in growing economies.

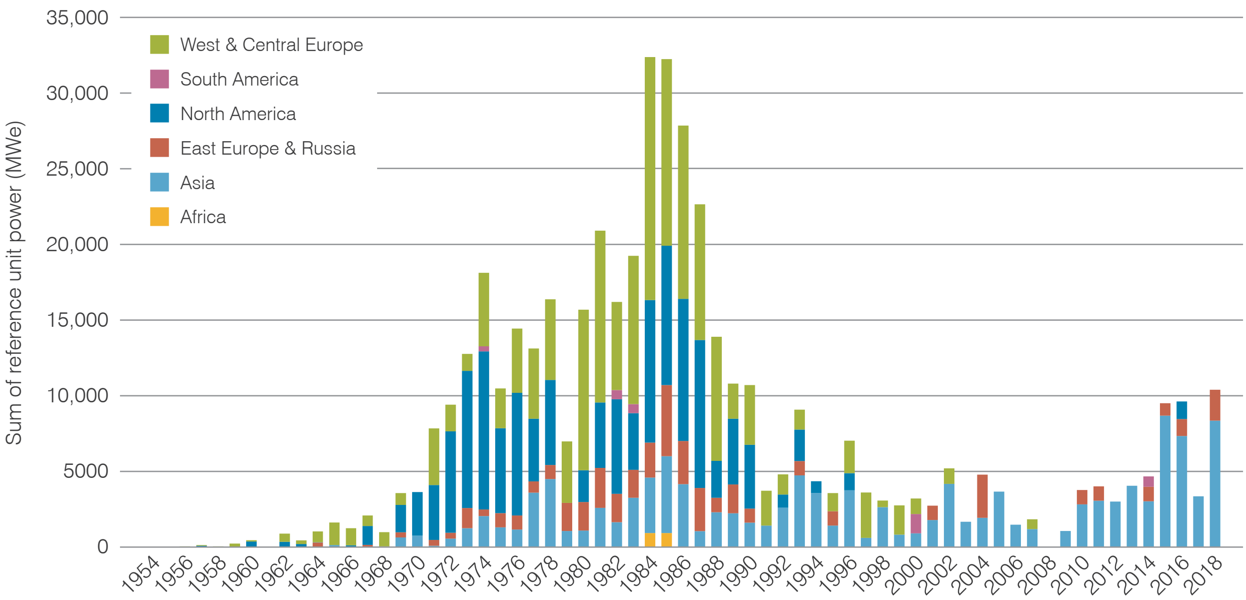
Figure 15. Capacity of OECD and non-OECD first grid connections 1954-2018



Source: World Nuclear Association, IAEA PRIS

The evolution of reactor start-ups in different regions is shown in Figure 16, below. The majority of reactor capacity built between 1970 and 1990 were in West and Central Europe and in North America. Since that period the majority of reactor startups have been in Asia, with first grid connections in East Europe and Russia also contributing to new global capacity.

Figure 16. Capacity of first grid connection 1954-2018



Source: World Nuclear Association, IAEA PRIS

3 | Case Studies

Fifty years of operation achieved by five reactors

Reactor details

	Construction start	First grid connection	Net capacity (MWe)	Model
Beznau 1	1 September 1965	27 July 1969	365	Westinghouse 2-Loop PWR
Nine Mile Point 1	12 April 1965	9 November 1969	613	BWR-2 (Mark 1)
R.E. Ginna	25 April 1966	2 December 1969	580	Westinghouse 2-Loop PWR
Tarapur 1	1 October 1964	1 April 1969	150	BWR-1 (Mark 2)
Tarapur 2	1 October 1964	5 May 1969	150	BWR-1 (Mark 2)

This year five reactors will celebrate 50 years of operation. Beznau 1 in Switzerland, Nine Mile Point 1 and R.E. Ginna in the USA, and Tarapur 1&2 in India all started operating in 1969. This is the first time this milestone has been achieved by any reactor worldwide.

Tarapur 1 has the distinction of being the oldest operating nuclear power reactor as it was first grid connected on 1 April 1969, however, both units 1&2 at Tarapur commenced commercial operation on 28 October 1969.

Begun as India's first nuclear power project, the first two units at Tarapur were built concomitantly, following the signing of a contract between the governments of India and the USA on 8 May 1964.

The BWRs were supplied by the US company General Electric. Construction began in October 1964.

The Tarapur nuclear power plant is located near Boiser in the Thane District of Maharashtra, India. It is also known as TAPS (Tarapur Atomic Power Station). Also operating on the Tarapur site are two newer 490 MWe PHWR reactors.

Tarapur 1&2 have gone through significant safety improvements based on periodic reviews, according to India's Atomic Energy Regulatory Board. This included extra sea protection installed following the Fukushima Daichi accident of 2011. While units 1&2 at Tarapur have not operated consistently at the same high levels of performance as the Swiss and US plants, unit 1 achieved a capacity factor of 92.9% in 2016 and unit 2 achieved 98.5% in 2017.

Control panel of R.E. Ginna (Image: Exelon)

Beznau 1&2 (Image: Axpo)

Beznau unit 1 is operated by Swiss energy utility Axpo. In combination the two nuclear power plants at Beznau employ over 500 people. Alongside its unit 2 sister plant, it contributes to a pool of power plants operated by Axpo with largely CO_2-free electricity production. Nuclear power plants, river-based hydroelectric plants and biomass power plants cover the base load of the electricity supply. High-pressure pumped storage power plants are used to manage fluctuations and peaks in demand.

Beznau is an inland nuclear power plant. Steam from the generator turbines is cooled in the condensers using water from river Aare. After mixing, the river temperature is raised by around 1°C, considerably less than natural monthly variations.

In addition to supplying electricity, the Beznau plant supplies district heating. Heat is extracted between the high- and low-pressure section of the turbine where steam with a temperature of 127°C is routed to a heat exchanger. There, the heat is transferred to the district heating network, whose water heats up in the process to 120°C. The power station's electrical output decreases by up to 7.5 MW during heat extraction.

Beznau 1 did not operate in 2016 and 2017 as operators successfully demonstrated the reactor vessel's compliance with regulations, following the discovery of aluminium oxide inclusions. Despite this outage, the lifetime capacity factor of the unit remains high, at 79.6%. Prior to the outage, the reactor demonstrated excellent performance, with capacity factors frequently over 90%.

Interview

Michael Dost, Head of Beznau nuclear power plant

What are you most proud of about achieving 50 years of operation?

For us, the 50 years of operation represent a piece of Swiss history. The Swiss pioneering spirit and a good deal of impressive engineering artistry manifest themselves in the plant. Our predecessors built something great, with a quality and precision that we still benefit from today. I feel privileged to be able to walk through this facility, to experience again and again how ingenious our predecessors were. At the same time, I am proud of our crew. And with the experience of the several power plants that I have been able to get to know in my professional life, I can say that our crew is the best I have ever been able to work with. In other words, I am proud of what we can show today, the result of 50 years of know-how and generations of experts from many professions. They have all put in their best efforts to keep the plant up to date and make it what it is today. I am proud that we can continue the work of our predecessors with the same foresight, calmness and professionalism, commitment and team spirit that have always been the pillars of Beznau culture.

What would you recommend to other reactor operators to help achieve a long operating lifetime?

I recommend comprehensive ageing management, continuous investment in plant safety and reliability and a dash of foresight to everyone. Thanks to the many investments in renewal and maintenance, we were able to keep the plant at the state-of-the-art in science and technology, as required by Swiss law. Thanks to our foresight, we were also able to anticipate technical and also increasing regulatory requirements. It is only thanks to this forward-looking planning over generations that the Beznau nuclear power plant is still able to operate almost trouble-free, safely and reliably today. All those who claim that the plant does not comply with modern safety requirements fail to appreciate this performance and prudence. We will not deviate from this path either. The technical condition of the plant will remain at a level that guarantees safe and reliable operation. Safety remains our top priority as an operator. We also want to continue to receive top marks, even in an international comparison.

Nine Mile Point 1, sited on the shores of Lake Ontario in New York state, is a 613 MWe BWR. A second unit, with a capacity of 1277 MWe, was grid connected nearly 20 years later, in 1987. Both units are licensed to operate for 60 years, which would see unit 1 operation continue to 2029.

Recent performance of Nine Mile Point 1 has been consistently high, with an average capacity factor of 93.2% since 2000.

The single unit at R.E. Ginna was first grid connected in December 1969. It is a 580 MWe BWR, also located on the shores of Lake Ontario. Since 2000 the average capacity factor of R.E. Ginna has been 94.5%. R.E Ginna's operation have prevented the release of more than 2 million tonnes of carbon dioxide annually, the equivalent of taking about 400,000 cars off the road.

The role that Nine Mile Point and R.E. Ginna play in helping to limit greenhouse gas emissions has been recognized by New York's Clean Energy Standard (CES). This policy, introduced in 2016, explicitly recognizes the zero-carbon contribution of nuclear power plants in its pursuit of clean energy goals. The New York Public Service Commission (PSC) estimated over the first two years of the program the combined economic and environmental benefits of keeping the two units at Nine Mile Point, the single unit at R.E. Ginna and an additional unit at James A. FitzPatrick in operation would be worth about $4 billion.

The robustness and reliability of Nine Mile Point and R.E. Ginna has be demonstrated by their continued operation during extreme weather. Both plants have supplied much-needed electricity through chilling polar vortex conditions and summer heatwaves.

Workers at Nine Mile Point (Image: Exelon)

Interview

Paul Swift, Plant Manager,
R.E. Ginna Nuclear Power Plant

What are you most proud of about achieving 50 years of operation?

Nuclear power plants generate 60% of the USA's carbon-free energy and I am proud to be a part of that effort, especially now that I have grandchildren. With decades of smart investments and upgrades, the plant is running better than ever. Over the last 10 years, the R.E. Ginna nuclear power plant has operated safely at more than 95% of capacity, making it one of New York's most efficient power generators. The Paris Climate Agreement set an objective to achieve an 80% reduction in greenhouse gas emissions by 2050. Nuclear energy needs to be part of the solution for the USA to reach this ambitious goal.

What would you recommend to other reactor operators to help achieve a long operating lifetime?

We build on decades of experience and a highly talented workforce to ensure our operations are the safest and most efficient of any industry. But powering our communities with reliable carbon-free energy is just the beginning. It also is our responsibility to improve the quality of life for our neighbours in the communities where we live, work and serve. One way we do this is by providing funding for STEM (science, technology, engineering and mathematics) programmes. This important investment in our future workforce demonstrates our commitment to be a good corporate citizen and helps ensure successful long-term operation of the plant.

Interview

Pete Orphanos, Site Vice President,
Nine Mile Point

What are you most proud of about achieving 50 years of operation?

Our 'Pride in the Point' is the common bond for everyone on our site, and we have much to be proud of here. The 50-year milestone for unit 1 is really an opportunity to reflect on the overall impact of the unit and the plant as a whole. We've been supplying reliable, clean energy to power homes, drive business growth and ensure grid resiliency for half a century – and we've been doing it carbon-free while being good stewards of the environment. We've also been good neighbours and partners with our community, building strong relationships. The community relies on jobs, taxes, workforce development programmes, charitable giving and other benefits from our plants and our incredible team of workers. I have great pride in these things, and I know that everyone on the site shares in that feeling.

What would you recommend to other reactor operators to help achieve a long operating lifetime?

Exelon Generation really sets the standard for world-class power plant operations. Our fleet's expertise and operational excellence is the cornerstone of long-term generation that is safe, cost-effective, efficient and reliable.

The Akademik Lomonosov Floating Nuclear Power Plant

The Akademik Lomonosov is the world's first purpose-built floating nuclear power plant. When it becomes operational the Akademik Lomonosov will be the source of up to 70 MWe electrical and 58 MWt heat energy.

It will supply electricity to mining projects, reduce the use of fossil fuels, and assist the sustainable development of the region. It will replace generating capacities of the Chaun-Bilibino Energy Hub – the Chaunskaya fossil fuel power plant and the Bilibino nuclear power plant.

Following an initial keel-laying ceremony in Severodvinsk, construction was transferred to the Baltiysky Zavod shipyard at St Petersburg, where a new keel-laying took place in May 2009. The hull of the vessel was launched at the end of June 2010 and the two 220-tonne steam generating units, each including one KLT-40S reactor from OKBM Afrikantov, were installed in October 2013. Mooring tests started in mid-2016, and in May 2018, the vessel completed the first leg of its journey to Pevek, sailing 4,000 km and crossing four seas: Baltic, Northern, Norwegian and Barents, before mooring in Murmansk for fuel loading, which was completed in October 2018. First criticality was reached in November 2018 and by March 2019 both reactors had been tested at maximum output.

The final leg of the plant's journey to Pevek started late August, and grid connection is expected before the year-end.

It is planned that the plant would operate in 12 year-stretches. Fuel would be reloaded every four years. After 12 years the vessel would be returned to port for waste removal. The plant would complete at least three of these cycles, for a design operational lifetime of 40 years, with the possibility of further cycles.

More floating nuclear power plants are planned. In addition to electricity and heat, these facilities will also be able to supply clean, desalinated water. In July 2017 Rosatom announced the second generation of floating nuclear power plants, now called Optimized Floating Power Units (OFPUs). These would use two RITM-200M reactors derived from those used for the latest icebreakers, which, at 50 MWe each, are more powerful than the KLT-40S reactors. The RITM-200M reactors are each 1500 tonnes lighter, so the barge would be smaller and displacement would be reduced from about 21,000 to 12,000 tonnes. Operational lifetime is 40 years, with possible extension to 50 years.

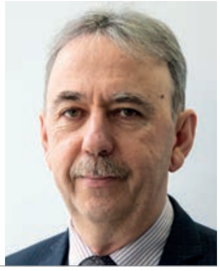
Reactor details

Reactor model	Two KLT-40S reactors
Combined electrical output	> 70 MWe
Rated thermal output to the interim loop of the heat supply system	58.15 MWt
Design operational lifetime	40 years

Vessel details

Length	140 m
Width	30 m
Draft	5.6 m
Displacement	21,500 tonnes

The Akademik Lomonosov (Image: Rosenergoatom)



Interview

Vitaly Trutnev, Director of Floating Nuclear Power Plant Construction & Operation, Rosenergoatom

What are the most remarkable achievements in the construction and startup of Akademik Lomonosov?

The two most remarkable achievements are the towing from the Baltic shipyard in Saint Petersburg to the Atomflot base in Murmansk, and the first criticality and integrated testing of the floating power unit.

What were the main challenges at the construction and startup stages?

From the construction point of view, the main challenge that faces scientists and designers is to accommodate two reactors on board a relatively small vessel while keeping all functional properties of an onshore nuclear power plant with fewer personnel. Furthermore, it is crucial to ensure the highest level of reliability and safety of work without any environmental impact.

The difficulties of onshore infrastructure arrangements are also worth mentioning bearing in mind the Arctic conditions and limited navigation period.

What experience from Akademik Lomonosov construction may be useful for the nuclear industry?

The most useful experience was that of the turn-key construction, with the contractor bearing the full responsibility at the construction and test stages.

What are the benefits to the region hosting the Akademik Lomonosov?

The Akademik Lomonosov is intended for operation in the Far North, in particular for reliable power supplies to Chukotka. The plant may replace the ageing generating capacities in Chukotka, namely the Bilibino nuclear power plant and the Chaunskaya fossil fuel power plant, allowing for reliable and continuous power supplies in the region.

The decisive factor for plant competitiveness in remote regions is the possibility to minimize expenses on long-distance electricity transmission in a hostile environment as such expenses may be several times higher than electricity generation costs.

The operational objective of the floating nuclear power plant is to considerably improve the life quality in regions with power shortages and to create favourable conditions for sustainable development.

The special thing about nuclear generation is its importance for ecology. The operation of the Akademik Lomonosov makes it possible to avoid the consumption of 200,000 tonnes of coal and 120,000 tonnes of fuel oil annually, either directly or indirectly due to gas savings. The plant decommissioning upon its service life expiration is also convenient for the hosting regions as the vessel will be towed to special facility berths leaving the site in a greenfield state.

What is your opinion on the prospects for floating nuclear power plant development?

These types of plant are necessary for remote Arctic areas as they are able to resist hostile environmental conditions. In addition, the equipment of the floating power unit is compliant with all reliability and safety requirements including recommendations of the International Atomic Energy Agency (IAEA) on nuclear and radiation safety.

Considering the above, the floating power unit is primarily in demand in the Far North and Far East of Russia that are not within the common power system and need reliable and affordable power sources. Floating nuclear power plants may be used in combination with a desalination system with reverse osmosis or multistage evaporators. Many African, Asian and European countries with acute fresh water shortages are interested in such systems.

Refurbishment of Darlington Nuclear Power Plant

Reactor details

Location	Ontario, Canada
Reactor type	Pressurized heavy water reactor (PHWR)
Owner	Ontario Power Generation
Operator	Ontario Power Generation
Net capacity	4 x 878 MWe
First grid connection	15 January 1990 (Unit 2)

The four 878 MWe PHWR Candu 850 reactors at the Darlington nuclear power plant meets about 20% of Ontario's electricity needs and has been in operation since the early 1990s. These pressurized heavy water reactors (PHWRs) are now reaching the mid-point of their planned operating lifetimes and Ontario Power Generation (OPG) is overseeing a multi-billion dollar refurbishment project.

In 2016, after years of detailed planning and preparation, OPG's team of project partners, industry experts, energy professionals, and skilled tradespeople shut down unit 2, the first of four Darlington reactors scheduled for refurbishment over the next 10 years.

After shutdown, 6240 fuel bundles were removed and placed in water-filled bays. Heavy water was drained from the reactor and the heat transport system, then stored, cleaned and purified, ready to be pumped back in after unit reassembly. Equipment was disconnected and physical barriers were put in place to isolate the reactor from the remaining operational plant.

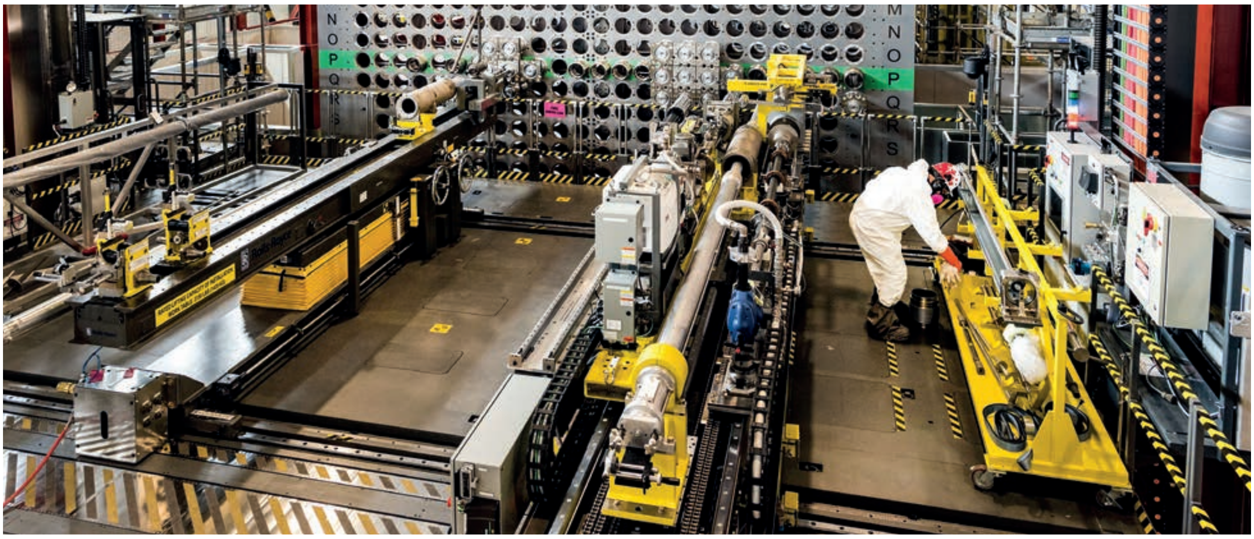
The reactor was then disassembled. A total of 960 feeder tubes were removed from the reactor, followed by 960 end fittings and 480 zirconium calandria tubes and 480 pressure tubes.

The calandria vessel was then inspected and cleaned, before the reassembly process could take place. 480 new calandria tubes were first inserted. After partially preassembling the fuel channels (an end fitting connected to a pressure tube) in a clean room, 480 fuel channels were then installed.

At time of writing, the upper and middle section of each of the 960 uniquely shaped feeder tubes have been installed.

OPG is already preparing for the refuelling of unit 2, which will follow installation of the lower sections of the feeder tubes. Following the refuelling there will be confirmation that containment has been restored, followed a round of inspections and approvals before reconnection to the power grid, expected to take place in February 2020.

In the first quarter of 2020 the unit 3 refurbishment will get underway, followed by unit 1 and unit 4. The complete refurbishment project is expected to be completed by 2026, and will ensure an additional 30 years of operation at the Darlington plant.



Mock-up training facility (Image: Ontario Power Generation)

Interview

Dietmar Reiner, Senior Vice-President, Enterprise Projects, OPG

What has proved the most challenging aspect of the project?

Some of the more challenging aspects of the Darlington refurbishment project include maintaining momentum, drive, and the required level of 'intensity' over the long term in order to ensure the project is completed on time and on budget.

Ensuring access to a sufficient pool of qualified trades has been a challenge for the project as well as for the nuclear sector, as a whole. OPG is building up new sources of supply by promoting trades programmes through recruitment initiatives at local jobs fairs, community outreach and specific initiatives to increase the level of interest of women and indigenous peoples in trades.

Having an experienced management team on an ongoing basis is key to the success of the project. OPG has a corporate-wide succession planning process and a number of training programmes to develop staff. OPG also has a pool of staff in Pickering who have extensive nuclear and project management experience and will be trained on refurbishment-specific activities as needed. There is always a risk that staff will move on and, where needed, OPG will recruit internally/externally.

What has contributed to the project's success?

The three main contributors to the project's success are employee expertise; transparency and communication; and looking ahead to anticipate issues and risks, and mitigating them before they have an impact.

Years of planning and preparation have gone into the refurbishment project with a clear definition of scope prior to its execution. For example, we front-loaded non-critical work early on in the schedule so as not to distract or affect the critical path of returning the unit to service near the end of construction.

OPG has maintained rigorous oversight of the project with continuous internal and external audits to provide real-time recommendations to make any course corrections.

We also have the Refurbishment Construction Review Board, which consists of seasoned experts providing focused reviews to provide feedback and recommendations for continuous improvement, and have been planning with other nuclear refurbishment projects to find efficiencies and sharing of information.

Shortly after opening the Darlington Energy Complex in 2013, OPG constructed a full-scale mock-up of a Darlington reactor and reactor vault to test tools, refine procedures and train the human interface. The mock-up also helped to establish an accurate timeline for all tasks as well as help to develop a robust cost and schedule outline.

Finally, safety is our top priority at OPG and something we take very seriously while undergoing any project. The safety standards for the refurbishment project are maintained at the highest level and are never sacrificed in favour of schedule or budget.

Have any lessons been learned from the project that could be applied more broadly in the industry?

The execution of the unit 2 project has provided numerous lessons learned that are being captured through a managed system and are being applied to future units to reduce schedule duration and improve cost efficiencies. OPG continuously looks for improvements and opportunities, particularly in the tooling innovation and engineering process. Each are evaluated to determine return on investment and then executed.

Other lessons learned from the refurbishment project include: a continuous effort to constantly look for cost savings and shared accountability at all levels in the organization; tool readiness ahead of the execution window start dates to allow time for quality training; and integration of training between contractor and operator.

We are exerting a lot of effort to focus on improving tooling performance for subsequent units to improve schedule, safety and quality. The focus is on tooling that impacts the critical path.

4 Director General's Concluding Remarks

There is growing demand for electricity, and that electricity must be clean. The world's population continues to grow, the economic and societal aspirations of developing countries are undimmed and demand grows as modern society produces ever-more uses of electricity.

Nuclear energy can meet this growing demand, providing clean and reliable supplies of electricity.

In May 2019, the International Energy Agency (IEA) published its report, "Nuclear Power in a Clean Energy System". The vital role for nuclear energy was set out by IEA Director General Fatih Birol, who said; "Without an important contribution from nuclear power, the global energy transition will be that much harder."

The IEA report made it clear that nuclear can make a significant contribution to achieving sustainable energy goals and enhancing energy security. However, urgent action is needed to ensure that this significant contribution can be made.

Fatih Birol said; "Policy makers hold the key to nuclear power's future. Electricity market design must value the environmental and energy security attributes of nuclear power and other clean energy sources."

These conclusions were echoed by the "The Costs of Decarbonisation" report by the OECD Nuclear Energy Agency (NEA), which observed that; "Decarbonizing the electricity sector in a cost-effective manner while maintaining security of supply requires the rapid deployment of all available low-carbon technologies."

To achieve this would require policy-makers to recognize and allocate the system costs to the technologies that cause them and to encourage new investment in all low-carbon technologies by providing stability for investors. The overall conclusion of the NEA analysis was that the most effective way to achieve deep decarbonization of the electricity generation mix was to have a high proportion of electricity supplied by nuclear power.

This conclusion echoes that reached in the Intergovernmental Panel on Climate Change (IPCC) report on Global Warming of 1.5°C, published in 2018. This report evaluated 85 scenarios that would achieve the goal of limiting global warming to 1.5°C.

On average, these scenarios would see nuclear generation increasing by around two and a half times by 2050. In a representative scenario, where societal and technological developments follow current patterns, nuclear generation increases over five-fold.

It is evident that, unless nuclear energy is a significant part of the global response to climate change it will be highly unlikely we will be able to achieve a full decarbonization of our generation mix, and even if it were possible the costs would be exorbitantly high.

Public support

If nuclear energy is to play its full role in providing clean, reliable and affordable electricity then it will need the backing of a broad range of stakeholders. Increasingly, in countries where politicians oppose nuclear energy, their views are out of step with those of their electorate.

In South Korea in 2017 President Moon Jae-in decision to halt construction of two reactors at Shin Kori was reversed by a Citizen's Jury.

In Germany public opposition to the country's nuclear phase-out has been growing, with little benefit being seen from the country's huge investment in renewables. In June 2019, Volkswagen CEO Herbert Diess said that Germany should have prioritized the phase-out of coal, rather than nuclear, commenting that; "if we give high priority to climate protection, nuclear power stations should operate for longer."

Nuclear can deliver if we act now

Over the last 18 months the call for action on climate change has become louder and more urgent. I admire the commitment of those who are calling for change and I share their concern for the planet's future.

Some have questioned whether nuclear energy can be deployed quickly enough to tackle climate change in time. The fact is that nuclear energy is making a major contribution to avoiding climate change today, with more than 10% of the world's electricity supplied by nuclear generation.

One of the most effective actions to be taken to avoid greenhouse gas emissions is to ensure those reactors continue to operate to their full potential. The average age of the nuclear fleet is around 30 years. This year, five reactors have achieved fifty years of operation and reactors today are seeking approval for 60 or even 80 years of operation. Many of our current reactors have the potential to still be part of a fully decarbonized generation mix in 2050.

More than 50 reactors are under construction, and half of those are expected to start generating electricity over the next two years. In total, reactors under construction today will avoid the emission of 450 million tonnes of CO_2 each year by 2025, adding to the more than two billion tonnes of CO_2 currently avoided by nuclear power each year, as it reduces our global dependence on coal. This is equivalent to the combined annual CO_2 emissions of Japan, Germany and Australia.

Where reactors are decommissioned over the next 30 years, new reactors should be constructed to replace them. As well as ensuring the continuation of the benefits of nuclear generation, construction and commissioning of replacement reactors will ensure that key skills are retained and local communities continue to have employment opportunities.

But can nuclear generation be expanded fast enough to combat climate change? During the rapid expansion of nuclear generation in France in the 1980s and 1990s, most reactors were built in six to seven years. In recent years in China, nuclear reactors have been frequently constructed in around five years. In 2018, the global median construction time was longer, eight-and-a-half years, primarily because of the high proportion of first of a kind reactors starting in 2018.

A commitment to a substantial expansion of nuclear generation would deliver the benefits of series construction, including faster and lower cost construction.

The IPCC's 1.5°C report states that global greenhouse gas emissions need to start to decline almost immediately. Reactors under construction and the continued operation of existing reactors can contribute to this goal. But to contribute to the further reductions that will be necessary from 2025 to achieve net zero emissions by 2050 decisions to invest in new nuclear build will need to accelerate urgently.

Our Harmony goal is for nuclear generation to supply 25% of the world's electricity before 2050. This would require at least 1000 GWe of new nuclear build. To achieve this, new nuclear capacity added each year would need to accelerate from the current 10 GWe to around 35 GWe for the period 2030-2050. Those countries operating nuclear power plants should commit to continue to do so and those countries with recent experience of new nuclear build should commit to a rapid expansion of their construction programmes to deliver significant new nuclear construction from 2025.

Beyond 2025 more countries will be able to contribute to achieving our Harmony goal. More new nuclear generation will be needed to bring economic growth, as developed countries continue their efforts to decarbonize their generation mixes and developing countries endeavor to meet demand for electricity driven by growing populations and industrial expansion essential to modern life.

If we are to be serious about climate change we should also be serious about the solutions. Transitioning to a low-carbon economy that meets the energy needs of the global community presents a daunting task. But it is a challenge that must be met, and one that can only be met by using the full potential of nuclear energy.

5 Status Update to 31 July 2019

Operable Reactors

395 GWe

Reactors Under Construction

52 GWe

New connections to the grid

	Capacity (net)	Location	First grid connection
Shin Kori 4	1340 MWe	South Korea	22 April 2019
Novovoronezh II-2	1114 MWe	Russia	1 May 2019
Taishan 2	1660 MWe	China	23 June 2019
Yangjiang 6	1000 MWe	China	29 June 2019

Construction starts

	Capacity (net)	Location	First concrete
Kursk II-2	1115 MWe	Russia	15 April 2019

Permanent shutdowns

	Capacity (net)	Location	Shutdown
Bilibino 1	11 MWe	Russia	14 January 2019
Genkai 2	529 MWe	Japan	13 February 2019
Pilgrim 1	677 MWe	USA	31 May 2019
Chinsan 2	604 MWe	Taiwan	15 July 2019
Fukushima Daini 1	1067 MWe	Japan	31 July 2019
Fukushima Daini 2	1067 MWe	Japan	31 July 2019
Fukushima Daini 3	1067 MWe	Japan	31 July 2019
Fukushima Daini 3	1067 MWe	Japan	31 July 2019

Abbreviations

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-cooled graphite-moderated reactor
LWR	Light water reactor (a BWR or PWR)
MOX	Mixed uranium and plutonium oxide
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 Reaktor (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, Poland, Russia, Ukraine

North America
Canada, Mexico, USA

South America
Argentina, Brazil

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

OECD countries with nuclear power plants
Belgium, Canada, Czech Republic, Finland, France, Germany, Hungary, Italy, Japan, Lithuania, Mexico, Netherlands, Portugal, Slovakia, Slovenia, South Korea, Spain, Sweden, Switzerland, UK, USA

Further Reading

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

World Nuclear Association Reactor Database
https://world-nuclear.org/information-library/facts-and-figures/reactor-database.aspx

The Nuclear Fuel Report: Global Scenarios for Demand and Supply Availability 2019-2040 (published September 2019)
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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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