WORLD NUCLEAR ASSOCIATION

World Nuclear Performance Report 2016

Asia Edition

For Singapore International Energy Week

Title: World Nuclear Performance Report 2016 - Asia Edition
Produced by: World Nuclear Association
Published: October 2016
Report No. 2016/003

Contents

Preface

At the start of 2015 there were 436 operable reactors around the world and by year-end there were 439. This increase in reactor numbers came despite the retirement of seven units during the year. A larger number of nuclear power units are under construction than at any other time in the last 25 years, and with another ten new reactors coming online – also a 25-year record for the industry – 2015 demonstrated improving new build performance all round. The existing global fleet generated roughly 10% of the world's electricity, making up around one-third of the world's low-carbon electricity supply.

Nevertheless, established fleets in several European countries face public acceptance issues and a negative policy environment; there are tough economic conditions for operators not only in some deregulated energy markets such as in parts of the USA, but also in European countries where electricity prices have been depressed by a growing share of renewable technologies subsidised to produce regardless of whether their electricity is needed or not.

In Asia we see the future of the Japanese fleet crystallising with the first reactors restarted in 2015 under a new safety regime. China continues to grow as a nuclear power hub, taking advantage of its stable and long-sighted policy regime as well as economies of scale. India is progressing both with new units and with imports of overseas technology, while South Korea is nearing completion of its first reactor exports to the United Arab Emirates which will be only the second country in the Middle East to generate nuclear electricity.

Even today's high rate of new build is, however, insufficient if the world is to meet the targets for reducing the impacts of global warming agreed at the 21st Conference of Parties (COP21) on climate change, which took place in Paris last year.

The World Nuclear Association's vision for the future global electricity system consists of a diverse mix of low-carbon technologies – where renewables, nuclear and a greatly reduced level of fossil fuels (preferably with carbon capture and storage) work together in harmony to ensure a reliable, affordable and clean energy supply. This mix must find the optimal balance between the need for human development and the protection of the natural environment. To achieve this, the role of nuclear energy must be expanded. Our *Harmony* vision sets a target for 1000 GWe of new nuclear capacity to be added by 2050, so that nuclear would supply about 25% of global electricity.

We are publishing this World Nuclear Performance Report 2016 to provide an up-to-date picture of the civil nuclear power sector today and how it is performing across several key metrics. This edition features a special focus on Asia, which we are proud to present at Singapore International Energy Week.

Agneta Rising
Director General
World Nuclear Association

1 Nuclear energy for sustainable development

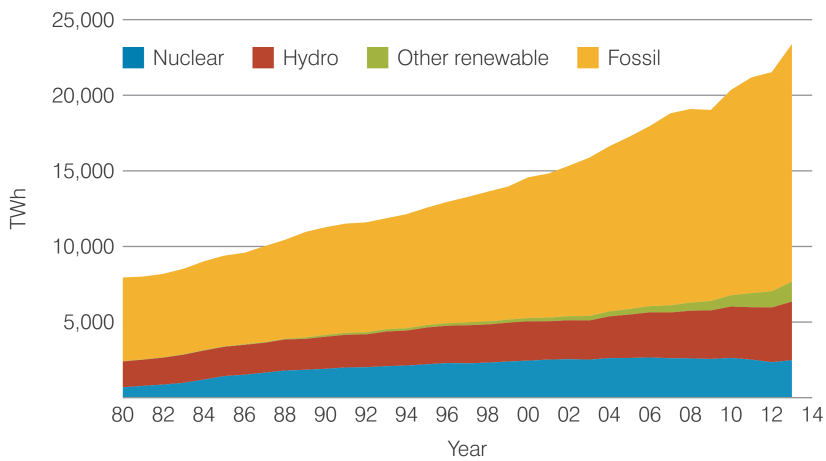
At the Paris Conference of Parties to the United Nations Framework Convention on Climate Change in December 2015, an agreement was reached to hold the increase in the global average temperature to less than 2°C compared to pre-industrial levels, and to pursue efforts to remain within a 1.5°C rise. This will require a dramatic reduction in the global rate of greenhouse gas emissions. At present, however, emissions continue to rise, with the average concentration of CO_2 in the Earth's atmosphere now standing at 400 parts per million (ppm). As the 2°C limit roughly corresponds to a concentration of 450 ppm, there is less and less scope to source energy requirements from fossil fuels.

Averting a temperature rise above 2°C will require the almost total decarbonisation of energy supply over the coming decades. Far from reducing dependency on fossil fuels, however, the world continues to burn ever greater amounts annually, especially for electricity, as shown in Figure 1.

Each country should have access to the most suitable portfolio of low-carbon technologies available in order to both meet its needs and satisfy climate goals. Nuclear energy is proven, scalable over the timeframe required, and helps to underpin sustainable development prospects. A recent report from the Intergovernmental Panel on Climate Change (IPCC) confirmed that nuclear energy is one of the forms of generation with a low CO_2 footprint, taking into account both direct emissions and its lifecycle impacts.[1] The use of nuclear energy is recognized widely as being crucial to achieving climate targets as well as the general energy policy goals of affordability and reliability.

In developing countries, 1.3 billion people living mostly in rural areas and slums lack access to electricity, and an even larger number, 2.7 billion, rely on traditional biomass fuels.[2] Under current plans, no-one should lack a power supply connection by 2030 in Latin America, China, India and South Africa. But despite investment in rural electrification and urban development (including slum clearance and rehousing), in the rest of Sub-Saharan Africa and in parts of South Asia, there will remain significant areas of energy poverty. The International Energy Agency

Figure 1. Electricity production by sources

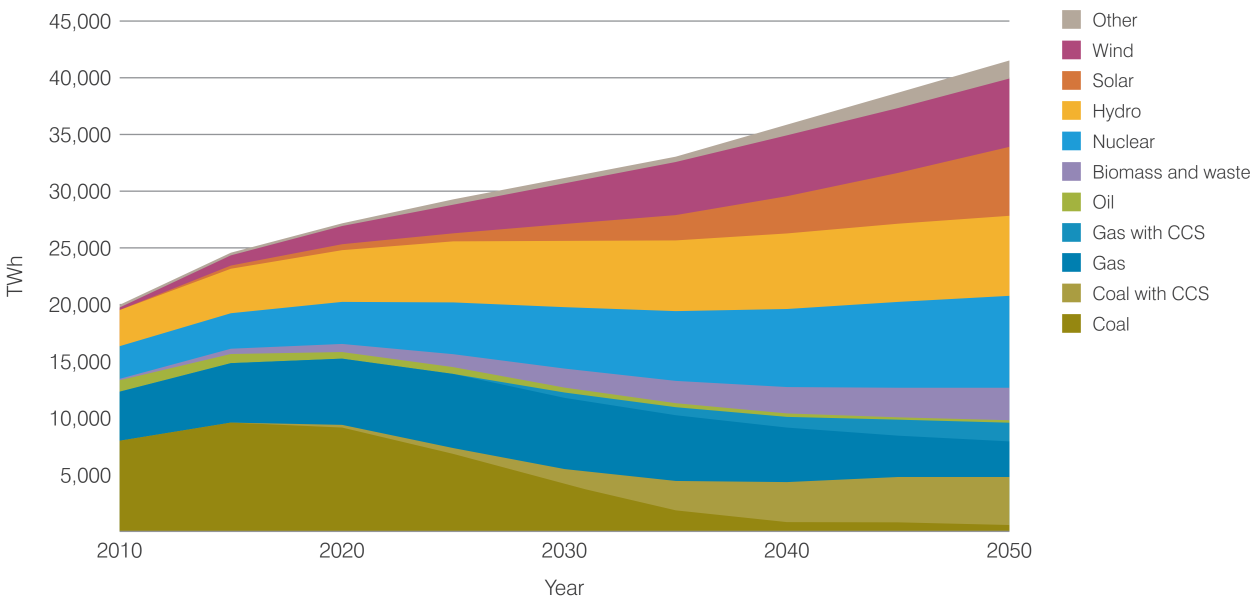


Source: International Energy Agency, World Energy Outlook 2014

[1] *Climate change 2014: Mitigation of climate change*, Summary for Policymakers, Intergovernmental Panel on Climate Change Working Group III Contribution to Assessment Report 5, Geneva, Switzerland: Intergovernmental Panel on Climate Change.

[2] *World Energy Outlook 2011*, International Energy Agency, p.472; *World Energy Outlook 2014*, International Energy Agency, p.73.

Figure 2. International Energy Agency 2°C Scenario for electricity generation



Each country should have access to the most suitable portfolio of low-carbon technologies available

forecasts that there will still be some 635 million people lacking a power connection by 2040, primarily in rural areas and in Central and East Africa.[3]

In light of this, in September 2015, the international community adopted a goal of universal access to affordable, reliable and sustainable modern energy by 2030.[4] Integrating such a goal with other development priorities, such as water supply and sanitation, will generate substantial benefits for low income households. Access to reliable and affordable energy, including nuclear power, was recognized as critical to sustainable development when the G20 countries met in 2013.[5]

Many decision-makers and commentators see distributed generation systems relying on solar power as a solution for Africa's rural population, but renewable energy sources are unlikely to be sufficient to meet the needs of rapidly growing cities and industry.[6] By 2050, 66% of the world's population will be urban according to UN projections, with rural populations in decline worldwide from the 2020s onwards. Ninety percent of the growth of the urban population will be in Asia and Africa. By 2030 there will be 41 megacities (of 10 million or more inhabitants), up from 28 today, with about 700 million inhabitants in total. Another 1.5 billion people will live in cities with 1 to 10 million inhabitants by 2030, up from 800 million today.[7] Altogether by 2030 there will be 2.2 billion living in cities of 1 million or

[3] *World Energy Outlook 2014*, International Energy Agency, p.536-537.

[4] Resolution of the 70th Session of the UN General Assembly of 25 September 2015, Transforming our world: the 2030 agenda for sustainable development, A/RES/70/1: 14/35.

[5] G20 Leaders' Declaration made at the St Petersburg Summit of 5-6 September 2013: paragraphs 90 and 97.

[6] African energy: The leapfrog continent, *The Economist*, p.42-43 (6 June 2015).

[7] United Nations Department of Economic and Social Affairs, *World Urbanization Prospects: The 2014 Revision - Highlights*, Figure 8.

over in size, compared to 1.25 billion now, an increase of 76%.

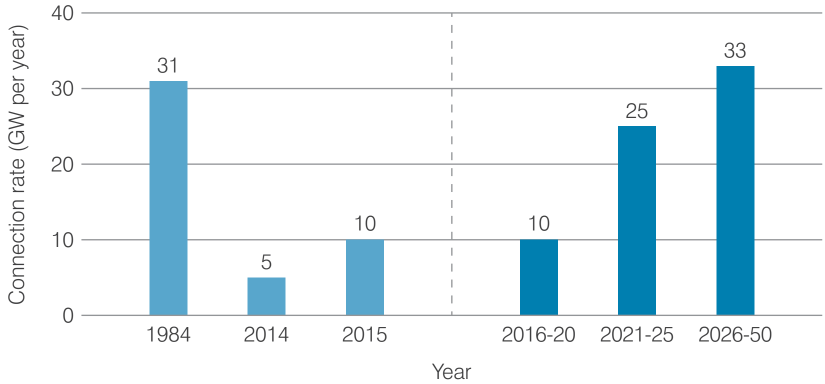
The International Energy Agency 2DS (2°C Scenario, Figure 2) envisages a substantial increase in the contribution from nuclear energy, rising to 7000 TWh by 2050 – enough to supply about 17% of global electricity in a world where consumption has doubled. Because the availability and scalability of some technologies in 2DS remain unproven, the World Nuclear Association's *Harmony* vision sets higher targets for nuclear power: 25% of electricity in 2050, which is estimated to require construction of 1000 GWe of new nuclear capacity when retirements are taken into account. One possible pathway to this target would be to build 10 GWe a year between 2015 and 2020, step this up to 25 GWe per year to 2025 and then 33 GWe per year to 2050. Industry performed at this level in 2015, adding 9.875 GWe of new capacity and prompting the IEA to state: "Progress and construction times in 2015 show the long-term 2DS targets to be more achievable than previously thought."[8]

Major investment and policy commitment is required to achieve the acceleration envisaged by *Harmony*, but the rate of nuclear grid connection required to meet these targets is not particularly ambitious. It was in fact achieved in the mid-1980s as Figure 3 shows.

Nuclear energy technology is available today; it can be scaled up quickly; it is efficient and affordable, including in the rapidly developing emerging industrial economies of Asia, Africa and Latin America.

IEA: "Progress and construction times in 2015 show the long-term 2DS targets to be more achievable than previously thought."

Figure 3. Nuclear grid connection rates required to meet the *Harmony* target of 1000 GW of new build by 2050



[8] International Energy Agency, *Energy Technology Perspectives 2016*, p.77

2 Recent industry highlights

The recent history of the global nuclear industry has been mixed. The industry is growing, albeit too slowly, with reactor additions taking place in Asia and particularly in China. The number of reactors currently under construction is at one of the highest points of the past two decades but in the USA and Europe premature reactor retirements are outstripping the rate of capacity addition.

The repercussions of the accident at Fukushima Daiichi nuclear power plant in 2011 continue to affect the nuclear industry worldwide. The accident led to a progressive idling of Japan's fleet as new operating requirements were drawn up. Three Japanese reactors have been restarted while many more are at various stages of the restart process. This idling has had consequences throughout the fuel cycle and has also caused Japanese nuclear vendors to concentrate on reactor exports rather than the domestic market.

The years since 2011 have been some of the most challenging for the global nuclear power plant fleet. Despite this, industry prospects seem brighter than they have been for a while, with the Japanese restarts, a range of new technologies (especially small modular reactors, SMRs) advancing in development, several major nuclear build programs about to get underway, and a positive shift in public support for nuclear energy in many Western countries.

North America

The ongoing discovery and exploitation of shale gas deposits has continued to reduce North American energy import dependency and has lowered power market prices. The increasing use of shale gas has decreased consumption of coal in the USA, freeing up large amounts for export to Europe and Asia, affecting markets there. It has also had an impact on the competitiveness of US nuclear plants at a time when many units have been operating for 25-35 years and were undergoing upgrades to ensure safe long-term operation for a period of 60 years or longer.

The combined pressures of cheap gas, poor market design and some negative political campaigning have led to several early unit retirements in the USA. Three years ago, the number of operable US reactors stood at 104. At the end of 2015 it was 99, with three further units scheduled for retirement before 2020. At the same time in the regulated markets, new nuclear capacity was being added with five reactors under construction. (At the time of writing in June 2016 Watts Bar 2 has been completed and brought into operation, while the early closures of one unit at Clinton in 2017 and two at Quad Cities in 2018 have been announced by the owners.)

The federal government finalised the Clean Power Plan in 2015 which aims to reduce carbon dioxide emissions, and therefore affects nuclear generators. It also committed substantial funding for the development of SMRs as a strategic priority.

In Canada, Gentilly 2 was permanently shut down at the end of 2012 as the regional Quebec government decided not to refurbish the unit. It was the only reactor in the province. Ontario, which receives over 60% of its electricity from nuclear, managed to completely eliminate coal power from its mix in 2014. In the first part of 2016 the government and utility signed major contracts for refurbishing six reactors at the Bruce Power generating station for an additional 30-35 years of operation.

South America

The second unit of the Atucha nuclear power plant in Argentina entered full operation in February 2015 increasing the share of nuclear power in the country's electricity mix to 10%. Construction started in 2014 on Argentina's prototype CAREM-25, a small domestically-designed and developed integral reactor. In the last two years Argentina has signed agreements with China for the construction of two reactors while work on Angra 3 continued in Brazil.

Europe

Supported by subsidies, large amounts of wind and solar generation in Germany and neighbouring countries are reducing European power prices on spot markets, while simultaneously increasing the price paid by customers.[9] As a result, European utilities are facing major unplanned asset devaluations, balance sheet write-downs and depressed market outlooks. This is tightening budgets and restricting the ability of utilities to invest in new generating capacity. Gas plants exhibiting high marginal cost are being hit particularly hard. The growing intermittent capacity base is increasing the need for load-following in both German and neighbouring reactors, with large peaks in photovoltaic generation and wind energy occurring with increasing frequency.

Following Japan's Fukushima Daiichi accident, the German government ordered the closure of eight reactors and a phase-out policy for the remaining reactors was reinforced, which will see them all close by 2022. In June 2015 the Grafenrheinfeld nuclear power plant was closed permanently, the first German reactor to do so since 2011.

The story for nuclear new build in the rest of Europe is mixed. There are four units currently under construction in Western and Central Europe but all projects are behind schedule. Slovakian new build continues with Mochovce units 3 and 4, while Olkiluoto 3 is still under construction in Finland, as is Flamanville 3 in France. Civil works are underway for the planned Hanhikivi 1 in Finland and early site works have been completed for Hinkley Point C in the UK. Other European countries looking to build new reactors include Bulgaria, Czech Republic, Hungary, Poland and Romania.

The European industry received a boost when the European Commission (EC) decided in favour of the market support arrangements to be applied to the UK's Hinkley Point C project in 2014. The government of Austria, however, filed a lawsuit with the European Court in July 2015 against the EC's approval of state aid on the grounds that the overall environmental impact of nuclear power plants is negative and the technology should not be supported by subsidies. The government of Luxembourg formally backed Austria in November. In its assessment of the UK government's proposed support for the project, the EC accepted that the measures were a form of investment aid, which is permitted under the Euratom Treaty and thus constitutes an objective of common European interest for which state aid may be appropriate.

In October 2015 China General Nuclear company agreed to take a one-third stake in the Hinkley Point project planned by EDF Energy and to take shares in two further projects. The two companies said that they will form a joint venture company to seek regulatory approval for a UK version of the Chinese-designed Hualong One reactor to be sited at Bradwell in England. The last operating Magnox reactor, Wylfa 1 in Wales,

[9] Finadvice, 2014, *Development And Integration Of Renewable Energy: Lessons Learned From Germany*

was closed at the end of 2015. It was the last and largest Magnox reactor to be constructed and had operated since 1971, generating 40% of Welsh electricity needs. Plans are in development to replace it with a new and much larger plant, Wylfa Newydd, in the 2020s.

In France, which has the largest European fleet counting some 58 operable reactors, the government signed off on a new energy policy in 2015 that would nominally reduce the country's dependence on nuclear energy for electricity from 75% today to 50% by 2025. It remains to be seen how this reduction will be achieved. The policy may not require reactor closures if overall electricity demand rises. The utility EDF is to acquire the reactor arm of the country's nuclear vendor and fuel cycle provider, Areva, which is being restructured.

In Spain, new tax laws introduced in 2012, coupled with licensing concerns, resulted in the owner of the Garoña nuclear power plant not filing for licence renewal in 2012, with operations ceasing in 2013. At the end of 2015 the plant's operators, Iberdrola and Endesa, were working towards a return to operation under a renewed licence.

Reactors in both Belgium and Switzerland have now undergone lengthy outages following the discovery of microscopic anomalies in the reactor pressure vessels at Doel 3 and Tihange 2. Beznau 1 in Switzerland has been in an outage since June 2015 after similar inclusions were discovered and the owners do not expect to restart the unit before August 2016 at the earliest.

A unit was added at Rostov 3 in Russia and the new fast reactor Beloyarsk 4 was grid connected. Russia continued to dominate the export market for new reactors, with many newcomer countries attracted by its integrated package (provision of nuclear fuel and fuel take-back, favourable financing, and access to training institutions). The country's national nuclear industry is currently committed to building new reactors in China, Hungary, India and Turkey and engaged with potential buyers in Jordan, Kazakhstan, Nigeria, South Africa and Vietnam among others.

Africa

At the end of December 2015, the South African government approved the issue of a request for proposal for the country's 9,600 MWe nuclear new build program. Proposals must include a funding model. South Africa is the only African nation currently to generate electricity from nuclear with its two Koeberg reactors, which have been in operation since the mid-1980s.

In Egypt, the El Dabaa project continued to make progress with agreements signed with China and Russia.

Oceania

Although Australia is a major producer of uranium, the country has not considered a nuclear energy program since the 1970s. That era could be coming to an end with the findings of a Royal Commission on South Australia's potential participation in the nuclear fuel cycle. The Commission looked at the feasibility and viability as well as the risks and opportunities associated with nuclear fuel cycle activities and issued tentative findings that would seem to motivate a change of national laws which currently prohibit most nuclear energy facilities from being built, and suggested that the state could profitably host a multi-national nuclear waste repository if public support allowed. A final report in line with this was issued to the state government in May 2016.ussia.

Nuclear taxes

The recent period has also seen an escalation in nuclear taxes in some European countries. A tax on reactor fuel was introduced in Germany and controversially maintained even after the country's nuclear policy turnaround. A long-standing reactor tax in Belgium was effectively doubled in 2011 and led to intensive government-industry discussions over 2015 to avoid premature closures. Also in 2015, the Swedish government increased the nuclear tax along with waste fees, which, combined with the depressed market conditions, led to the Swedish utilities announcing the early retirement of four units: Oskarshamn 1 and 2 and Ringhals 1 and 2. Under the previous government Swedish utilities had been planning to build new reactors at Ringhals but these ideas have now been shelved. However, in June 2016, the government announced that it would phase out the nuclear tax and allow new reactors to be built to replace ones that retire.

Asia Special Update

Much of the impetus for developing nuclear energy comes from the need to improve air quality

China

The Chinese nuclear program continued to deliver predictable series construction of large reactors. In 2015 new units were connected to the grid at Fangjiashan, Fuqing, Hongyanhe, Ningde, Changjiang, Fangchenggang and two at Yangjiang. Construction started on two new units at Fuqing and another two at Hongyanhe.

China resumed new reactor approvals in 2015, having put new projects on hold after the 2011 accident at Fukushima Daiichi caused China in common with most countries to re-confirm its nuclear safety regime.

Much of the impetus for developing nuclear energy comes from the need to improve air quality in China's rapidly growing cities as well as reducing greenhouse gas emissions in line with international commitments. According to the Chinese government's Energy Development Strategy Action Plan, 2014-2020 it will cut reliance on coal-fired generation and promote the use of low-carbon energy, confirming the 2012 target of 58 GWe of nuclear online by 2020, with 30 GWe more under construction.

The plan called for the "timely launch" of new nuclear power projects on China's eastern coast and for feasibility studies for the construction of inland plants. It said that efforts should be focused on promoting the use of large pressurized water reactors (including the AP1000 and CAP1400 designs), high temperature gas-cooled reactors (HTRs) and fast reactors.

The plan also said that research should be conducted into fuel reprocessing technology. In addition, it called for the active promotion of basic research into nuclear power and the research and development of nuclear safety technology. It also says that research should be conducted to "improve the nuclear fuel cycle system."

The Sanmen 1 unit is to be the first AP1000 unit to operate in the world, with containment tests completed at the end of 2015 and hot functional tests commencing in late 2016. It is expected to begin commercial operation and provide electricity to the grid in early 2017.

Meanwhile, good progress at Taishan unit 1 has seen cold tests begin at the end of 2015. This unit is expected to be the first EPR-design unit to operate, scheduled for the first half of 2017.

In Chinese Taiwan, construction has been suspended since 2014 on the almost completed Lungmen ABWR reactors as debate continues on a potential nuclear phase-out.

Japan

In Japan, Kyushu Electric Power Company became the first nuclear power plant operator to gain all necessary approvals to restart Japanese reactors since they were shutdown following the Fukushima accident. Two units of the Sendai nuclear power plant were restarted in the third quarter of 2015 with yet more safety enhancements planned.

Two further units at Kansai electric Power Company's Takahama nuclear power have restarted, although a court injunction forced them back into shutdown.

Kansai Electric Power Company applied to restart Mihama 3 in March 2015; in mid-2105 Shikoku Electric Power Company received permission to carry out certain safety installations at its Ikata 3 reactor; and in November 2015 JAPC applied to regulators for a safety review of Tsuruga 2.

Pakistan

Ground was broken in August 2015 in the relaunch of a project to build large reactors at Karachi. Since the project stalled in 2013 the design of the proposed units changed from ACP100 to China's export model, the Hualong One. Both are large pressurized water reactors. The first Hualong One in Pakistan is expected to operate in late 2021 with the second one year later.

South Korea

The Korean government's seventh basic long-term power development plan of electricity supply and demand was released in July 2015 with 12 new reactors wanted in operation by 2029, and the oldest current unit, Kori 1, closed by then without a ten-year license extension. Long term operation of Wolsong 1 was approved, giving it a lifespan until 2022 or possibly 2036.

Korea Hydro and Nuclear Power began commissioning Shin Kori 3 at the end of the year, the first APR-1400 pressurized water reactor to go into service. It had originally been due to begin operating at the end of 2013, with unit 4 following in September 2014. Their operation has been delayed due to component issues, after the discovery that quality certificates had been falsified for cabling and other components in 2012 and 2013.

After several years of negotiations, a 20-year extension to Korea's civil nuclear cooperation agreement with the USA was signed in 2015, worded more in terms of a partnership than the original from 1974 and allowing Korea more freedom to manage used nuclear fuel.

India

The Indian government put renewed vigour into the nuclear power element of its massive infrastructure development program with negotiations to unlock long-standing agreements with French, Russian and US companies to build nuclear power plants in the country. Its overall goal is to have 14.5 GWe of nuclear generating capacity online by 2024, compared to 6219 MWe now.

The government gave in principle approval for new nuclear plants at ten sites in nine states. Those for indigenous PHWRs are: Gorakhpur in Haryana's Fatehabad; Chutka and Bhimpur in Madhya Pradesh; Kaiga in Karnataka; and Mahi Banswara in Rajasthan. Those for plants with foreign cooperation are: Kudankulam in Tamil Nadu (VVER); Jaitapur in Maharashtra (EPR); Chhaya Mithi Virdhi in Gujarat (AP1000); Kovvada in Andhra Pradesh (originally ESBWR) and Haripur in West Bengal (VVER), though this location had been in doubt. In addition, two 600 MWe fast breeder reactors are proposed at Kalpakkam.

Unit 2 of the Russian-built Kudankulam nuclear power plant in Tamil Nadu was completed in 2015 with the unit continuing to grid-connection in mid-2016. A prototype fast breeder reactor is nearing completion at Kalpakkam.

Kudankulam

Iran

The conclusion of the negotiations between the Iranian government and China, France, Germany, Russia, the UK, the USA plus the European Union in July 2015 opened the door to commercial relations in the nuclear energy field. Iran agreed to limit its uranium enrichment activities, eliminate its stockpile of medium-enriched uranium and limit its stockpile of low-enriched uranium over the next 15 years. The Iranian government also agreed to implement provisionally the Additional Protocol to its safeguards agreement with the International Atomic Energy Agency, which, together with other measures, will increase the agency's ability to monitor nuclear activities in Iran.

UAE

Barakah 1 in the United Arab Emirates reached 80% completion during 2015 and is expected to begin operation in 2017. That milestone would make the UAE the 32nd country in the world to use nuclear power.

All four forthcoming reactors units at the Barakah site are now under construction with unit 4 pouring first concrete in September 2015. They should all be complete and operating by 2020, at which point the country is expected to set its sights on a further multi-unit nuclear power project.

3 Nuclear industry performance

The nuclear power sector provides a reliable, cost-effective and low-emissions source of electricity generation. The fleet is also working longer than originally expected, with 60 years becoming the norm, and upgrades in capacity continue to be made. This section provides an overview of current industry trends in reactor operation and construction.

Overall situation

Nuclear power plants generated 2,441 TWh of electricity in 2015, which was about 10% of total generation. Nuclear generating capacity has grown substantially since 1980. Figure 4 shows nuclear production of electricity since 1970. The decline in electricity production since 2011 is attributable in large measure to the closure of nuclear power plants in Japan and Germany following the Fukushima Daiichi reactor accident.

As Figure 4 indicates, electricity generated from nuclear power plants rose until the 1990s and has shown a slow decline since the turn of the century. The share of nuclear energy in the electricity supply system is shown in Figure 5. The lower curve represents the share of world electricity and the upper curve is the share taken by nuclear energy in those countries with nuclear power plants. The 30 countries with nuclear capacity represent 62% of the world's population. The decline in the share reflected an increasing role in the generating mix of gas-fired plants; the electricity generated from gas-fired power plants doubled between 1990 and 2012.[10]

Table 1 on page 14 shows the number and type of nuclear power reactors by region in the world today. Europe, including the European Economic Area (EEA) and the Commonwealth of Independent States (CIS), has 42% of all nuclear reactors and North America has 27%. Pressurized water reactors (PWRs) comprise nearly 65% of nuclear generating capacity. The scale of nuclear power generation around the world is indicated on the map on pages 12-13.

Operating results

Nuclear power plants were again among the world's best performing generating stations in 2015. The global fleet regularly performs to its highest technical capability. The average capacity factor, which reflects the actual amount of electricity provided to the grid as a percentage of the maximum possible, has been over 80% since the start of the century. The best performing reactors in the world regularly exceed capacity factors of 90%.

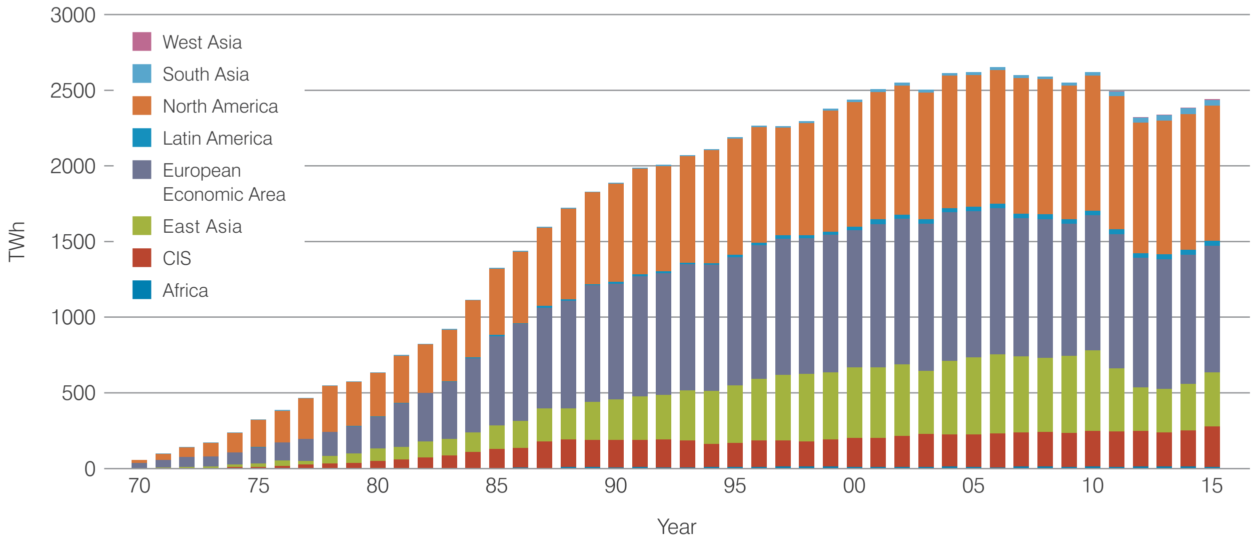
Figure 6 shows that there is no significant age-related trend in nuclear reactor performance. Older plants operate as well as the average and younger plants require no 'running-in' time.

Figure 7 shows that in the 20-year period from 1980 to 2000 there was a rise of almost 20 percentage points in the average capacity factor. The capacity factor has been stable at around 80% since 2000, with a drop as a result of the idling of Japanese plants. If Japanese reactors which did not generate electricity in 2012-2014 are excluded from the calculation, it is clear that a high capacity factor has been maintained at operating reactors around the world.

The spread of reactor performance is shown in Figure 8. There is still scope for improvement in the performance of the global reactor fleet through the improvement of day-to-day operations among mid-range performers that would allow them to match the best performers.

[10] World Energy Outlook 2014, International Energy Agency, p.606.

Figure 4. Nuclear electricity production

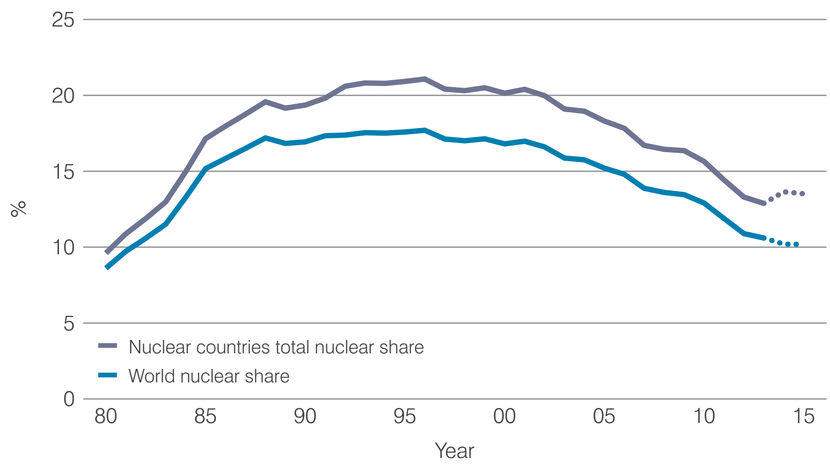


Source: IAEA PRIS

A snapshot of performance over one year is presented for 2015 in Figure 9, along with a ten-year average for each reactor type (2005-14). Most plant operating cycles are longer than one year, meaning that some indicators should be derived over a longer period. This figure shows that improved performance was achieved across all reactor types.

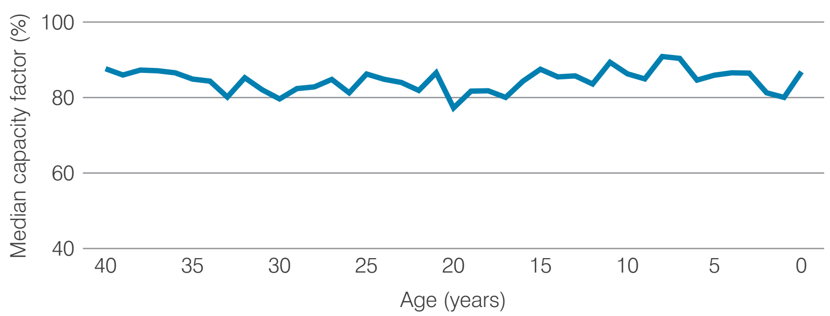
Nuclear power plants were among the world's best performing generating stations in 2015.

Figure 5. Share of nuclear generation in total power supply

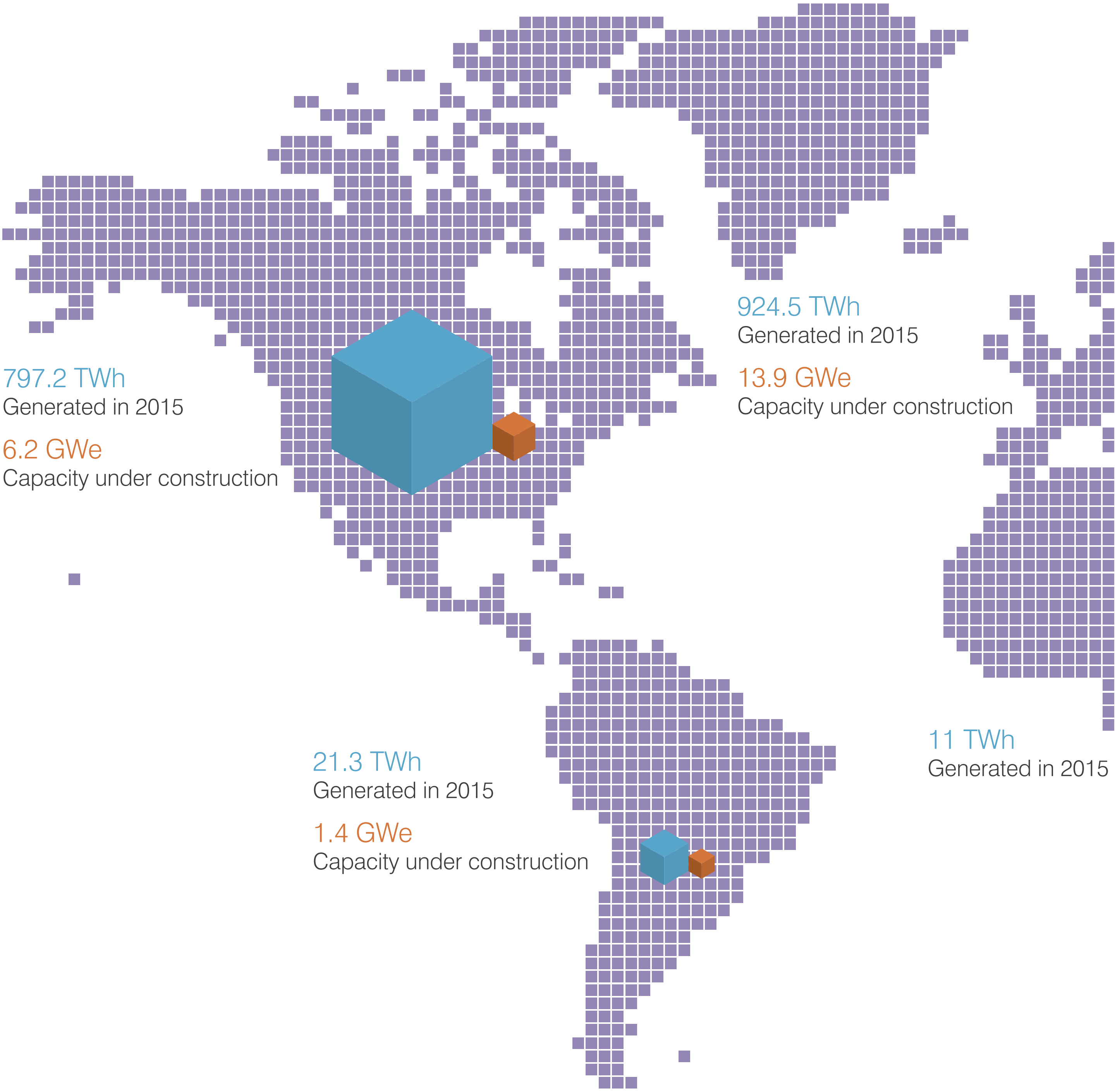


Source: IEA, World Energy Outlook 2014; IAEA PRIS; World Nuclear Association (for 2014-15 data)

Figure 6. Median capacity factor 2006-2015 by age of reactor

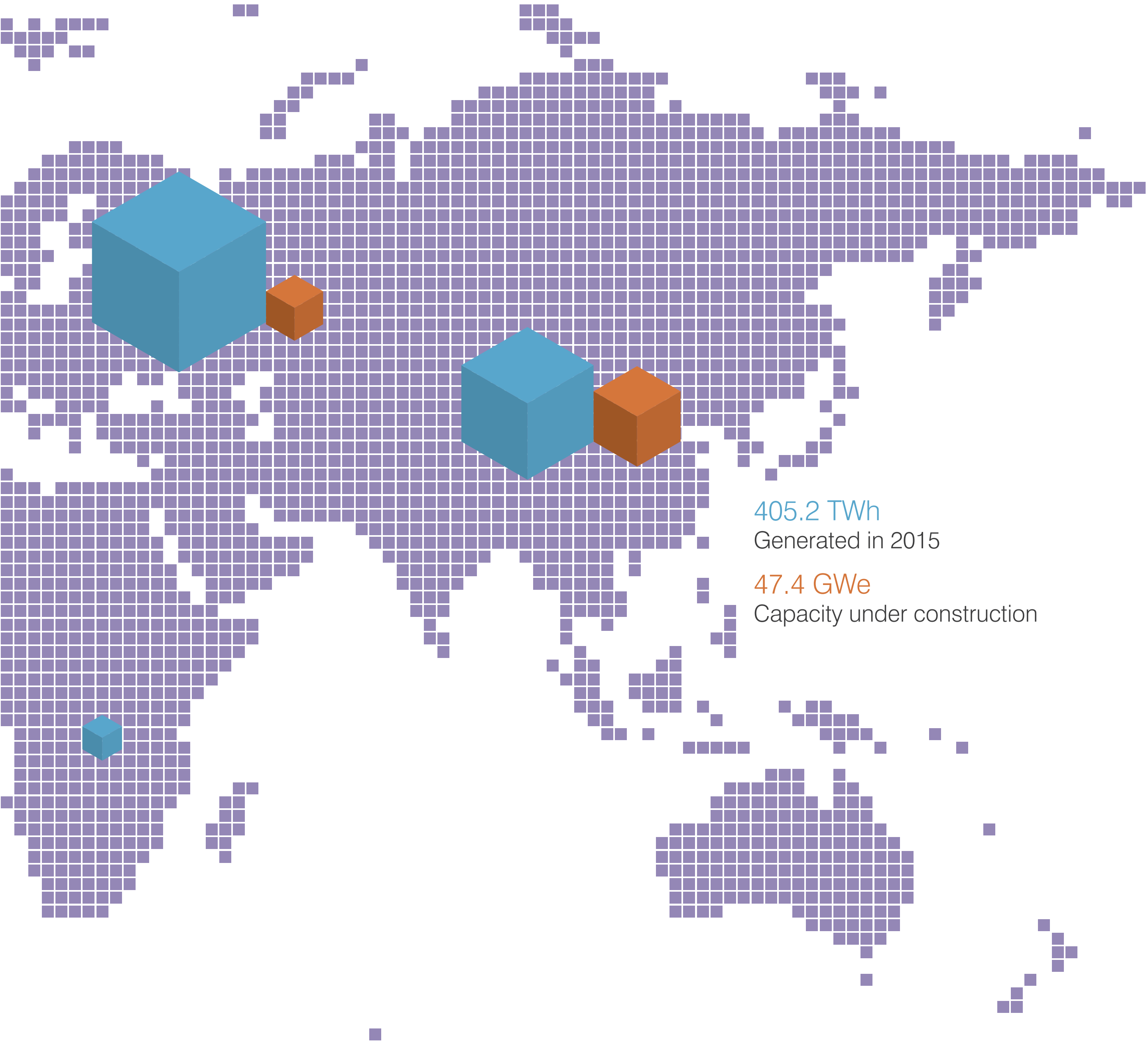


Global nuclear generation and construction



Nuclear industry performance indicators, 2015

81.7%	2441 TWh	10
Global average capacity factor (excluding Japan)	Electricity generated in 2015	New reactors bro

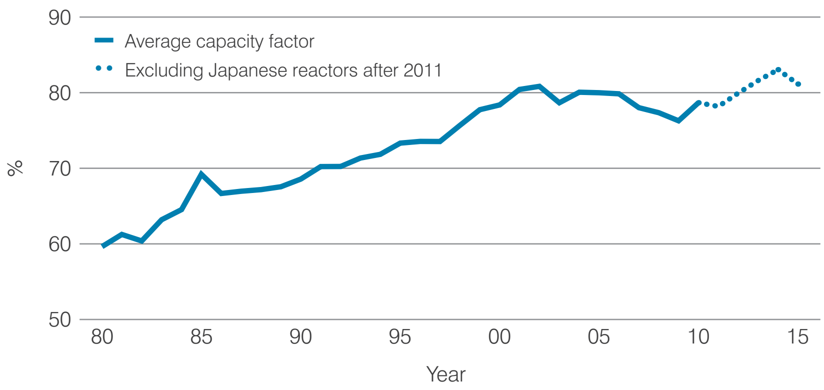


ught online

9875 MWe
Net increase in generating capacity

73 months
Average construction period for new reactors starting in 2015

Figure 7. Global capacity factor



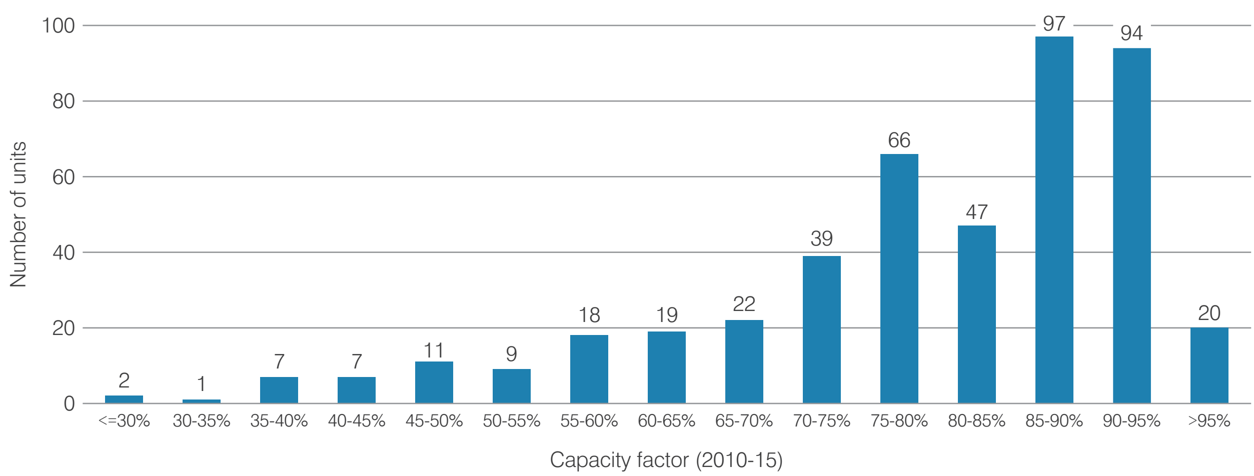
Source: World Nuclear Association analysis based on IAEA PRIS data

Table 1. Nuclear power reactors (December 2015)

Type	Africa	CIS	EEA	North America	Latin America	East Asia	South Asia	West Asia	Total	%
BWR	-	-	14	34	2	26	2	-	**78**	17.6
FNR	-	2	-	-	-	1	-	-	**3**	0.7
GCR	-	-	14	-	-	-	-	-	**14**	3.2
HTGR	-	-	-	-	-	-	-	-	-	-
LWGR	-	15	-	-	-	-	-	-	**15**	3.4
PHWR	-	-	2	19	3	6	19	-	**49**	11.1
PWR	2	33	104	65	3	72	3	1	**283**	64.0
Total	**2**	**50**	**134**	**118**	**8**	**105**	**24**	**1**	**442**	100.0
%	0.5	11.3	30.3	26.7	1.8	23.8	5.4	0.2	100.0	

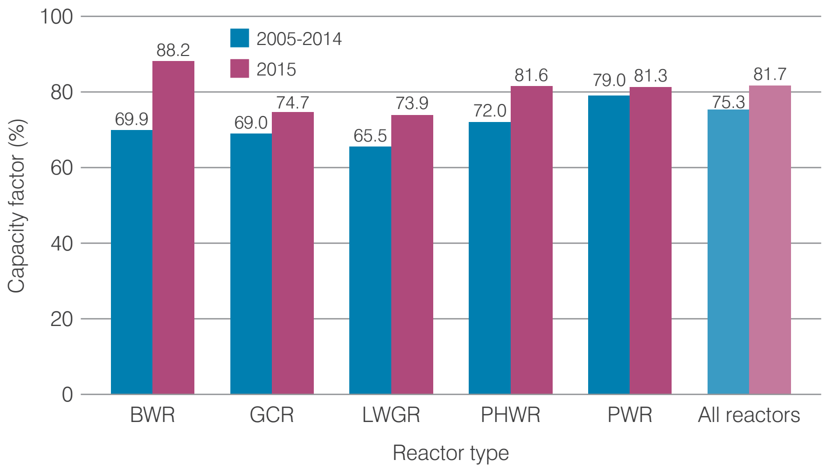
Source: IAEA PRIS; World Nuclear Association Reactor Database

Figure 8. Number of units by capacity factor



Data for each calendar year excludes reactors that did not operate for that year. Source: IAEA PRIS

Figure 9. Capacity factors by type of reactor



Data for each calendar year excludes reactors that did not operate for that year. Source: IAEA PRIS

Upgrades for capacity or long-term operation

A power uprate is a process by which the reference unit power of a reactor is increased so that it becomes capable of producing additional electricity. This comparatively inexpensive form of capacity addition typically involves changes to the plant's components, operating, maintenance and accident response procedures as well as a corresponding licensing effort. The larger the uprate, the more work is required in all of these areas. Table 2 shows recent extended power uprates involving eight reactors in Mexico, Sweden and the USA and one case of a minor power uprate (Fermi 2) in the USA.

Uprating can have substantial impacts on plant availability in the short term as longer outages may be required to replace key components. Since large uprates typically involve older plants and require significant capital investment they often take place as part of long-term operation work. A success criterion for an uprate is typically that it has a net zero or even net positive impact on plant availability over the longer term.

Most nuclear power plants in the USA were originally licensed for a set period that related to estimates of how long it would take to amortise the costs of construction. There was, and is still, no technical concept of an engineering 'end of life' for a nuclear plant as this is determined by component ageing and the cost of replacement.

The licensing requirements that need to be completed for extending operation vary significantly from country to country. In the USA, reactor operating licences are limited to 40 years of operation but a regulatory process was adopted by the Nuclear Regulatory Commission in the mid-1990s to consider applications to extend the period of the licence for an additional 20 years. Most reactor operators in the USA have applied for and/or given notice that they will apply for extensions to their operating licences.

In some other countries, such as Sweden and France, licences are granted for a ten-year period but there is no predetermined operating lifespan fixed by the regulatory body.

Regulatory bodies may insist on additional checks on older plants, and may require upgrades to be carried out. But such requirements may be imposed on licensees at any time.

However reactors are not guaranteed to operate for their licence period. A licensee may decide to shut down a reactor permanently if, for example, operating costs are too high or if it encounters technical or political problems. Even if operating costs are not too high, a closure decision may come because a plant requires major additional capital expenditure to keep it in operation (for example, steam generator and turbine replacement, or the redesign and renewal of the control rooms and associated instrumentation and control systems). The cost of servicing the additional capital, added to existing costs, may make operating the plant uneconomic.

The main power reactor types in the world today – the PWR, BWR and PHWR – can all benefit from long-term operation. There are examples of reactors approved for 60 years in each and it appears possible that they could operate for longer than this. Other reactor technologies such as the AGR (operating only in the UK) and RBMK (operating only in the Russian Federation) face specific technical issues related to ageing and these units are not expected to make it to 60.

Recently, tight operating margins as a result of low gas prices and subsidies for renewable generation have driven some US operators to forgo the opportunity to extend operating life, as the cost of replacing components have been difficult to justify.

In 2014, the French nuclear operator EDF estimated that it will need to invest €55 billion up to 2025 to

At the end of 2015 there were 66 civil power reactors under construction around the world and another 158 planned.

Table 2: Recent reactor capacity uprates

Reactor	Previous capacity (MWe)	Uprate (MWe)	Year of uprate	Type of reactor
Mexico				
Laguna Verde 1	765	134	2013	BWR
Laguna Verde 2	765	134	2013	BWR
Sweden				
Forsmark 2	996	120	2013	BWR
Ringhals 4	940	175	2015	PWR
USA				
Fermi 2	1,037	20	2014	BWR
Monticello	578	71	2013	BWR
Monticello	649	71	2015	BWR
Peach Bottom 2	1,125	130	2015	BWR
Turkey Point 4	693	124	2013	PWR

Source: World Nuclear Association

extend the operation of its reactor fleet to beyond 40 years. Other major refurbishment works include the replacement of the main circulation pumps at the Finnish Olkiluoto nuclear power plant in 2016-2018. Altogether 12 pumps are to be replaced at the two units and a contract for this was signed in 2014 for €40 million.

A number of plants have returned to operation after lengthy outages. Canadian-designed PHWRs, known as Candu reactors, require regular refurbishment often involving such steps as replacing fuel channels, calandria and steam generators and upgrading ancillary systems to current standards. While refurbishing usually takes less time and is less costly than building a new plant, there have been several cost overruns.

Two Bruce A units in Ontario, Canada, returned to service in 2012 after being taken offline for refurbishment in 1995-97. The Point Lepreau 1 reactor in New Brunswick, Canada, was refurbished between 2008 and 2012 and regained full power in 2013.

Under construction

At the end of 2015 there were 66 civil power reactors under construction around the world and another 158 planned (that is, approval has been granted and/or funding has been committed by a developer) – see Table 3.

At the end of 2015 half the reactors under construction were in East Asia, with 24 being built in mainland China alone. Construction projects in Japan and Chinese Taiwan were stalled. Several reactor construction projects are underway in Russia and Belarus, and four new reactors are being built in the USA along with the completion of Watts Bar 2 that was half complete in 1985 when the original project was halted. (Watts Bar 2 came into operation in June 2016).

Demonstration fast neutron reactors (FNRs) are operating in Russia, under construction in India, and in long-term shutdown in Japan. A high temperature gas-cooled reactor (HTGR) is being built in China.

Table 3. Reactors under construction by region (number, December 2015)

Type	Africa	CIS	EEA	North America	Latin America	East Asia	South Asia	West Asia	Total
BWR	-	-	-	-	-	4	-	-	4
FNR	-	1	-	-	-	-	-	-	1
GCR	-	-	-	-	-	-	-	-	
HTGR	-	-	-	-	-	1	-	-	1
LWGR	-	-	-	-	-	-	-	-	
PHWR	-	-	-	-	-	-	4	-	4
PWR	-	10	6	5	2	26	3	4	56
Total	-	10	6	5	2	31	8	4	66

Source: World Nuclear Association

Construction began on eight reactors in 2015 (see Table 4). Ten reactors were completed and connected to the grid over the same period (see Table 5).

New build is led mostly by industrializing countries which have enjoyed high levels of economic growth with an accompanying increase in energy demand. Four countries are expected to account for 70% of reactors commissioned in the period to 2030: China, Russia, India and South Korea. In Europe the nuclear option is appearing more attractive in the face of the EU's measures to reduce carbon emissions and the Energy Union goal to increase collective energy security. Ten governments in the 28-member union have collectively stated their desire to see new nuclear development.[11] Single reactors are under construction at Olkiluoto in Finland, Flamanville in France, and two are being completed at Mochovce in Slovakia. Two units at the UK's Hinkley Point C await an investment decision, with nine other reactors planned to follow at different sites. In northern Finland, plans are well advanced for a new unit at Hanhikivi.

In West Asia and North Africa, development is being driven firstly by the determination of the oil and

Table 4. Recent reactor construction starts

Reactor	Capacity (MWe)	Start of construction	Expected date for commissioning	Type of reactor
China				
Fangchenggang 3	1,150	Dec 2015	Dec 2019	PWR
Fuqing 5	1,150	May 2015	Dec 2019	PWR
Fuqing 6	1,150	Dec 2015	Dec 2020	PWR
Hongyanhe 5	1,080	Mar 2015	Nov 2019	PWR
Hongyanhe 6	1,080	Jul 2015	Aug 2020	PWR
Tianwan 5	1,080	Dec 2015	Apr 2021	PWR
Pakistan				
Karachi Coastal	1,161	Aug 2015	July 2021	PWR
United Arab Emirates				
Barakah 4	1,400	Jul 2015	Jun 2020	PWR

Source: World Nuclear Association

[11] Ten nations petition Brussels for nuclear, World Nuclear News, 4 July 2014.

Table 5. Recent reactor grid connections

Reactor	Capacity (MWe)	Start of construction	Grid connection	Type of reactor
China				
Fangjiashan 2	1,020	Jul 2009	Jan 2015	PWR
Fuqing 2	1,020	Jun 2009	Aug 2015	PWR
Hongyanhe 3	1,020	Jan 2009	Mar 2015	PWR
Ningde 3	1,020	Jan 2010	Mar 2015	PWR
Yangjiang 2	1,020	Jun 2009	Mar 2015	PWR
Yangjiang 3	1,020	Nov 2010	Oct 2015	PWR
Changjiang 1	610	Apr 2010	Nov 2015	PWR
Fangchenggang 1	1,020	Jul 2010	Oct 2015	PWR
Korea Republic				
Shin Wolsong 2	960	Sept 2008	Feb 2015	PWR
Russia				
Beloyarsk 4	789	Jul 2006	Dec 2015	FBR

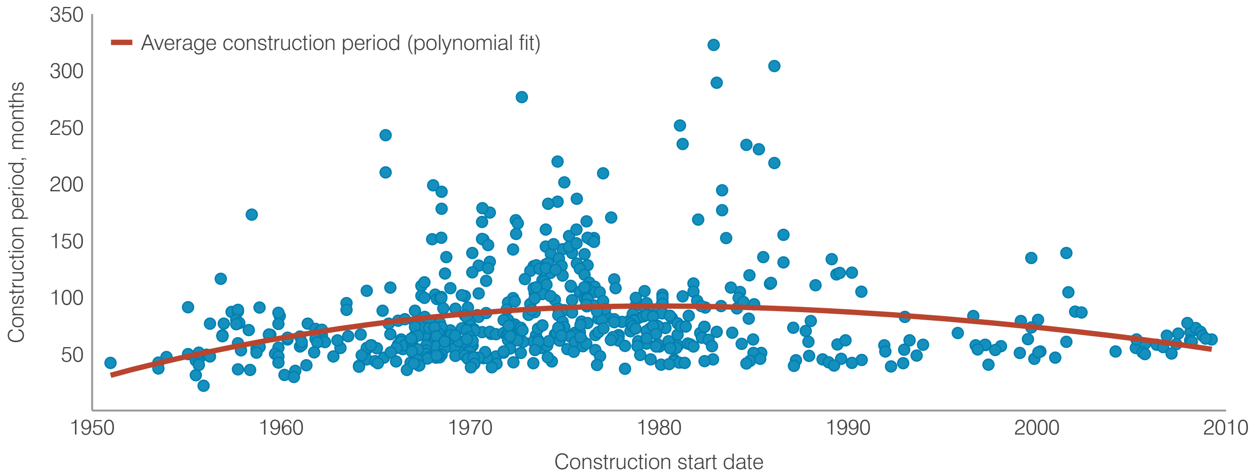
Source: World Nuclear Association

gas exporters to maximize their oil export revenues by reducing oil-based domestic energy demand; secondly, by the ever-increasing need for fresh water (to be supplied by desalination plants); and thirdly, by the desire to see a new local skilled industry established. The United Arab Emirates is the first Gulf State to have started a nuclear power plant project.

The construction period for nuclear power plants has lengthened in several countries but shortened in others (South Korea, for example). It is clear from an analysis of past trends that the increased requirements for safety since the 1980s lengthened construction times (see Figure 10). The construction time of a nuclear power plant is usually taken as the duration between the pouring of the first 'nuclear' concrete and grid connection. In advance of this, a substantial amount of time and effort is involved in planning and gaining approvals and licensing for the facility.

As Figure 10 indicates, the previous tendency for construction times to lengthen has started to reverse. The average construction time for all civil nuclear reactors built of the last 60 years (600 units) was 82.5 months, but this figure includes a number of projects that experienced unusually lengthy delays, some for political reasons. The average falls to 71.8 months if we exclude the lengthiest 10% of construction projects (60 units) and to 55 months for the fastest 50% (300 units) – or 4½ years.

Figure 10. Construction period by construction start date

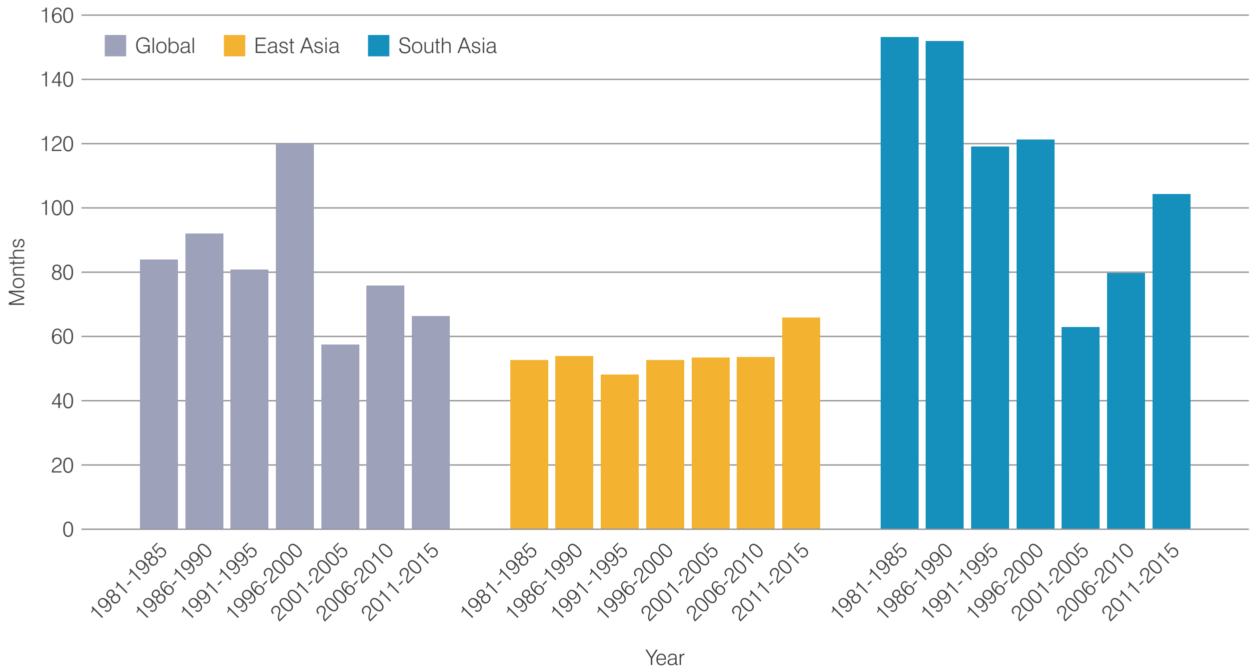


Periods during which a project was stalled for political reasons are excluded. Source: IAEA PRIS

[12] EDF Energy, Draft Overview of HPC Construction, February 2011, p.9, Figure 2.1.

Asia Special Update

Figure 11. Median construction times for reactors since 1981



Source: IAEA PRIS

There has also been a considerable variation in construction times, but it is noticeable (see Figure 11) that construction times have typically shortened in the last decade and a half. The average of construction time in 2015 was 73 months, compared to 127 months for 2014 – the average was raised by the lengthy delays in bringing Atucha 2 online in Argentina.

Construction times in East Asia (China, Japan and South Korea) have been consistently around 55 months whereas in South Asia (India and Pakistan) these have varied from 153 months to 63 months. Until 2008, India had to rely upon its domestic resources to develop nuclear energy and the country's ability to import nuclear components was restricted. Figure 11 is based on grid connection dates, so the reactors shown in the bars for the 1980s began construction in the 1970s when the Indian economy's growth rate was variable and weak. Only two reactors started construction in the 1990s (Rajasthan 3 and 4) and these were completed in 121 and 129 months respectively. The average construction time for reactor construction from 2000 onwards has been 85 months. The two Pakistani reactors built over the period 1981 to 2015 (Chashma 1 and 2) were constructed in 82 and 63 months respectively.

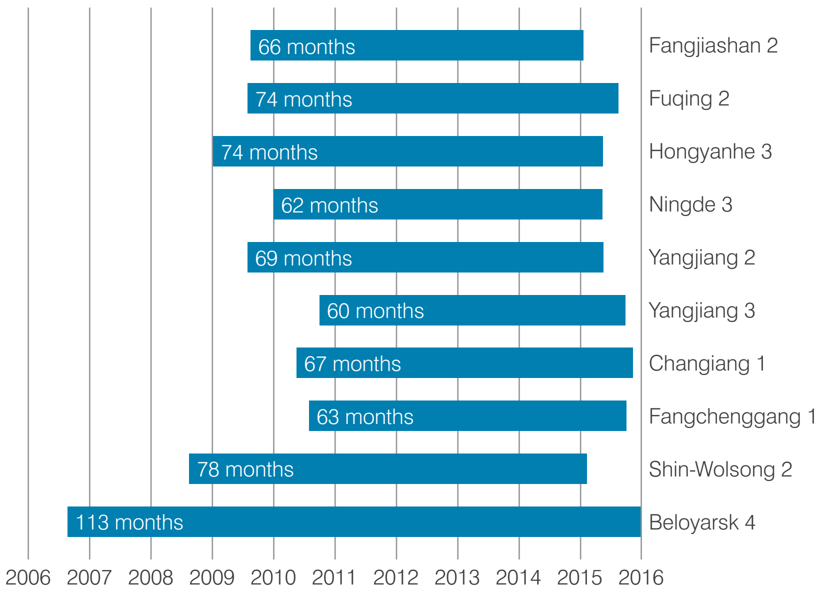
Twenty-three reactors were built in South Korea, with an average time of 59 months. Taipower's four reactors were constructed on average in 70.5 months. China's 29 reactors were constructed in 65 months on average. Japan built 35 reactors between 1981 and 2015 with an average time of 47 months. The scale and pace of reactor construction in East Asia contributed to faster new build.

The reactors under construction for the Barakah nuclear power plant in the United Arab Emirates currently remain slightly ahead of their 54-month schedules, with the key components being imported from South Korea and with considerable usage of expatriate personnel.

While a lot of negative attention is often focused on the two overdue single-unit EPRs underway in Finland and France (which are expected to come on line after 140-150 months), these schedules are not expected to be typical for future plants. EPRs being built in China look likely to be completed in about 80 months while UK timelines for the design are set at 60 months.[12] The four US AP1000s being built in Georgia and South Carolina have experienced some delays pushing construction up to 80 months, whilst the AP1000s being constructed in China are still mostly on track to be finished in around 60 months.

The average construction time in 2015 was 73 months

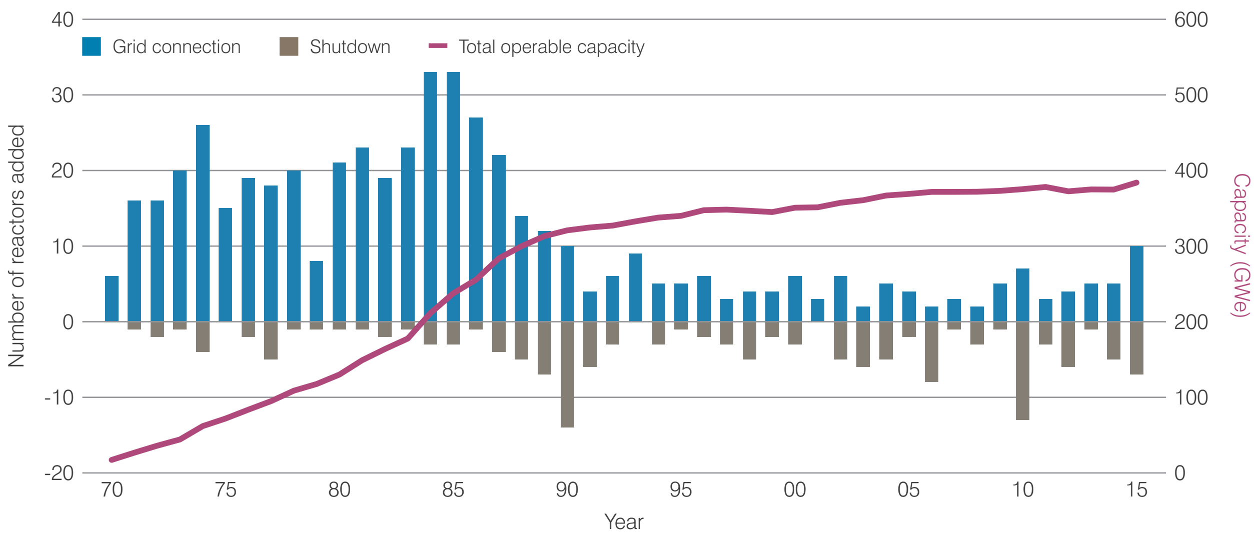
Figure 12. Construction times of new units connected to the grid in 2015



Source: IAEA PRIS

Looking at the balance between additions to nuclear capacity and retirements, there is a levelling off in the growth of overall capacity as fewer new plants were constructed. Policy direction and market conditions will be crucial to operator decisions on long-term operation of existing reactors, and therefore the ability to sustain the current contribution of nuclear power. If the reactors constructed in the 1970s are retired instead of being prepared for long-term operation then shutdowns will exceed new build in North America and Europe in the

Figure 13. Reactor construction and shutdown



Source: IAEA PRIS

Table 6. Recent capacity additions

Added capacity in 2015		MWe
New build	Fangjiashan 2	1,020
	Fuqing 2	1,020
	Hongyanhe 3	1,020
	Ningde 3	1,020
	Yangjiang 2	1,020
	Yangjiang 3	1,020
	Changjiang 1	610
	Fangchenggang 1	1,020
	Shin-Wolsong 2	960
	Beloyarsk 4	789
Uprates	Ringhals 4	175
	Monticello	71
	Peach Bottom 2	130
Total		9,875

2020s. Figure 13 shows how nuclear capacity grew quickly until the mid-1980s, but has tailed off since.

Decommissioning

All power plants have a finite service period beyond which it is not economically viable to operate them. Generally speaking, early nuclear plants were designed for a life of about 30 years, though some have proved capable of continuing well beyond this. Newer plants are expected to enjoy a 60-year operating life. At the end of commercial operation a power plant needs to be taken out of service, dismantled and demolished so that the site is cleared, cleaned up, and made available for other uses.

Seven reactors were shut down permanently during 2015 (see Table 7). It is noteworthy that of these only one (Wylfa) was due to business-as-usual engineering and economic reasons. Grafenrheinfeld in Germany was closed for political reasons and the five Japanese units had been offline since soon after the accident at Fukushima Daiichi in 2011 and their status as permanently shutdown was made official in 2015 as an accounting change.

The IAEA has defined three options for decommissioning, the definitions of which have been internationally adopted:

- Immediate Dismantling (or Early Site Release/'Decon' in the US terminology). This option allows for the facility to be removed from regulatory control relatively soon after shutdown or termination of regulated activities. Final dismantling or decontamination activities can begin within a few months or years, depending on the facility. Following removal from regulatory control, the site is then available for re-use.
- Safe Enclosure ('Safstor') or deferred dismantling. This option postpones the final removal of controls for a longer period, usually of the order of 40 to 60 years. The facility is placed into a safe storage configuration until the eventual dismantling and decontamination activities occur after residual radioactivity has decayed sufficiently.
- Entombment (or 'Entomb'). This option entails placing the facility into a condition that will allow some radioactive material to remain onsite without ever removing it totally. This option usually involves reducing the size of the area where the radioactive material is located and then encasing the facility in a long-lived structure such as concrete, that will last for a long enough period of time to ensure the remaining radioactivity is no longer of concern.

Each approach has its benefits and disadvantages. National policy determines which approach or combination of approaches is adopted or allowed. In the case of immediate dismantling (and early site release), responsibility for completion of decommissioning is not transferred to future generations. The knowledge, experience and skills of operating staff can also be used during the decommissioning program. Alternatively, the Safe Enclosure option allows significant reduction in residual radioactivity, thus reducing the radiation hazard during the eventual dismantling. Expected improvements in

Table 7. Reactor final closures in 2015

Reactor	Capacity (MWe)	Electricity generated (TWh)	Date of closure	Type of reactor
Germany				
Grafenrheinfeld	1,345	333.0	Jun 2015	PWR
Japan				
Genkai 1	529	127.7	Mar 2015	PWR
Mihama 1	320	60.1	Mar 2015	PWR
Mihama 2	470	101.6	Mar 2015	PWR
Shimane 1	439	101.9	Mar 2015	BWR
Tsuruga 1	341	80.1	Mar 2015	BWR
UK				
Wylfa 1	490	123.2	Dec 2015	GCR
Total	3934			

Source: World Nuclear Association

mechanical techniques might also lead to a reduction in the hazard and also to costs if dismantling is postponed. Waste treatment and disposal comprises 20-40% of decommissioning costs. Around 10% of the volume of waste requires radiological precautions. The bulk of this can be recycled or disposed of through conventional means.

In general, nuclear power plant operators are required to set aside funds for decommissioning, site clean-up and disposal of wastes. These funds are accumulated from revenue during operation and the regulatory body (and the environment ministry) will oversee the process to ensure that the operator is putting enough aside to complete the job. Closing a reactor prematurely reduces revenue and also the opportunity to accumulate a decommissioning fund, leading to the possibility that the fund could prove inadequate for immediate dismantling. This might be the case in Germany, for instance, where some plants have been forced to close by government decree and the remaining ones will suffer the same fate in future. As a result the operators have proposed that the government fund part of the decommissioning program, especially since Germany has adopted a policy of immediate dismantling. There is about €34 billion available to cover decommissioning costs, and there are 33 reactors to dismantle entirely and experts estimate it may cost €1 billion per reactor. The four nuclear operators have proposed that the funds be paid into a public foundation managed by the government, which would then become liable for any cost overruns. In return, the companies could drop their claims for compensation for the premature shutdown of their stations.[13]

Considerable experience has been gained in decommissioning various types of nuclear facilities. About 90 commercial power reactors, 45 experimental or prototype power reactors, as well as over 250 research reactors and a number of fuel cycle facilities, have been retired from operation. Of the 140 or so power reactors including experimental and prototype units, at least 15 have been fully dismantled, over 50 are being dismantled, over 50 are in Safstor and three have been entombed; for others the decommissioning strategy is not yet specified.

[13] German utilities want a public body to shut nuclear plants-sources, Reuters, 11 May 2014; Jeevan Vasagar, Nuclear ‘bad bank’ plan fuels dispute, *Financial Times*, 12 May 2014.

Asia Special Update

In general Asian nuclear capacity factors have been high and improving. For reactors in China (including Taiwan), Japan and South Korea, capacity factors have risen from 60 to 80 percent. The capacity factors in India and Pakistan have shown greater variation, reaching 60 percent and above in the 2010s.

East Asia

China (Mainland)

China had 27 operable PWRs, two PHWRs and one small fast reactor at the end of 2015. The twin units at Daya Bay and the single Qinshan unit entered into service in 1994. These longest running of all China's nuclear power plants have cumulative capacity factors of 85 and 82 percent respectively. The twin unit Qinshan III PHWRs operating since 2002-2003 have cumulative capacity factors of 91 and 92 percent.

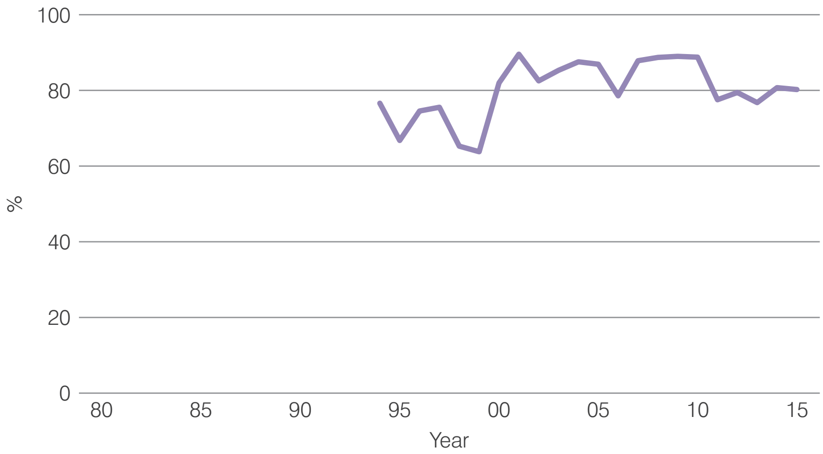
China (Taiwan)

Operating data for Taiwanese reactors is only available from 1989, although its four BWRs and two PWRs have been in commercial operation since 1978-79, 1981-83, and 1984-85 respectively.

Japan

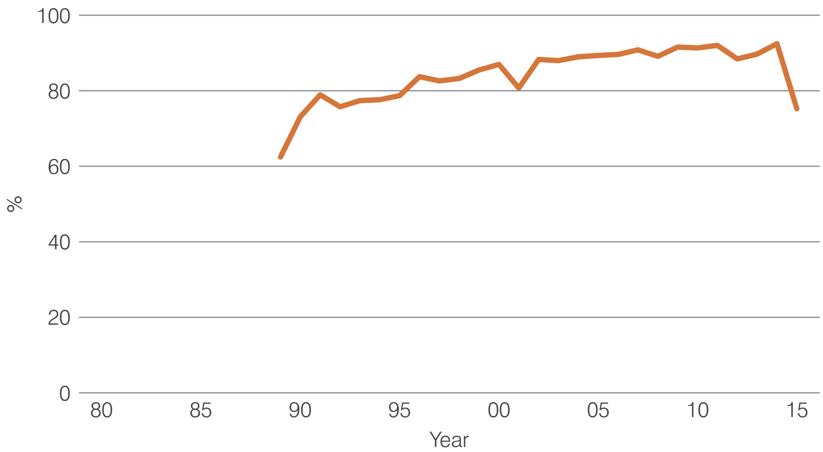
Japan has 42 operable light-water reactors but most have been shut down since the Fukushima accident in 2011 and only three are back in service. The average capacity factor dipped from 2002 from over 80 percent as some of the Fukushima Daiichi and Daini, the Hamaoka, and the Kashiwazaki Kariwa nuclear power plants were taken out of service in 2002-2004 for additional inspections of BWRs ordered by the nuclear safety regulator.

Figure 14. Capacity factor, China (Mainland)



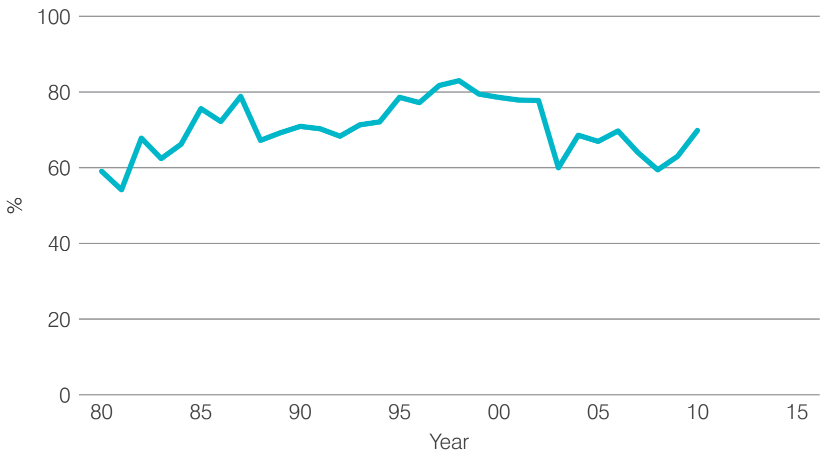
Source: IAEA PRIS

Figure 15. Capacity factor, China (Taiwan)



Source: IAEA PRIS

Figure 16. Capacity factor, Japan



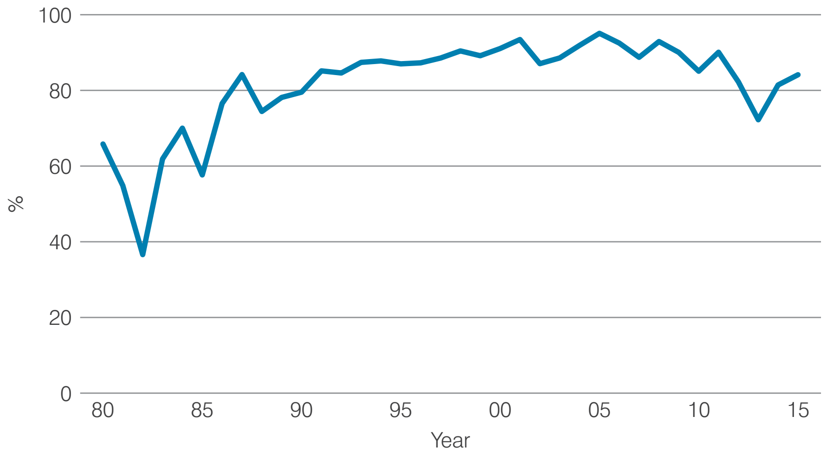
Source: IAEA PRIS

Asia Special Update

South Korea

South Korea had 20 PWRs and four PHWRs in operation at the end of 2015. The first PWR, Kori 1, entered into commercial operation in 1978 and achieved a capacity factor of 94 percent by 1987; its lifetime average is 75.4 percent. Hanul 3, the first OPR-1000 to enter service in 1998 achieved 100 percent capacity in 2010 and an overall cumulative capacity factor of 88 percent.

Figure 17. Capacity factor, South Korea



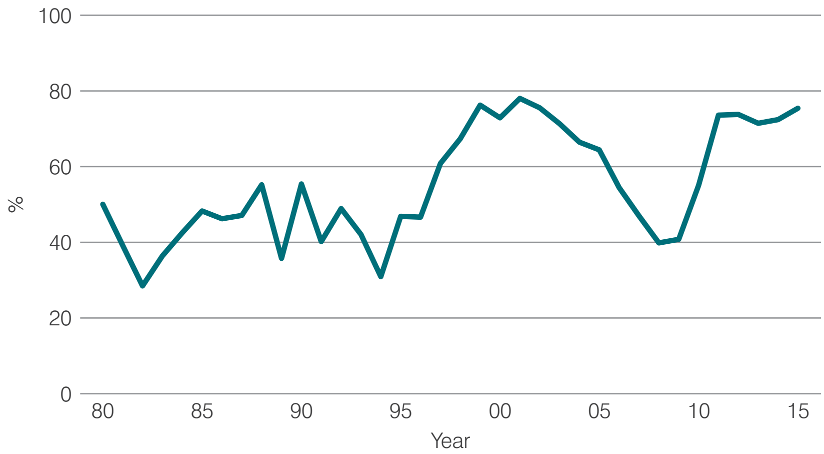
Source: IAEA PRIS

South Asia

India

India has constructed mainly PHWRs, with the first units at Rajasthan coming into commercial operation in 1973. Rajasthan 1 has had a mixed history with lengthy outages from 1982 to 1987 and 1994 to 1997 and has been out of service since 2005. Rajasthan 2 which came into service in 1981 performed more reliably, despite long outages between 1994 and 1998 and from 2007 to 2009, and achieved a lifetime capacity factor of 56 percent. Rajasthan 3, starting in 2003, has managed a cumulative capacity factor of 76.5 percent. Altogether, the country has commissioned 18 PHWRs, two small BWRs (in 1969) and two PWRs (at Kudankulam in 2014 and 2016 respectively). A dip in the average capacity factor in 2008 and 2009 resulted from contemporaneous outages at Rajasthan 2, Kakrapar 1 and Narora units 1 and 2.

Figure 18. Capacity factor, India

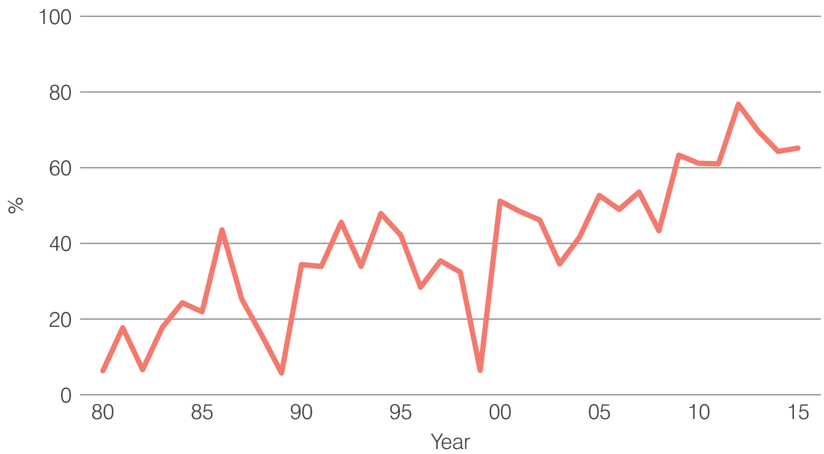


Source: IAEA PRIS

Pakistan

Pakistan has three operable PHWR nuclear power plants: Karachi 1 from 1972 and Chashma 1 and 2, in commercial operation since 2000 and 2011 respectively. The Karachi unit was taken out of service in 1989 and in 1999 and the unit was shut down between 2003 and 2006. Its average capacity factor has been 29 percent since start of operations. The two Chashma units have operated

Figure 19. Capacity factor, Pakistan



Source: IAEA PRIS

well since their commissioning with average capacity factors of 74 and 81 percent respectively.

West Asia

Iran

Iran's first commercial nuclear power plant Bushehr 1 started commercial operation in September 2013 and achieved a 60.6 percent capacity factor since that time.

Nuclear Expansion

In Asia 134 operable reactors generated 400 TWh of electricity in 2015 (Table 8), representing 16% of global nuclear generation. There are firm plans underway to increase this. One strong driver for this is to reduce air pollution, which is responsible for the death of 6.5 million people each year worldwide, as well as to reduce greenhouse gas emissions and improve electricity supplies.

38 reactors are currently under construction in Asia; this represents almost two thirds of global reactor construction (Table 9). With the exception of UAE, this new build is in countries already operating nuclear reactors. There are also plans for more than 50 reactors in nine newcomer countries (Table 10), with most planning to have their first nuclear reactors enter operation before 2030.

Nuclear generation can help reduce air pollution responsible for 6.5 million deaths globally each year.

Table 8. Asian nuclear power, operating reactors

	Operating reactors		
	Nuclear generation 2015 (TWh)	Number	Nuclear capacity (MWe)
China (Mainland)	161.2	34	30597
China (Taiwan)	35.1	6	4927
India	34.6	22	6219
Iran	3.2	1	915
Japan	4.3	43	40480
Pakistan	4.3	3	725
South Korea	157.2	25	23017

Table 9. Asian nuclear power, under construction

	Under construction		
	Number	Nuclear capacity (MWe)	First nuclear electricity
China (Mainland)	20	22596	1994
China (Taiwan)	2	2700	1978
India	5	3300	1969
Iran	0	0	2013
Japan	3	3036	1966
Pakistan	1	1841	1972
South Korea	3	4200	1978
UAE	4	5600	2017

Table 10. Newcomer countries' plans

	Planned reactors	Nuclear capacity (MWe)	First nuclear electricity
Bangladesh	2	2400	2022
Indonesia	4	6000	2025
Jordan	2	2000	2025
Kazakhstan	2	600	after 2025
Malaysia	4	4000	2023
Saudi Arabia	16	17000	2022
Thailand	2	2000	2035
Turkey	12	13500	2023
Vietnam	4	4800	2028

List of abbreviations

AGR	Advanced gas-cooled reactor
BWR	Boiling water reactor
CCGT	Combined-cycle gas turbine
CCS	Carbon capture and storage
CIS	Commonwealth of Independent States
CO_2	Carbon dioxide
COP21	21st Conference of Parties to the United Nations Framework Convention on Climate Change
EEA	European Economic Area
EPR	Evolutionary Power Reactor
EU	European Union
FNR	Fast neutron reactor
GCR	Gas-cooled reactor
GDP	Gross domestic product
GHG	Greenhouse gas
GWe	Gigawatt (one billion watts of electric power)
GWh	Gigawatt hour (one billion watt hours of electricity)
HTGR	High temperature gas-cooled reactor
IAEA	International Atomic Energy Agency
I&C	Instrumentation and control
IEA	International Energy Agency
IPCC	Intergovernmental Panel on Climate Change
kWh	Kilowatt hour (one thousand watts hours of electricity)
LTO	Long-term operation
LWGR	Light water gas-cooled reactor
LWR	Light water reactor (i.e. a BWR or PWR)
MWe	Megawatt (one million watts of electric power)
MWh	Megawatt hour (one million watts hours of electricity)
NRC	Nuclear Regulatory Commission
PHWR	Pressurized heavy water reactor
PRIS	Power Reactor Information System
PV	Photovoltaic
PWR	Pressurized water reactor
RBMK	*Reaktor Bolshoy Moshchnosti Kanalniy* (an LWGR)
SMR	Small modular reactor
TWh	Terawatt hour (one trillion watts hours of electricity)
UN	United Nations
VVER	*Vodo-Vodyanoi Energetichesky Reactor* (a PWR)

World Nuclear Association
Tower House
10 Southampton Street
London WC2E 7HA
United Kingdom

+44 (0)20 7451 1520
www.world-nuclear.org
info@world-nuclear.org

The nuclear power sector provides a reliable, cost-effective and low-emissions source of electricity generation. The global reactor fleet is also working longer than originally expected, with 60 years becoming the norm, and upgrades in capacity continue to be made. This World Nuclear Association report provides an overview of current industry trends in reactor operation and construction.

The World Nuclear Association is the industry organisation 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.