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The World Nuclear Industry
Status Report 2021

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The World Nuclear Industry Status Report 2021

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Another difficult year. We all thought it could hardly get worse than 2020. Then came 2021. Several team members lost family members, to COVID-19 or other circumstances. Climate-related disasters from California to Louisiana, from Germany to Greece, from Argentina to China have dominated the news. Most of the WNISR team members and contributing authors are living in rather privileged, rather protected environments, but not all of us, and definitely not all of the families and friends.

Despite all the adverse side-effects of the global situation, here's *The World Nuclear Industry Status Report 2021* (*WNISR2021*). Once again, the project coordinator is *particularly* thankful to everyone who made the production of this year's report possible, the authors and data-manager, the designers and artists, the webmaster and all the supporters.

As for so many years now, a big thank you to Antony Froggatt for his conceptual ideas, his contributions, his reactivity and his friendship.

At the core of the WNISR is its database, designed and maintained by data manager and information engineer Julie Hazemann, who also develops most of the drafts for the graphical illustrations and manages much of the cooperation with designer and webmaster. She expanded her contribution significantly over the past few years. As ever, no WNISR without her. Thanks so much.

The WNISR project can solidly count on the regular, reliable, professional and insightful contributions from M.V. Ramana, Ben Wealer, and for the second year in a row from Ali Ahmad. Many thanks to all of you. I'm very fortunate to be working with you.

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Nina Schneider has expanded her meticulous proof-reading capacities, source verification, and fact-checking. Authors have experienced her demanding precision. Her production skills round up her invaluable input. Thanks so much.

Artist and graphic designer Agnès Stienne created the redesigned layout in 2017 and is constantly improving our graphic illustrations that get a lot of praise around the world. Thank you.

A big thank-you to Arnaud Martin for his continuous, highly reactive and reliable work on the website www.WorldNuclearReport.org, dedicated to the WNISR.

For the third time, we owe the idea, design, and realization of the cover to renowned German painter Friedhelm Meinass and designer Constantin E. Breuer, ("who congenially implements his ideas"), who have also contributed the acclaimed original artwork for the WNISR2019 edition and the cover of WNISR2020. Thanks so much for another fascinating, original, and very generous contribution.

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NOTE

This report contains a very large amount of factual and numerical data. While we do our utmost to verify and double-check, nobody is perfect. The authors are always grateful for corrections and suggested improvements.

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FOREWORD

By Naoto KAN, Former Prime Minister of Japan

Ten years have now passed since the Fukushima Daiichi accident, a disaster on a scale surpassing even that of Chernobyl. The reactors in Units 1 to 3 suffered not only meltdowns, but also melt-through of the nuclear fuel, while the spent fuel pool at Unit 4 came close to evaporating entirely. Had this come to pass, it would have necessitated the evacuation of all residents within a radius of 250 kilometers – an area including the metropolis of Tokyo, the consequences of which would have been unimaginable.

Thanks to the selfless front-line work of TEPCO employees, members of the Japan Self-Defense Force, firefighters, and the police, and with vital assistance from the USA and other countries, we were able to avoid the worst-case scenario. I would like to take this opportunity to again express my sincere gratitude to all those to whom we are so deeply indebted.

As Prime Minister of Japan at the time of the disaster, I now believe that the time has come for Japan and the world to end its reliance on nuclear power. To this end, I am currently involved with various projects, working alongside my like-minded predecessor Junichiro Koizumi.

The global nuclear power situation has changed greatly in the 35 years since the Chernobyl disaster, and even in the 10 years since the Fukushima Daiichi disaster began. New nuclear construction projects are few and far-between, even in heavily-reliant countries such as France and the USA, while the number of operational reactors is in decline. On the other hand, some countries, notably China, are actively pushing ahead with the construction of new nuclear power plants. However, in the wake of the Fukushima Daiichi accident, construction costs have doubled or even tripled, and the number of new plants under construction remains limited.

The *World Nuclear Industry Status Report* (*WNISR*) is amongst the most reliable data resources available on the subject and allows for an impartial and comprehensive understanding of the current status of nuclear power around the world. It is an invaluable tool when it comes to objectively assessing the situation faced by Japan's own nuclear power industry.

While Japan's power companies are still pushing to restart their existing reactors, the safety standards that must be met in order for this to happen are becoming ever-more stringent. Combined with the fact that no new facilities have entered service since the Fukushima Daiichi accident, the upshot of this is that no more than ten reactors are currently operational in Japan.

Japan is looking for ways to reduce its reliance on fossil fuel-based power generation as part of the fight against climate change. However, the current Japanese administration remains committed to including nuclear power in its projections. For my part, I am doing my best to persuade the Diet [the Japanese Parliament] that Japan's power needs can be fully met by renewable energy sources, without the need to fall back on nuclear.

Specifically, I am pushing for the large-scale rollout of solar power generation that shares space with agricultural land. This concept of "solar sharing" envisages installing solar panels three meters above the ground while continuing to use the farmland below.* The Japanese Ministry of Agriculture, Forestry and Fisheries (MAFF) refers to such solar sharing schemes as "farm-type solar generation". This approach enables solar power generation to be combined with food production. In principle, implementing such farm-type solar generation over just half of Japan's agricultural land area would provide enough electricity to meet Japan's entire power requirements. The MAFF is now showing enthusiasm for this concept.

Only 200 years ago, the energy consumed in Japan's towns and cities was produced in the countryside in the form of firewood and charcoal. Over the past 200 years, our major sources of energy have transitioned through coal, oil, and nuclear technology. The rise of renewable energy in the form of farm-type solar schemes would bring energy production back to the countryside where it began.

Around once a year, I still visit the remains of the Fukushima Daiichi site. Even though ten years have passed, progress in the decommissioning process remains frustratingly slow, driving home to me the importance of avoiding any repeat of such an event. The large quantities of radioactive debris that remain within the stricken reactors continue to release alarming levels of radiation. We already know from the example of Chernobyl that the timescale needed for this nuclear waste to drop to safe radioactivity levels will be measured in terms of centuries.

It is my wish that the WNISR will reach an ever-increasing audience of people around the world as they switch their focus to the nuclear industry.

* For details and examples refer to Fraunhofer ISE, "Agrivoltaics: Opportunities for Agriculture and Energy Transition", Undated, see https://agri-pv.org/en/.

KEY INSIGHTS

Capacity Up, Production Down

■ China passes France and becomes Number 2 in the World.
■ As of mid-2021, 33 countries operated 415 nuclear reactors, up seven units compared to mid-2020—but still below mid-2019 and 23 fewer than the 2002 peak of 438.
■ In 2020, globally, five reactors started up including first ones in Belarus and UAE – eight less than scheduled as of mid-2019. Six units closed.
■ The total operating nuclear capacity increased by 1.9 percent from one year earlier to reach 369 GW as of mid-2021, a new mid-year peak just above the record of 367 GW in 2006.
■ In 2020, nuclear power generation decreased—for the first time since 2012—by over 100 TWh or more than the individual national production of 28 of the 33 nuclear countries.
■ Excluding China, nuclear power generation dropped to the lowest level since 1995. The nuclear share in the electricity mix in France dropped to the lowest level since 1985.
■ For the first time, China generated more nuclear electricity than France and becomes the second largest nuclear generator in the world behind the United States.
■ The mean age of the world's nuclear fleet has increased steadily since 1984 and now stands at about 31 years with one in five units reaching 41 years or more.
■ Nuclear energy's share of global gross electricity generation continues its slow but steady decline from a peak of 17.5 percent in 1996 with a share of 10.1 percent in 2020.

China Continues to Dominate Domestic Nuclear Development... On a Lower Level

■ Nuclear generation in China increased by 4.4 percent, the lowest growth rate since 2009.
■ One third or 18 of the 53 units listed under construction in the world as of mid-2021 are in China. The global total remains well below the 69 units at the end of 2013.
■ In 2020, construction began on five reactors globally including four in China and one in Turkey.
■ China General Nuclear Corp. (CGN) abandoned nuclear export ambitions entirely.
■ China missed its 5-Year nuclear targets of 58 GW installed and 30 GW under construction but expanded wind power capacity by over 70 GW and solar by almost 50 GW in 2020 alone.
■ Russia is involved in 17 of the 53 construction projects in 8 of the 17 countries building

Chernobyl
35 Years After the Disaster Began

■ Most of the 6,800 thyroid-cancer patients of the first 20 years survived but at a high price.
■ Food contamination persists in large areas of Europe, e.g. in Germany exceeding legal limits.
■ A New Safe Confinement (NSC), an arch-like structure, covers Unit 4 since November 2016.
■ Dismantling of Units 1–3, undamaged in 1986, is to take at least until 2065.
■ Visitors to the Chernobyl site—the Ukrainian government seeks UN World Heritage status—went from 1,000 in 2004 to 200,000 in 2019.

Fukushima Status Report
Ten Years After

Onsite. The highly controversial plan to release more than 1 million m³ of contaminated water into the ocean is conditioned on re-processing at least 70 percent of the water and the dilution of all of it by a factor of 100. The operation would take at least three decades.

Health. As of July 2021, 218 persons—children at the time of exposure—were diagnosed with thyroid cancer. The number of cases is several dozen times higher than expected.

- The cancer incidence amongst residents clearly increases with the level of environmental contamination. No health survey on any group of workers has been released.
- In total, the number of officially recognized "disaster-related deaths" following evacuation in the prefectures of Fukushima, Iwate, and Miyagi reached 3,717, of which almost two thirds in Fukushima. That is very high, considering its share of deaths due to earthquake and tsunami was only 10 percent.

Costs. The Japanese government released a new cost estimate of the disaster tripling a 2012-estimate and reaching US$$_{2021}$223.1 billion. An independent assessment established a range of US$322–758 billion largely depending on the kind of water and waste treatment and disposal.

Judicial. Numerous legal cases have been filed and many are ongoing including a lawsuit to clarify the civil liability of TEPCO executives for the Fukushima disaster.

- Lawsuits have been filed against all operating reactors and restart attempts by nuclear operators except for one. As of April 2021, there have been eight court decisions that have suspended the operation of nuclear power plants.

Many Construction Delays Worsened
Construction Time of Latest Reactors Improved

- At least 31 of the 53 units under construction are behind schedule; 13 have reported *increased* delays and four have had documented delays for the first time over the past year.
- In 10 cases (19 percent), first construction starts date back a decade or more, including two units that had construction starts 36 years ago and one unit that goes back 45 years.

Nuclear Power and Criminal Energy

- The nuclear sector appears to have a problem of multiple forms of criminal activities.
- Some problems date back decades or have been ongoing for decades. Organized-crime organizations in Japan have been supplying workers to nuclear sites for over a decade.
- Serious insider sabotage has occured in major nuclear countries (e.g. Belgium) in recent years.
- Transparency International's 2020 Corruption Perceptions Index rates half of the 35 countries operating or constructing nuclear power plants on their territory below 50 out of 100.
- In the Bribery Payers Index, seven out of the ten worst rated countries amongst a total of 28 surveyed operate or are building nuclear power plants on their territory.

Renewables Continue to Thrive

- Total investment in new-renewable electricity exceeded US$300 billion again, 17 times the reported global investment decisions for nuclear power.
- Renewables proved highly resilient against the global pandemic and yet another record 256 GW of non-hydro renewables were added to the world's power grids in 2020. Wind added 111 GW and solar 127 GW. Nuclear power added a net 0.4 GW (startups vs. closures).
- Since 2009, levelized cost estimates for utility-scale solar dropped by 90 percent, wind by 70 percent, while nuclear increased by 33 percent.
- In the European Union, renewables for the first time overtook fossil fuels to become the primary source of power in 2020 which is also the first year that *non-hydro* renewables generated more power than nuclear reactors.

EXECUTIVE SUMMARY AND CONCLUSIONS

The World Nuclear Industry Status Report 2021 (*WNISR2021*) provides a comprehensive overview of nuclear power plant data, including information on age, operation, production, and construction of reactors. As 2021 is the tenth anniversary of the beginning of the Fukushima disaster in Japan, this year's report analyzes in more detail the onsite/offsite status, including the issues of contaminated water and waste management, health consequences, cost estimates and legal cases. A dedicated chapter assesses the lasting impacts of the Chernobyl accident in Ukraine 35 years later.

As the world continues to struggle with a global pandemic, record temperatures, wildfires, flooding, and other extreme weather events, WNISR2021 presents a first look at Nuclear Power and Climate Change Resilience including a case study on France.

WNISR has reported for years about irregularities, fraud, counterfeiting, corruption, and other criminal activities in the nuclear sector. WNISR2021 has, for the first time, dedicated an entire chapter to Nuclear Power and Criminal Energy documenting multiple criminal activities associated with nuclear power in many countries.

The WNISR assesses the status of new-build programs in the 33 nuclear countries (as of mid-2021) as well as in potential newcomer countries. WNISR2021 includes sections on ten Focus Countries representing about two-thirds of the global fleet and four of the five largest nuclear power producers. The Decommissioning Status Report 2021 provides an overview of the current state of nuclear reactors that have been permanently closed. The chapter on Nuclear Power vs. Renewable Energy Deployment offers comparative data on investment, capacity, and generation from nuclear, wind and solar energy, as well as other renewables around the world. Finally, Annex 1 presents overviews of nuclear power in the countries not covered in the Focus Countries sections.

REACTOR STARTUPS & CLOSURES

Startups. WNISR2019 noted 13 reactors scheduled for startup in 2020; only three of these units did so, while the other 10 were delayed at least into 2021. Two additional reactors started up that were not on the list. Four units were commissioned in the first half of 2021.

The COVID-19 pandemic impacted some of the commissioning schedules.

Closures.[1] Six units were closed in 2020, two each in France and in the U.S., and one each in Russia and Sweden. In the first half of 2021, two units were closed, in Taiwan and in the U.S.

Over the two decades 2001–2020, there were 95 startups and 98 closures in the world. As there were 47 startups and no closures in China over the period, the 98 closures outside China were only matched by 48 startups, a drastic decline by 50 units over the period.

1 - WNISR accounts for closures in the respective years of last electricity generation and adjusts statistics retroactively if units have not generated power in the year in review.

OPERATION & CONSTRUCTION DATA[2]

Reactor Operation and Production. As of 1 July 2021, 33 countries operated 415 nuclear reactors—excluding Long-Term Outages (LTOs)—up seven units compared to WNISR2020[3] but still two below mid-2019, three less than in 1989 and 23 fewer than the 2002 peak of 438. Two countries, Belarus and the United Arab Emirates, started up their first reactors.

A total of 26 units were in LTO, five less than in WNISR2020, of which 24 in Japan and one each in India and South Korea, all of which are considered operating by the International Atomic Energy Agency (IAEA).

The total operating capacity increased by 1.9 percent from one year earlier to reach a record 369 GW as of mid-2021, just above the previous maximum of 367 GW in 2006.[4]

In 2020, nuclear power generation decreased for the first time since 2012 (by 104 TWh or 3.9 percent). Annual nuclear electricity generation declined to 2,553 net terawatt-hours (TWh or billion kilowatt-hours) in 2020, a 3.9 percent drop over the previous year. Outside of China, nuclear power generation dropped by 5.1 percent to the lowest level since 1995.

For the first time, China generated more nuclear electricity than France.

The "big five" nuclear generating countries—by rank, the United States, China, France, Russia, and South Korea—generated 72 percent, the top three alone count for 58 percent of all nuclear electricity in the world in 2020.

Share in Electricity/Energy Mix. Nuclear energy's share of global gross electricity generation lost the 0.2-percentage-point increase of 2019 and returned to its slow but steady decline from a peak of 17.5 percent in 1996 with a share of 10.1 percent in 2020.

Nuclear power's share of global commercial primary energy consumption has remained stable since 2014 at around 4.3 percent.

Reactor Age. In the absence of major new-build programs, apart from China, the average age of the world operating nuclear reactor fleet continues to rise, and by mid-2021 reached 30.9 years. The mean age of the world's fleet has been increasing since 1984.

A total of 278 reactors, two-thirds of the world's operating fleet, have operated for 31 or more years, including 89—more than one in five—that have operated for 41 years or more; six units have operated for 51 years or more.

Lifetime Projections. If all currently operating reactors remained on the grid until the end of their licensed lifetime, including many that already hold authorized lifetime extensions (PLEX Projection), and all units under construction scheduled to have started up, an additional 123 reactors or 95 GW— one unit or 0.8 GW per month—would have to be started up or restarted prior to the end of 2030 in order to maintain the status quo. This would mean, in the *current* decade, the need to more than double the annual building rate of the *past* decade from 6 to 12. Construction starts are on a declining trend. The required number of new units

2 - See Focus Countries and Annex 1 for a country-by-country overview of reactors in operation and under construction as well as the nuclear share in electricity generation.

3 - Unless otherwise noted, all figures indicated reflect the situation as of 1 July 2021.

4 - All figures are given for nominal net electricity generating capacity. GW stands for gigawatt or thousand megawatts.

might be even higher because many reactors are being shut down long before their licenses are terminated: the mean age at closure of the 23 units taken off the grids between 2016 and 2020 was 42.6 years.

Construction. Seventeen countries are currently building nuclear power plants. As of 1 July 2021, 53 reactors were under construction—one more than WNISR reported for mid2020, but 16 fewer than in 2013—of which 18 are in China with with a total capacity of 17 GW.

Total capacity under construction in the world increased by 0.5 GW to 54 GW. The current average time since work started at the 53 units under construction is 7 years compared to 7.3 years one year ago and 6.2 years as of mid-2017. Many units are still years away from completion.

- *All* reactors under construction in at least 12 of the 17 countries have experienced, mostly year-long, delays. At least 31 of the building projects are delayed.
- Of the 31 reactors clearly documented as behind schedule, at least 13 have reported *increased* delays and four have reported *new* delays over the past year.
- Thirteen reactors were scheduled for startup during 2020, but only five did.
- Construction starts of two projects date back 36 years. Firstly, Mochovce-3 and -4 in Slovakia, where their startup has been further delayed, currently to late 2021 and 2023 respectively. Secondly, Bushehr-2 originally started construction in 1976, 45 years ago, and resumed construction in 2019 after a 40-year-long suspension. Grid connection is currently scheduled for 2024.
- Five additional reactors have been listed as "under construction" for a decade or more: the Prototype Fast Breeder Reactor (PFBR) and Kakrapar-4 in India, Olkiluoto-3 (OL3) in Finland, Shimane-3 in Japan, and Flamanville-3 (FL3) in France. The Finnish project has been further delayed this year, grid connections of the French and Indian units are likely to be postponed again, and the Japanese reactor does not even have a provisional startup date.
- Ten countries completed 63 reactors—with 37 in China—over the past decade, with an average time between construction start and grid connection of 10 years.

CONSTRUCTION STARTS & NEW-BUILD ISSUES

Construction Starts. In 2020, construction began on five reactors—four in China and one in Turkey—and in the first half of 2021 on six units, of which three in China. This compares to 15 construction starts in 2010. Construction starts peaked in 1976 at 44.

Over the decade 2011–2020, construction began on 57 reactors in the world, of which three have been abandoned. As of mid-2021, only 15 have started up, while 39 remain under construction.

Construction Cancellations. Between 1970 and mid-2021, a total of 93 or one in eight of a total of 783 constructions were abandoned or suspended in 19 countries at various stages of advancement.

FOCUS COUNTRIES

The following ten Focus Countries covered in depth in this report represent almost one third of the nuclear countries hosting about two-thirds of the global reactor fleet. Key facts for year 2020:

Belarus. On 3 November 2020, the country connected its first reactor Belarusian-1 at Ostrovets to the grid and became the 33rd country operating nuclear power plants. The plant is highly controversial amongst neighboring countries, and the European Commission has called for safety upgrades.

China. Nuclear power generation grew by 4.4 percent in 2020, the lowest annual growth rate since 2009, but China overtook France as the second largest nuclear generator in the world nevertheless.

Finland. The Olkiluoto-3 EPR project was delayed again, this time "due to extension of turbine overhaul". According to an announcement from August 2021, "regular production of electricity" will not happen before June 2022, 13 years after the original planned startup date.[5]

France. Nuclear plants generated almost 12 percent less power than in 2019, representing 67 percent of the country's electricity, the lowest share since 1985. Outages at *zero capacity* cumulated 6,475 reactor-days or almost one third of the year per reactor *on average*. The Flamanville-3 EPR project was delayed again and is now scheduled for startup at mid-2023. Meanwhile, as of the end of 2020, the national utility EDF's competitors had captured half of the commercial customers and 26 percent of the residential clients.

India. Kakrapar-3 eventually started operating in January 2021 after over 10 years of construction. Nuclear plants generate 3 percent of the country's electricity. Solar plants and wind turbines each generate more power than nuclear plants. Both technologies together generate three times as much electricity as nuclear plants.

Japan. Nuclear plants generated 5 percent of the electricity in the country, down from 7.5 percent in 2019. As of mid-2021, ten reactors had restarted at some point but hardly produced simultaneously. One returned to LTO status. For six weeks in November-December 2020, only one unit was operating.

South Korea. For the second year in a row, nuclear power output increased by almost 10 percent following a significant decline in the years after 2015 and supplied 29.6 percent of the country's electricity. According to the ninth energy plan, the country will reduce nuclear's role to providing just 10 percent of power by 2034. However, that policy could be overturned following the next elections.

Taiwan. Another reactor was closed in July 2021, and the remaining three are to be closed by 2025. With the reelection in 2020 of President Tsai Ing-wen, the phaseout policy has been maintained. Nuclear's share in electricity generation has already declined from 41 percent 1988 to 13 percent in 2020.

5 - TVO, "The regular electricity production of OL3 EPR will be postponed due to extension of turbine overhaul", 20 August 2021, see https://www.tvo.fi/en/index/news/pressreleasesstockexchangereleases/2021/theregularelectricityproductionofol3eprwillbepostponedduetoextensionofturbineoverhaul.html, accessed 23 August 2021. Just as one year earlier, this latest announcement happened after the editorial deadline for the main body of this report.

United Kingdom. Nuclear generation decreased another 11 percent while renewable power generation increased by 11 percent. Two reactors in LTO were closed. Four more units are slated for closure before mid-July 2022. The fleet's aging units, over 37 years on average, are struggling with many technical issues, in particular irreparable damage to moderator graphite bricks leading to lengthy outages of the Advanced Gas-cooled Reactors (AGRs). The projected startup of Unit 1 of Hinkley Point C has been delayed to mid-2026 and the cost estimate raised again.

United States. The nuclear fleet continues to age, with a mid-2021 average of 40.7 years, exceeding 40 years for the first time. Nuclear units have increasing difficulties to compete in the market. State subsidies have been granted to four uneconomic nuclear plants to avoid their "early closure". Following the revelation of an unprecedented corruption scheme in Ohio, the "bailouts" of four reactors are likely to be reversed. Many other units remain threatened with early closure for economic reasons. The former CEO of nuclear utility SCANA pleaded guilty to conspiracy fraud charges involving a cover-up of financial problems with the now abandoned V.C. Summer construction project. Westinghouse's most senior executive managing the project was charged with the felony offence of lying to the FBI over his role in the scandal.

FUKUSHIMA STATUS REPORT – TEN YEARS AFTER

Ten years have passed since the Fukushima Daiichi nuclear power plant accident (Fukushima accident) began, triggered by the East Japan Great Earthquake on 11 March 2011 (referred to as 3/11 throughout the report) and subsequent events.

This anniversary edition goes beyond the traditional overview of onsite and offsite challenges and provides dedicated sections to the complex issue of health effects, cost assessments and judicial decisions on the responsibilities of operator and the state for the disaster, and on the conditions of reactor restarts.

Overview of Onsite and Offsite Challenges

Onsite Challenges

Spent Fuel Removal from the pool of Unit 3 was completed in February 2021. Units 1 and 2 have not gone beyond the preparatory stage.

Fuel Debris Removal, planned to start with Unit 2 by 2021, has been delayed by "about one year due to the spread of COVID-19".

Contaminated Water Management. Water injection continues to cool the fuel debris of Units 1–3. Highly contaminated water runs out of the cracked containments into the basements where it mixes with water that has penetrated the basements from an underground river. The commissioning of a bypass system and the pumping of groundwater had reduced the influx of water from around 400 m^3/day to about 170 m^3/day. However, in FY2019, pumped contaminated water increased again to 180 m^3/day, and to 228 m^3/day as of mid-2021. An equivalent amount of water is partially decontaminated and stored in 1,000-m^3 tanks. Thus, a new tank is needed every 4.5 days. The storage capacity onsite of 1.4 million m^3 is expected to be saturated by the end of 2022. Plans to release the contaminated water into the ocean are widely contested, including overseas. If implemented, at least about 70 percent of the water has to be processed again, and all of it must be diluted by a factor of 100. The operation would take at least three decades.

Worker Health. As of February 2021, there were close to 7,000 workers involved in decommissioning work on-site, 86 percent of whom were subcontractors; only the remaining 14 percent worked for Tokyo Electric Power Company (TEPCO).

Offsite Challenges

Amongst the offsite issues are the future of tens of thousands of evacuees, food contamination, and the management of decontamination wastes. Separate sections are dedicated to health consequences, legal issues, and cost assessments of the Fukushima disaster.

Evacuees. As of April 2021, about 35,500 Fukushima Prefecture residents—not including "self-evacuees"—were still officially designated evacuees. According to the Prefecture, the number peaked just under 165,000 in May 2012. The government intends to continue the lifting of restriction orders for affected municipalities. However, according to a recent survey, only 2.5 percent of the people returned to Okuma Town and 9.2 percent to Tomioka Town.

Food Contamination. According to official statistics, among 54,412 samples taken in the first 11 months of FY 2020 (five times less than in FY2019), a total of only 127 food items were identified as being contaminated beyond legal limits. As of March 2021, post-3/11 import restrictions remain in place in 14 countries/regions (six less than a year earlier), including the E.U.

Decontamination. The contaminated soil in the temporary storage area in Fukushima Prefecture is currently being transferred to intermediate storage facilities in eight areas. As of April 2021, around 76 percent of the total amount of 14 million m^3 had been shipped. The soil is to be processed through various stages of volume reduction before being retransported to a final repository.

Health Effects

In the immediate aftermath of 3/11, the Japanese government increased the public exposure dose limit by a factor of 20 from 1 to 20 millisieverts per year. In March 2017, the government terminated housing support for evacuees from outside specific evacuation zones to encourage residents to return to (what is left of) their homes.

The Fukushima accidents did not lead to cases of acute radiation deaths but to lower-level radiation exposure of large numbers of people as well as several thousand casualties from indirect effects following evacuation.

Thyroid Radiation Dosimetry and Potassium Iodine. According to the results of the body surface screenings, at least 1,000 evacuees received dose levels at the thyroid exceeding 100 millisievert that should have led to decontamination and intake of potassium iodine.

However, this did not happen. Instructions by the Nuclear Safety Commission (NSC) for iodine distribution got lost and only about 10,000 people took iodine on the initiative of the heads of four towns.

Thyroid Examination Program. About 380,000 children at the age of 18 or younger (including in utero) at the time of the accidents are eligible for the program. As of July 2021, a total of 260 malignant or suspected malignant cases were detected: 219 underwent surgery, and 218 were diagnosed as cancer. The number of cases is several dozen times higher than usual. In addition, an NGO revealed that there are at least 19 additional, unreported thyroid cancer cases and possibly twice as many which would mean that one in eight cases had not been included in the official results.

Causal Relationship Between Thyroid Dose and Cancer Incidence. Measurements of children's thyroid doses started only two weeks after the release (iodine-131 has a half-life of eight days). Only about 1,000 children were measured at a distance beyond 30 kilometers with high environmental contamination. The cancer incidence clearly increases with the level of environmental contamination. Exposure levels were estimated and segmented by the Oversight Committee on the basis of aircraft measurements in the evacuation zone and three regions outside. The causal relationship that is clearly visible when the exposure doses are segmented by contaminated area incorrectly seems to disappear when the doses were segmented according to the UNSCEAR estimate based on the calculated sum of external and internal exposure for two different age groups.

Other Cancer Cases and Other Disaster Related Deaths. While mortality rates decreased and morbidity rates have remained flat or decreased in nine other prefectures, incidence rates in Fukushima Prefecture seem to be on the rise since 2012 for thyroid, cervical, prostate, and breast cancer. No increase in congenital anomalies have been reported. Deaths from heart attack increased by 10-20 percent in Fukushima Prefecture in 2011 for both men and women in the age groups of 40-69, and 70 and over. In total, the number of officially recognized "disaster related deaths"[6] following evacuation in the prefectures of Fukushima, Iwate, and Miyagi reached 3,717 of which almost two thirds in Fukushima. That is very high, considering its share of deaths due to earthquake and tsunami was only 10 percent.

Health Issues of Nuclear Power Plant Workers. Amongst the almost 25,000 workers who have worked onsite in the six months following 3/11, the maximum documented exposure dose was 679 mSv, and 174 workers (0.7 percent) are documented to have been exposed to more than 100 mSv. The average exposure dose was 12.4 mSv. Reliability of these values is highly questionable as, at least for two months, the doses were only measured in groups due to the lack of individual dosimeters. In addition to the radiological impact of the ongoing decommissioning work, workers are exposed during handling, shipment and storage of millions of cubic meters of contaminated soil. No health survey on any group of workers has been released over the past decade.

6 - These include amongst others suicides, worsening of chronic diseases due to reduced access to medical care (loss of hospital functions, difficulty in visiting hospitals), health impairment due to prolonged and severe evacuation environment and loss of livelihood.

Cost Estimates

Ten years after 3/11, disaster response remains decades away from completing the essential clean-up and mitigation tasks. Cost estimates are therefore essentially hypothetical. However, the government has recently offered an updated estimate that can be compared to an independent assessment by the Japan Center for Economic Research (JCER), an established independent economic think tank.

Government Estimates for 3/11 disaster-related costs covering decommissioning, decontamination, and compensation rose from $US\$_{2021}$74.3 billion in 2012 to $US\$_{2021}$223.1 billion in 2021. Decommissioning increased by a factor of five to $US\$_{2021}$75 billion and compensation by 26 percent to $US\$_{2021}$74 billion. Decontamination, not even factored into the first estimate, represents $US\$_{2021}$52.5 billion and a new position for "others" comes in with $US\$_{2021}$21.6 billion.

JCER Estimates released in 2019 range from US$322 billion to US$758 billion covering in three scenarios decontamination with US$186 billion and compensation with US$96 billion while decommissioning costs vary from US$40 billion (if delayed to 2050, not including post-2050 costs) to US$476 billion. The range of decommissioning costs largely depends on the quantity and type of contaminated water treatment with the upper number including tritium removal.

The biggest difference between the government and JCER estimates comes from the fact that the official estimate does not include final disposal costs for radioactive waste generated by decommissioning and decontamination.

Judicial Decisions on Damages and Criminal Liability for the Fukushima Nuclear Accidents

Over the past decade, many court cases have been filed by citizens around nuclear power issues. The most significant lawsuits include attempts to establish a link between the responsibilities for the disaster and complaints filed against Fukushima owner-operator Tokyo Electric Power Company (TEPCO) and the Japanese Government. In addition, cases have been filed against all operating reactors and restart attempts by nuclear operators except for one (Higashidori).

Government Responsibility. Judicial decisions are divided: the September 2020 Sendai High-Court decision and the February 2021 Tokyo High-Court decision acknowledged government responsibility while a separate February 2021 Tokyo High-Court decision rejected the responsibility of the state. All three of these cases have been appealed, and the Supreme Court's decisions are expected to be issued within the coming year.

TEPCO Criminal Case. In September 2019, the Tokyo District Court acquitted three TEPCO executives from criminal responsibility for manslaughter through the Fukushima disaster.

TEPCO Civil Liability Case. The TEPCO shareholder representative lawsuit to clarify the civil liability of TEPCO executives for the Fukushima disaster is still underway.

Lawsuits Against Reactor Operation and Restarts. As of April 2021, there have been eight court decisions that have accepted the opinions of plaintiffs and suspended the operation of nuclear power plants, including the following:

- In April 2015, the Fukui District Court issued a provisional injunction order against the operation of Takahama Units 3 and 4, thereby forcing the shutdown of actually operating reactors.
- In December 2017, the Hiroshima High Court, presided by Judge Tomoyuki Nonoue, issued a provisional injunction against the operation of Unit 3 of the Ikata Nuclear Power Plant, for a limited nine-month period.
- In January 2020, the Hiroshima High Court granted an injunction against the operation of the Ikata nuclear power plant.
- In December 2020, the Osaka District Court ruled to revoke the license for the modification of the installation of Units 3 and 4 of the Ohi Nuclear Power Plant. This was the first time since 3/11 that residents' claims have been accepted in an administrative lawsuit.
- In March 2021, the Mito District Court issued an injunction against the restart of the Tokai Daini nuclear power plant—directly impacted by 3/11—for the first time, on the grounds of a missing credible evacuation plan.

CHERNOBYL – 35 YEARS AFTER THE DISASTER BEGAN

Thirty-five years ago, on 26 April 1986, the world witnessed its worst nuclear power plant accident. Unit 4 of the Chernobyl nuclear power plant experienced a critical power excursion. Within seconds, nominal energy output of the reactor core surged by a factor of more than 100, followed by a steam and then a hydrogen explosion that tore through the roof of the reactor building. About 40 percent of European territory has been contaminated, potentially affecting some 400 million people. To date, in some regions, radioactivity levels in various food stuffs remain above legal limits. Nevertheless, much has changed in three and a half decades.

Offsite Challenges

- The death toll of the disaster remains controversial. Prior to 2005 only some 50 deaths were directly attributed to the accident. In 2006, a WHO-IAEA study estimated 9,000 excess cancer deaths. U.S. nuclear physicist Richard Garwin estimated 24,000 and other independent experts 40,000 excess cancers over the coming 50 years. Russian and Belarussian scientists claimed that Chernobyl's death toll from radiation-related diseases would even surpass 200,000 in Europe and approach 20,000 in the rest of the world.
- **The health detriments** obviously do not all entail death. Most of the 6,800 thyroid-cancer patients in the first 20 years following the accident survived but suffered physical and psychological harm. There are contradicting studies about transgenerational effects.
- **Abortions** sky-rocketed in the aftermath of the accident. The IAEA estimated that between 100,000 and 200,000 abortions were related to Chernobyl radiation concerns in the year following the accident in Western Europe alone.
- **Psychological trauma** caused by the disaster, resettlement, loss of community and livelihood, resulted in significantly higher rates of mental illness, including depression, anxiety, and substance abuse. There is also evidence of direct neuropsychiatric effects of ionizing radiation on the brain. In 2018, the Ukrainian government reported estimates

that mental illness was about twice as prevalent and by some estimates suicide rates are as much as 20 times higher among the Chernobyl liquidators compared to the general population. In Ukraine, 20 years after the Chernobyl disaster began, some 83 percent of the population affected by the accident had experienced some form of adverse health consequences; 92 percent among liquidators.

- **Persisting food contamination** remains widespread in Europe. In southern Germany, for example, wild game and mushrooms are still found contaminated with caesium-137 to several times the legal limits for sales.

Onsite Challenges

- **A New Safe Confinement** (NSC), an arch-like structure, covers Unit 4 since November 2016. The arch is the largest land-based movable structure ever built. The NSC is meant to hermetically seal off Unit 4 from the environment and has a projected lifetime of at least 100 years.
- **Dismantling** of Units 1–3 is estimated to take at least until 2065.
- **Spent fuel**, some 21,000 assemblies or 2,500 tons, from the four Chernobyl units has been moved from reactor pools to a centralized five-pool interim storage facility. Then, it is to be transferred to a centralized dry store that received the operating license in April 2021.
- **Visitors to the Chernobyl Exclusion Zone**—the Ukrainian government seeks UN World Heritage status for it—went from 1,000 in 2004 to 200,000 in 2019.
- **Wildlife Refuge?** Significant media coverage has been dedicated to the return of wildlife following the depopulation of the zone; but its abundance has likely been significantly tempered by radiation effects. Studies across some 30 species, found an unusually high rate of radiation-related genetic mutation and suggest that transgenerational population-wide effect of radioactive contamination could be significant.
- **Wildfires**, once a rarity, have become more frequent in the exclusion zone, often due to arson, reactivating radionuclides and significantly increasing ambient radioactivity.

NUCLEAR POWER AND CRIMINAL ENERGY

A stunning number of revelations in recent years on irregularities, fraud, counterfeiting, bribery, corruption, sabotage, theft, and other criminal activities in the nuclear industry in various countries suggest that there is a systemic issue of "criminal energy" in the sector.

While WNISR has reported for years about illegal and criminal practices, WNISR2020 mentions "corrupt" 14 times in connection with corruption cases involving nine countries on four continents.

This is the first systematic international analysis of the issue within the framework of this annual report. Although not comprehensive, this analysis offers several noteworthy insights:

- Criminal activities in the nuclear sector are not new. Some major scandals date back decades or have been ongoing for decades.
- Organized crime organizations have been supplying workers to nuclear sites—e.g. the Yakuza in Japan—for over a decade.

- Serious insider sabotage has hit major nuclear countries in recent years—like a Belgian nuclear power plant—without ever leading to arrests.
- There is no systematic, comprehensive, public database on the issue.
- In 2019, the IAEA released a report on cases of counterfeit or fraudulent items in at least seven countries since at least the 1990s.
- In Transparency International's 2020 Corruption Perceptions Index about half of the 35 countries operating or constructing nuclear power plants on their territory rate under 50 out of 100.
- In the Bribery Payers Index (BPI, last published in 2011), seven out of the ten worst rated countries operate or are building nuclear power plants on their territory.
- The first part focuses on 14 cases with serious implications (safety, public governance) that came to trial in the period 2010–2020 either involving companies from or having taken place in the 2020 Top-8 nuclear power fleets (by operating capacity)7 including the following:
  - **International (Ukraine/Czech Republic), Energoatom/Skoda, October 2020**—A Swiss court sentenced Mykola Martynenko, a former Ukrainian member of parliament and chair of the energy committee, to a 28-month prison term for aggravated money laundering through Swiss banks.
  - **Japan, KEPCO, September 2019**—A Kansai Electric Power Co. (KEPCO) internal investigation revealed that the utility's President and 19 other employees received cash and gifts worth US$3 million from former Deputy Mayor Eiji Moriyama who aimed to encourage KEPCO to work with local suppliers he had ties with.
  - **France, AREVA, 2016**—AREVA informed the French Nuclear Safety Authority (ASN) about "irregularities in the manufacturing checks" at its Creusot Forge, including "inconsistencies, modifications or omissions in the production files, concerning manufacturing parameters or test results" for about 400 components fabricated since 1969. EDF subsequently identified 2,982 "anomalies" in the manufacturing documentation related to parts already installed in 58 French reactors.
  - **International (Russia/U.S.), Rosatom, 2015**—Former President of U.S.-based Rosatom subsidiary TENAM, Vadim Mikerin, received a 4-year prison sentence for his participation in a US$2.1-million bribery scheme involving several American companies and Rosatom officials.
  - **International (China, South Korea, U.S.), 2012**—CEO and five executives of Control Component Inc. (CCI), an American control valve manufacturer, received up to 5-year prison sentences each, for making "236 corrupt payments to officers and employees of state-owned and private companies in thirty-six countries totalling approximately [US]$6.85 million and earned approximately [US]$46.5 million in net profits from the sales related to those corrupt payments."
  - **South Korea, November 2012**—Korea Hydro & Nuclear Power (KHNP) reported fraudulent documents on equipment qualification in 60 procurement contracts involving 7,682 items.

7 - United States, France, China, Russia, South Korea, Canada, Ukraine, and Japan.

- The second part provides a cross-country comparison of events involving sabotage and organized crime on nuclear power plant sites in Japan, Russia, and the U.S. including:
  - **Fukushima Nuclear Power Plant, Japan, October 2014**—Yuuki Sagawa, a member of the Matsuba Kai mob was arrested in 2014 for brokering unlicensed workers to Fukushima cleanup operations. In **May 2012,** Makoto Owada, high-ranking member of Sumiyoshi-kai, the second largest Yakuza group in the country, was arrested for the same crime.
  - **St. Lucie Nuclear Power Plant, U.S., August 1996**—Employees glued backup switches in a high security area during a labor strike over their working conditions. The month before, it had been discovered that padlocks and doors had also been glued.

DECOMMISSIONING STATUS REPORT

As more and more nuclear facilities either reach the end of their pre-determined operational lifetime or close due to deteriorating economic conditions, their decommissioning is becoming a key challenge. Note that waste management is not part of this decommissioning analysis.

- As of mid-2021, 196 reactors were closed, seven more than a year earlier, of which 176 are awaiting or are in various stages of decommissioning including 74 in long-term enclosure.
- Only 20 units have been technically fully decommissioned, no change over the situation a year earlier: 14 in the U.S., five in Germany, and one in Japan. Of these, only 10 have been returned to greenfield sites for unrestricted use.
- The average duration of the decommissioning process is about 20 years, with a large range of 6–42 years (both extremes for very small reactors with respectively 22 MW and 17 MW).
- The analysis of 11 major nuclear countries shows that progress in decommissioning projects remains slow: of 169 closed units, 57 are in the "warm-up stage" and only 10 are in the "hot-zone stage".
- None of the early nuclear states—U.K., France, Russia, and Canada—have fully decommissioned a single reactor yet.

SMALL MODULAR REACTORS (SMRs)

Following assessments of the development status and prospects of Small Modular Reactors (SMRs) in earlier WNISR editions, this year's update does not reveal any major advances but some modest progress.

Argentina. The CAREM-25 project under construction since 2014 is reportedly 58 percent complete. COVID-19 led to a provisional complete construction stop. Completion shall take another three years.

Canada. There is strong federal and provincial government support for the idea to promote SMRs. The federal Minister of Natural Resource released an action plan aiming at "first units in operation by the late 2020s". Various models are being investigated. Two designs (Moltex SSR-W300, Hotec's SMR-160) completed Phase 1 review process by the safety authorities with numerous issues remaining to be solved.

China. Two 100 MW high-temperature reactor modules have been under construction at one site since 2012. Startup has been delayed several times and is still planned for 2021, four years later than scheduled. The module size shall be increased to 600 MW in a second project, which would be twice the 300 MW maximum for the SMR label. Construction of a reactor with another design called ACP100 is believed to have commenced, but it was never officially report; according to the promoter, the cost per kilowatt would be two times higher than that of a large reactor.

India. An Advanced Heavy Water Reactor (AHWR) design has been under development since the 1990s, and its construction start is getting continuously delayed. No major news since WNISR2019.

Russia. After a construction lasting four times longer than planned, two "floating reactors" were connected to the grid in December 2019. The costs per unit of generation capacity has been estimated at about twice as high as that of the most expensive Generation III reactors. Performance in 2020 was poor with load factors of 29 percent and 16 percent. Construction of a 300 MW lead-cooled fast reactor got underway.

South Korea. The System-Integrated Modular Advanced Reactor (SMART) has been under development since 1997. In 2012, the design received approval by the safety authority, but there have been no orders, because it is not cost-competitive. Saudi-Arabian engineers are assisting in the redesign of a larger model.

United Kingdom. The government to provide up to US$0.5 billion for SMR development in as part of an "Advanced Nuclear Fund". Rolls-Royce, the only company that has demonstrated interest, has recently increased the capacity of its pre-design to 470 MW, thus beyond the SMR size. The general design is to be submitted to the regulator in the second half of 2021.

United States. The Department of Energy (DOE) has funded companies promoting SMR development. A single design by NuScale has received a final safety evaluation report by the regulator. However, the capacity of the design has been increased by 25 percent and the modifications need to be certified by the regulator. Meanwhile, the withdrawal of eight municipalities leaves NuScale with less than one ninth of the output of a typical 12-module plant under tentative contract.

Overall, there are additional delays in development and construction, and no new design certifications beyond an already outdated NuScale design in the U.S. There are thus no new signs that of a major breakthrough for SMRs, neither technologically nor commercially.

NUCLEAR POWER VS. RENEWABLE ENERGY DEPLOYMENT

Renewable energy deployment and generation has far better resisted the impacts of the global COVID-19 pandemic than the nuclear power sector. In 2020, nuclear power added net 0.4 GW (+startups, -closures) while renewable capacity increased by a record 256 GW (+30 percent); nuclear production dropped 4 percent while non-hydro renewables increased 13 percent.

Costs. Levelized Cost of Energy (LCOE) analysis shows that between 2009 and 2020, utility-scale solar costs came down 90 percent and wind 70 percent, while new nuclear costs increased by 33 percent. The gap has continued to widen between 2019 and 2020.

Investment. In 2020, for the second time in a row, and the fourth time after 2015 and 2017, the total investment in non-hydro renewable electricity capacity exceeded US$300 billion, almost 17 times the reported global investment decisions for the construction of nuclear power of around US$18 billion for 5 GW. Investment in nuclear power is one eighth of the individual investments in wind (US$142 billion) and solar (US$149 billion).

Installed Capacity. In 2020, wind nearly doubled its annual expansion with 111 GW and solar-photovoltaics (PV) added 127 GW (+22.5 percent), both new record levels, largely contributing to the new global record of 256 GW of non-hydro renewables added to the world's power grids. These numbers compare to a net 0.4 GW addition in nuclear power capacity.

Electricity Generation. In 2020, annual growth for global electricity generation from solar was 21 percent, and 12 percent for wind power, but nuclear generation dropped by 4 percent. Non-hydro electricity generation outperformed nuclear power production by 16.5 percent.

Low-Carbon Power. Compared to 1997, when the Kyoto Protocol was signed, in 2020 an additional 1,580 TWh of wind power was produced globally and 855 TWh of solar PV electricity, compared to nuclear's additional 289 TWh (net). Compared to 2010, thus prior to 3/11, non-hydro renewables generated 2,386 TWh more electricity, hydro 861 TWh more while nuclear power generated 68 TWh *less*.

Share in Power Mix. After experiencing the strongest annual growth on record, the share in power generation from new renewables (excluding hydro) reached 10.7 percent, widening the gap with nuclear energy's shrinking share at 10.1 percent.

In **China**, electricity production of 466 TWh from wind alone again by far exceeded the 366 TWh from nuclear, while solar power is already at 261 TWh. Solar and wind combined generate twice as much electricity as all nuclear plants put together.

In **India**, generation from wind and solar individually outpaced nuclear by 50 percent; combined they produced in excess of three times as much electricity as nuclear power plants.

In the **European Union**, renewables including hydro for the first time overtook fossil fuels to become the primary source of power in 2020 contributing 38 percent to the mix with fossil fuels covering 37 percent and nuclear 25 percent. 2020 is also the first year that *non-hydro* renewables generated more power than nuclear reactors.

In the **United States**, nuclear generation declined by 3.6 percent to the lowest level since 2012, due to effects of the COVID-19 pandemic and competition from other sources. In contrast, the U.S. generated a record amount of renewable electricity in 2020, about 12 percent of the total vs. 20 percent for nuclear. Wind power output increased by 14 percent in 2020, while the generation of solar increased by 22 percent.

NUCLEAR POWER AND CLIMATE CHANGE RESILIENCE

Recent studies have generated evidence that energy generation and services are increasingly disrupted by climate change through the increase in the variability, intensity, and predictability of weather conditions. Power-system resilience can be broadly defined as the ability to cope with, recover from, and minimize the impact of various types of potentially disruptive developments or events. The special focus chapter on the issue of Nuclear Power and Climate Change Resilience provides an overview of problems all electricity generating technologies and grid systems are facing and a case study on France.

- The operations of all thermal power plants are most frequently vulnerable to ambient and water temperature variations. Nuclear plants are especially vulnerable to droughts.
- The most vulnerable renewable energy source to climate change is hydropower, which is expected given the high dependency on water availability. Wind energy output is strongly dependent on the wind density at given wind turbine sites. Solar energy output is dependent on the cloudiness and ambient temperature. The efficiency of solar panels decreases as the ambient temperature increases.
- High ambient temperature levels lead to greater transmission and distribution losses. For every 5°C air temperature-increase, research has found, the capacity of a fully loaded transmission line would be diminished by an average of 7.5 percent. Wildfires can also severely impact the grid.

Overview of specific challenges to nuclear facilities. There are two main pathways:

- **Thermal Disruptions**, driven by droughts and heatwaves, include outages that result from the limitation on evacuating the thermal power generated within the reactor, triggering either reduced power output or a full outage at zero capacity.
  - In Europe, temperature extremes are the main contributor to climatic disruptions. Over the past two decades, heatwaves have frequently forced shutdown or curtailment of nuclear power reactors, the largest of which were observed in 2003, 2006, 2015 and 2018.
- **Severe Storm Pathway**, including outages triggered by violent storms like hurricanes or typhoons, often accompanied by floods, lightning, etc., that can impact in particular the electrical power supply systems at the power plant.
  - Nuclear power plants in North America and East Asia, are particularly susceptible to suffer from cyclone activity.

Indirect climate driven effects, and nuclear facilities other than reactors:

- **Indirect Climate-Driven Effects** impacting nuclear power plant operation include jellyfish proliferation that can block the inlet of cooling water channels, wildfires that can necessitate plant evacuation, floods that can cut power supply, road access, and sea level rise that can lead to the intensification of storms.

- WNISR does not cover fuel chain facilities such as uranium mining, nuclear fuel production, spent fuel reprocessing, waste management and disposal facilities. However, it should be noted that all of them are at risk of being affected by climate change induced events.

Case Study France – Historic and Recent Events

- First weather-related disruptions of nuclear power production reported as early as 1976. In August 2003, 10–15 GW or 16–24 percent of total installed nuclear capacity was unavailable due to high temperatures.
- Recent incidents include the unavailability of three out of four 900 MW Blayais reactors in the Bordeaux region in March 2021 due to an accumulation of foreign matter disabling their pumping stations (fouling) and a one-month shutdown of the two 1450 MW units in Chooz at the Belgian border caused by the low level of the Meuse River in August–September 2020.

Case Study France – Impact on Nuclear Generation 2015–2020

A study by the French transmission system operator RTE analyses the impact of weather on nuclear power production between 2015 and 2020. The results show:

- Between 2015 and 2020, weather was responsible for about 4,000 hours of outages at zero power—a loss of 166 reactor-days of production—and an additional 4,000 hours of derating.
- Climate-induced unavailabilities occurred every year: 2016 was the least affected with just 18 deratings while 2018 was the worst year with 23 full outages and 103 deratings.
- Over the 6-year period, 26 reactors were affected at least once (including both Fessenheim reactors) and 12 were shutdown (including one Fessenheim unit) at some point.
- The cumulated production loss is 8.5 TWh or an average 1.4 TWh per year. This represents only about 0.4 percent of French annual nuclear production.
- The production losses appear to have an increasing trend with the highest loss occurring in 2020 with 3 TWh.
- While the absolute production losses appear negligeable, they are difficult to forecast and are often concentrated over a relatively short period of the year. The 2019 heatwave, for example, impacted nine reactors and lead the loss of 10 percent of the installed nuclear capacity, which in turn lead to a surge in electricity spot market prices.
- Climate-induced unavailabilities over the period were concentrated between July and November, and half of the production losses occurred in the September months. The Chooz site had a 28-day full unavailability in September 2020. September is the month with the lowest flow on the Rhône and Meuse rivers and is increasingly exposed to late heatwaves.
- Among the fourteen nuclear sites located inland, nine experienced climatic unavailability over the period. Three plants lost output in excess of 1 TWh: Chooz (4.4 TWh), Saint Alban (2 TWh) and Bugey (1.1 TWh).
- Disruptions can be classified into three broad categories: summer type (caused by temperature), autumn type (caused by low water flow), and winter type (caused by floods or storms).

- **Summer disruptions** are usually short but can touch multiple plants simultaneously and will almost certainly occur more frequently.
- **Autumn disruptions** often stretch over longer periods but remain more localized. They occur during low flowrate periods when rivers cannot efficiently dilute hot water discharged from the power plant, making it harder to comply with temperature regulations.
- **Winter disruptions** are due to lower frequency events that can carry higher risks (e.g. the December 1999 flooding of the Blayais site).

→ Adaptation options are limited for existing plants. Also, while most adaptation strategies are based on climate projections, EDF uses extrapolations. Maximum temperatures are calculated by extending historical observations over a 10-year period. This implicitly carries a risk of underestimating future temperature variation.

→ Safety implications of nuclear-climate interactions remain poorly understood, especially as nuclear power is being introduced into potentially particularly adverse climate environments like in the Middle East or Bangladesh for example. Unexpected extreme weather events could also have particularly detrimental effects if they coincided with an ongoing nuclear accident.

INTRODUCTION

Mid-2020, the world had hoped the pandemic would be gone long before year end. Mid-2021, a growing number of people starts wondering whether they will have to live with COVID-19 over the long term and adjust with repeated vaccinations.

WNISR2020 provided a first international overview of some of the COVID-19 impacts on the nuclear industry. Generally speaking, the nuclear industry and safety authorities remain very confident that the pandemic had limited or no impact on the operating conditions of their facilities. The Swiss Federal Nuclear Safety Inspectorate (ENSI) told the public that "the safety of nuclear facilities as well as their oversight had been guaranteed at all times".[8] The French Nuclear Safety Authority (ASN) thought that the "level of nuclear safety and radiation protection achieved remained satisfactory".[9] The Nuclear Energy Institute (NEI) that represents the industry in the U.S. enthusiastically concluded "the COVID-19 public health emergency brought out the best in industry and the NRC [U.S. Nuclear Regulatory Commission]".[10] The industry also points to profound and lasting changes, in particular the role of telework with the COVID experience having "overturned assumptions about the benefits and costs of expecting support staff to be onsite".[11] The International Atomic Energy Agency (IAEA) reported as early as summer 2020 that "the Agency quickly and effectively adapted to remote working conditions and continued to deliver on its mandate".[12]

Surprisingly, as of mid-2021, there is still no comprehensive international assessment of consequences of the global pandemic on nuclear safety and security systems. There is no doubt that while much can be done through telework, there are countless operations, inspections and training exercises needing physical presence that were delayed by months or not carried out at all since the pandemic got underway. This is true for safety and security.

"Thankfully, no major nuclear security incidents have made headlines during this time, but this should not be considered as evidence that nuclear security systems are operating, and will continue to operate, effectively," three senior academic nuclear security experts concluded in a June 2021 paper.[13] They report that

> There has been a surge in cyber security incidents during the pandemic, with cyber criminals and other actors taking advantage of the move to remote online working. According to a recent cybercrime assessment by Interpol, the focus of these attacks has altered significantly,

8 - ENSI, "Tätigkeits- und Geschäftsbericht 2020 des ENSI-Rates", 8 July 2021 (in German), see https://www.ensi.ch/de/wp-content/uploads/sites/2/2021/07/Taetigkeits_und_Geschaeftsbericht_2020_des_ENSI-Rates.pdf, accessed 20 August 2021.

9 - ASN, "ASN Report on the state of nuclear safety and radiation protection in France in 2020", 27 May 2021, see http://www.french-nuclear-safety.fr/Information/Publications/ASN-s-annual-reports/ASN-Report-on-the-state-of-nuclear-safety-and-radiation-protection-in-France-in-2020, accessed 20 August 2021.

10 - Cheryl Gayheart, Jean Fleming, Jim Slider, "Industry's COVID Lessons Learned", Southern Nuclear Operating Company, Public Service Enterprise Group, Nuclear Energy Institute, NEI Presentation, 21 April 2021, see https://adamswebsearch2.nrc.gov/webSearch2/main.jsp?AccessionNumber=ML21110A707, accessed 20 August 2021.

11 - Ibidem.

12 - IAEA, "The IAEA and the COVID-19 Pandemic", Reports by the Director General, General Conference, Sixty-Fourth Regular Session, GC(64)INF4/5/6, 24 August 2020, see https://www.iaea.org/sites/default/files/gc/gc64-inf4-gc64-inf5-gc64-inf6.pdf, accessed 20 August 2021.

13 - Christopher Hobbs, Nickolas Roth and Daniel Salisbury, "Security Under Strain? Protecting Nuclear Materials During the Coronavirus Pandemic", *The RUSI Journal*, Vol. 166, 28 June 2021, see https://www.tandfonline.com/doi/full/10.1080/03071847.2021.1937302, accessed 11 August 2021.

> switching 'from individuals and small businesses to major corporations, governments and critical infrastructure'.[14]

The U.K. Nuclear Decommissioning Authority (NDA) admitted in its March 2021 strategy paper:

> We recognise the many threats that face the NDA and its supply chain, from cyber-attacks, data breaches and Information Technology (IT) system failures to extreme weather conditions, global pandemics and terrorism. (…).
>
> The impact of the COVID-19 pandemic may be considerable, introducing uncertainty into the timing and duration of the spending review process so that any exercise undertaken will be set in a radically different fiscal environment and is likely to compound an already challenging situation.[15]

WNISR2021 does not include an update to the assessment of the impact of the global pandemic on the nuclear industry, not because it would not be considered important but simply because of a lack of capacity. However, this edition does look at the question whether there is a systemic issue of Nuclear Power and Criminal Energy. In addition to this first attempt to describe typologies of irregularities, fraud, corruption and other criminal activities, various country chapters provide more detailed information on specific affairs, notably China Focus, Japan Focus, Annex 1 – Slovakia, and United States Focus.

Criminal conduct is an ongoing concern for the nuclear industry, as for example in the U.S. in mid-August 2021, there were media headlines like "New criminal charges filed against Westinghouse official in SC's [South Carolina's] nuclear plant failure" calling it "one of the largest business failures in South Carolina history".[16] The Westinghouse official who oversaw worldwide construction of nuclear reactors, including the now abandoned V.C. Summer project in South Carolina, faces "16 felony counts, including conspiracy, wire fraud, securities fraud, and causing a publicly-traded company to keep a false record" and risks a maximum of 20 years in prison and a US$5 million fine.[17] He was the fourth top manager to plead guilty to a range of criminal charges in this affair (see also Guilty Pleas and On-going FBI Investigations Over V.C. Summer Project).

Almost exactly at the same time, in Japan, the Nuclear Regulation Authority (NRA) suspended its safety screening of Unit 2 at Japan Atomic Power Company's Tsuruga nuclear power plant in Fukui Prefecture after "data tampering was found in documents submitted to the regulator".[18] Reportedly, the data manipulations concerned geological information obtained from a drilling survey conducted at the plant's premises. The NRA said it will not license the restart of the reactor until it receives credible data.

14 - Ibidem.

15 - NDA, "Nuclear Decommissioning Authority Strategy effective from March 2021", UK Nuclear Decommissioning Authority, Corporate Report, 18 March 2021, see https://www.gov.uk/government/publications/nuclear-decommissioning-authority-strategy-effective-from-march-2021, accessed 27 August 2021.

16 - John Monk, "New criminal charges filed against Westinghouse official in SC's nuclear plant failure", *The State*, 19 August 2021, see https://www.thestate.com/news/local/crime/article253576236.html, accessed 19 August 2021.

17 - Ibidem.

18 - *Jiji Press*, "Central Japan N-Reactor Screening Halted over Data Tampering", 18 August 2021, see https://jen.jiji.com/jc/eng?g=eco&k=2021081800646, accessed 22 August 2021.

This edition marks the tenth anniversary of the beginning of the Fukushima disaster, also termed 3/11, and the 35 years of the Chernobyl accident. These catastrophes continue to impact the lives of many people and we were fortunate to be able to count on the contributions by some outstanding experts on technical challenges, health issues, legal cases, and cost assessments around these tragic events.

In addition, Naoto Kan, Prime Minister of Japan at the time when the Great East Japan Earthquake triggered the Fukushima disaster in March 2011, honored WNISR2021 with a Foreword.

At a time when the Sixth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC) stressed human responsibility in the climate crisis, it has become clear that we have passed the point of discussions about whether policy should focus on avoidance or adaptation. Responsible policy strategies will need to address both. The question how energy technologies fare in this context is of great importance. Following an extensive assessment of Climate Change and Nuclear Power in WNISR2019, the chapter Nuclear Power and Climate Change Resilience provides a first look at nuclear's challenges in this context. A case study on France illustrates the relative significance and impact of extreme weather events like heat and drought, heavy rain, and storms.

NUCLEAR POWER AND GREEN TAXONOMY

In July 2020, the European Taxonomy Regulation entered into force.[19] The regulation provides a framework for future investments in the European Union (EU) to further the goals of the European Green Deal[20] that targets no net greenhouse gas emissions by 2050. The EU is currently debating whether nuclear power should be granted the same access to funding under the taxonomy criteria—in particular the Do-No-Significant-Harm (DNSH) criteria—as renewable energies.

The European Commission asked its Joint Research Centre (JRC) to assess the question. The decision to commission the evaluation from JRC raised eyebrows as the center is directly involved in nuclear research and operates EU nuclear research facilities in various countries.[21] Thus a classical conflict-of-interest situation seemed obvious.

Ten days prior to the release of the JRC report, a coalition of seven European nuclear countries led by France, including the Czech Republic, Finland, Hungary, Poland, Slovenia, and Slovakia, released a joint letter to the European Commission stating that "all available zero and low-

19 - European Parliament and Council of the European Union, "Regulation (EU) 2020/852 of the European Parliament and of the Council of 18 June 2020 on the establishment of a framework to facilitate sustainable investment, and amending Regulation (EU) 2019/2088", *Official Journal of the European Union*, 22 June 2020, see https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:32020R0852, accessed 12 August 2021.

20 - See European Commission, "A European Green Deal", undated, see https://ec.europa.eu/info/strategy/priorities-2019-2024/european-green-deal_en, accessed 12 August 2021.

21 - "The specific objectives of the JRC's direct actions under Annex I to Regulation (Euratom) 2018/1563 are to (a) improve nuclear safety; (b) improve nuclear security; (c) increase excellence in the nuclear science base for standardisation; (d) fostering knowledge management, education, and training; and (e) support the policy of the Union on nuclear safety and security.", see European Commission, "Commission Implementing Decision on the adoption of multi-annual work programmes under Council Decision 2013/743/EU and Council Regulation (Euratom) 2018/1563, to be carried out by the Joint Research Centre for the period 2019-2020, and amending Commission Implementing Decision C(2018) 1386", 18 March 2019, see https://ec.europa.eu/jrc/sites/default/files/c_2019_1872_f1_commission_implementing_decision_en_v2_p1_1007927.pdf, accessed 21 August 2021.

emission technologies" should be "actively supported by the European Union. This is especially valid for nuclear power whose development is one of the primary objectives of the Treaty establishing the Euratom Community, obliging EU institutions to promote it."[22]

In March 2021, the JRC released a 387-page report of which a single sentence has been abundantly quoted by nuclear industry representatives and the media: "The analyses did not reveal any science-based evidence that nuclear energy does more harm to human health or to the environment than other electricity production technologies already included in the Taxonomy as activities supporting climate change mitigation."[23]

The report has been severely criticized.

The European Commission's own Scientific Committee on Health, Environmental and Emerging Risks (SCHEER) concluded that

> … [JRC's] overall conclusion of "no evidence of does more harm" is not sufficiently supported by the information provided within the report…
>
> … the impact [of thermal pollution] has the potential to be greater than described in the JRC report…
>
> … clearly nuclear energy produces larger quantities of waste than other energy generation technologies… The SCHEER is of the view that high-level waste storage remains an open research question, with considerable uncertainties.[24]

Some SCHEER comments on specific parts of the JRC report are particularly critical. The section on the impact of radiation on the environment, SCHEER concluded, "does not provide any useful or detailed information for assessing the impacts". Some statements were found "simplistic".

The German Government commissioned a joint assessment of the JRC report by two of its own nuclear expert organizations that concluded:

> This expert response finds that the JRC has drawn conclusions that are hard to deduce at numerous points. Subject areas that are very relevant to the environment have also only been presented very briefly or have been ignored. (…)
>
> … the problem of disposing of radioactive waste has already been postponed by previous generations to today's and it will 'remain' a problem for many future generations. The principle of "no undue burdens for future generations" (pp. 250ff) has therefore already been (irrevocably) infringed, while the DNSH-hurdle "significant[ly] harm" has also been infringed.

22 - Letter to Ursula von der Leyen, Frans Timmermans, Mairead McGuinness, Kadri Simson, signed by the Prime Ministers of Czech Republic, Finland, Hungary, Poland, Slovenia, Slovakia and the French President, dated 19 March 2021, see *WNN*, "Message: 7 EU leaders urge support for nuclear", 25 March 2021, see https://world-nuclear-news.org/Articles/Message-Nuclear-is-green-energy,-say-7-EU-leaders, accessed 21 August 2021.

23 - JRC, "Technical assessment of nuclear energy with respect to the 'do no significant harm' criteria of Regulation (EU) 2020/852 ('Taxonomy Regulation')", JRC Science for Policy Report, European Commission, 19 March 2021, see https://ec.europa.eu/info/sites/default/files/business_economy_euro/banking_and_finance/documents/210329-jrc-report-nuclear-energy-assessment_en.pdf, accessed 21 August 2021.

24 - SCHEER, "SCHEER review of the JRC report on Technical assessment of nuclear energy with respect to the 'do no significant harm' criteria of Regulation (EU) 2020/852 ('Taxonomy Regulation')", European Commission, Adopted 29 June 2021, see https://ec.europa.eu/info/sites/default/files/business_economy_euro/banking_and_finance/documents/210629-nuclear-energy-jrc-review-scheer-report_en.pdf, accessed 21 August 2021.

> The JRC Report is therefore incomplete and therefore fails to comprehensively assess the sustainability of using nuclear energy.[25]

Seven ministers representing the governments of five countries (Austria, Denmark, Germany, Luxembourg, Spain) complained in a joint letter to the European Commission about "grave methodological shortcomings". The JRC report "neglects to address the residual nuclear risk, assessing only the normal operation of nuclear power plants" and "disregards the life-cycle approach" as the lack of an effective radioactive waste management solution violates the principle of "no undue burdens on future generations". The governmental statement concludes:

> Nuclear power is incompatible with the Taxonomy Regulation's "do no significant harm" principle. We therefore urge the European Commission not to jeopardise the courageous path it has taken towards making the EU the global lead market for sustainable finance.[26]

Reclaim Finance, a newly established NGO affiliated with Friends of the Earth France, concluded an assessment of the Taxonomy process by stating:

> By planning to include fossil gas and providing a specific process to welcome nuclear through the backdoor, the EU is likely to end up with a sustainable Taxonomy that undermines the transition of the energy sector. (...)
>
> The EU is setting its energy agenda for the decades to come: it is time to sever the ties between officials and energy lobbies that contribute to untamed global warming or undermine the sustainable transition.[27]

Nuclear Transparency Watch has requested a round of public participation according to the Aarhus Convention.[28] A public consultation, carried out prior to the release of the JRC report, had triggered tens of thousands of comments from European citizens. The European Commission is expected to make a final decision before the end of 2021. WNISR2022 will report on the outcome.

Meanwhile, the nuclear industry had to absorb a serious blow in the U.K. with nuclear being officially excluded from the country's green taxonomy. The 31-page "UK Government Green Financing Framework" document mentions nuclear power just in one paragraph, under "Exclusions": "Recognising that many sustainable investors have exclusionary criteria in

25 - BASE, "Expert response to the report by the Joint Research Centre entitled Technical assessment of nuclear energy with respect to the 'Do No Significant Harm' criteria in Regulation (EU) 2020/852, the Taxonomy Regulation'", Federal Office for the Safety of Nuclear Waste Management with support from the Federal Office for Radiation Protection (BfS), June 2021, see https://www.base.bund.de/SharedDocs/Downloads/BASE/EN/reports/2021-06-30_base-expert-response-jrc-report.pdf.pdf, accessed 21 August 2021.

26 - Svenja Schulze, Leonore Gewessler, Dan Jørgensen et al., Joint-Letter addressed to Commissioners Frans Timmermanns, Vladis Dombrovskis, Mairead McGuinness, and Virginijus Sinkevičius, Signed by the German Federal Minister for the Environment, Nature Conservation and Nuclear Safety, Austrian Minister for Climate Action, Environment, Energy, Mobility, Innovation and Technology, Danish Minister for Climate Energy and Utilities, Danish Minister for Industry Business and Financial Affairs, Luxembourg Minister for the Environment, Climate and Sustainable Development, Spanish Deputy Prime Minister & Minister for the Ecological Transition and Demographic Challenge and Spanish Deputy Prime Minister & Minister for the Economy and Digital Transformation, undated, see https://www.euractiv.com/wp-content/uploads/sites/2/2021/07/Joint-ministerial-letter_AT_DE_DK_LU_ES.pdf, accessed 14 August 2021.

27 - Reclaim Finance, "Out with Science, in with Lobbyists: Gas, Nuclear and the EU Taxonomy", July 2021, see https://reclaimfinance.org/site/en/2021/07/22/abandoning-science-how-the-gas-and-nuclear-lobbies-are-winning-the-eu-taxonomy-fight/, accessed 15 August 2021.

28 - Nadja Železnik, Letter to the European Commission, Nuclear Transparency Watch, dated 20 July 2021.

place around nuclear energy, the UK Government will not finance any nuclear energy-related expenditures under the Framework."[29]

"AND THE WINNER IS…"

The likely winner of the taxonomy debate in Europe will be renewables that have also shown a remarkable resistance to the impact of the COVID-19 pandemic. In May 2020, the World Economic Forum stated:

> The ongoing COVID-19 pandemic has put a stop to business as usual, setting off a chain of events disrupting all sectors – including energy. (…) Resilience, in economic, financial, regulatory and infrastructure terms, is a crucial prerequisite for an effective energy transition.[30]

The total investment in non-hydro renewables globally—despite the economic impact of the COVID-19 pandemic—exceeded US$300 billion in COVID-19-year 2020.[31] Significantly, falling capital costs enabled record volumes of both solar (>130 GW) and wind (>70 GW) to be installed despite relatively small increases in investment.

In the meantime, so-called advanced reactors of various designs, including so-called Small Modular Reactors (SMRs), make a lot of noise in the media but their promoters have provided little evidence for any implementation scheme before a decade at the very least. Even staunch industry supporters like William Magwood, Director General of the OECD's Nuclear Energy Agency (NEA) in Paris and a former member of the U.S. Nuclear Regulatory Commission (NRC), recently stated: "If these technologies cannot be brought to market … in about a decade … they may not be relevant to the energy transition."[32] Mark Cooper, Senior Fellow for Economic Analysis at the Institute for Energy and the Environment, Vermont Law School, concluded a recent analysis more bluntly:

> Small modular reactors appear to be repeating the path of large reactors, with rising costs and increasing delays. Much of the battle to meet the challenge of climate change will be over before even one of these reactors is online.[33]

Time will be of the essence.

29 - UK Debt Management Office, "UK Government Green Financing Framework", HM Treasury, UK Government, June 2021, see https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/998127/20210630_UK_Government_Green_Financing_Framework_Final.pdf, accessed 15 August 2021.

30 - WEF, "Fostering Effective Energy Transition – 2020 edition", World Economic Forum, May 2020, see http://www3.weforum.org/docs/WEF_Fostering_Effective_Energy_Transition_2020_Edition.pdf, accessed 21 August 2021.

31 - BNEF, "Energy Transition Investment Hit $500 Billion in 2020 – For First Time", BloombergNEF, 19 January 2021, see https://about.bnef.com/blog/energy-transition-investment-hit-500-billion-in-2020-for-first-time/, accessed 6 June 2021.

32 - Edwin Lyman, "It's time to cancel the Versatile Test Reactor", *The Hill*, 27 July 2021, see https://thehill.com/opinion/energy-environment/565024-its-time-to-cancel-the-versatile-test-reactor, accessed 28 July 2021.

33 - Mark Cooper, "Building a Least-Cost, Low-Carbon Electricity System with Efficiency, Wind, Solar, & Intelligent Grid Management: Why Nuclear Subsidies are an Unnecessary Threat to the Transformation", Institute for Energy and the Environment, Vermont Law School, July 2021, see https://www.vermontlaw.edu/sites/default/files/2021-07/Building_a_21st_Century_Electricity_System.pdf, accessed 21 August 2021.

GENERAL OVERVIEW WORLDWIDE

PRODUCTION AND ROLE OF NUCLEAR POWER

In 2020, the world nuclear fleet generated 2,553 net terawatt-hours (TWh or billion kilowatt-hours) of electricity[34], a drop of 104 TWh or 3.9 percent over the previous year (see Figure 1). This is the first time that nuclear generation declined since post-3/11-year 2012. Without China, global nuclear power generation decreased by 5.1 percent and reached the lowest level since 1995. China for the first time produced more nuclear electricity than France and takes second place—behind the U.S.—among the top nuclear power generators.

Nuclear energy's share of global commercial gross electricity generation in 2020 fell slightly from 10.4 percent to 10.1 percent, significantly below the peak of 17.5 percent in 1996.

With a new record non-hydro renewables' annual growth, their share in world power generation grew by 1.4 percentage points to 11.7 percent.[35]

In a global economic environment depressed by the COVID-19 pandemic, fossil fuel consumption slumped: oil by 9.7 percent, coal by 4.2 percent, and natural gas by 2.3 percent. The nuclear commercial primary energy consumption dropped by 4.1 percent, but, due to the overall decline, its share in global consumption remained stable at 4.3 percent. It has been around this level since 2014. Hydropower's primary energy consumption increased, by 1 percent on the global average and by 7.2 percent in the EU. Renewables, including mainly solar, wind and biofuels, continued their spectacular growth with a 9.7 percent increase in primary energy—in spite of the global pandemic.[36]

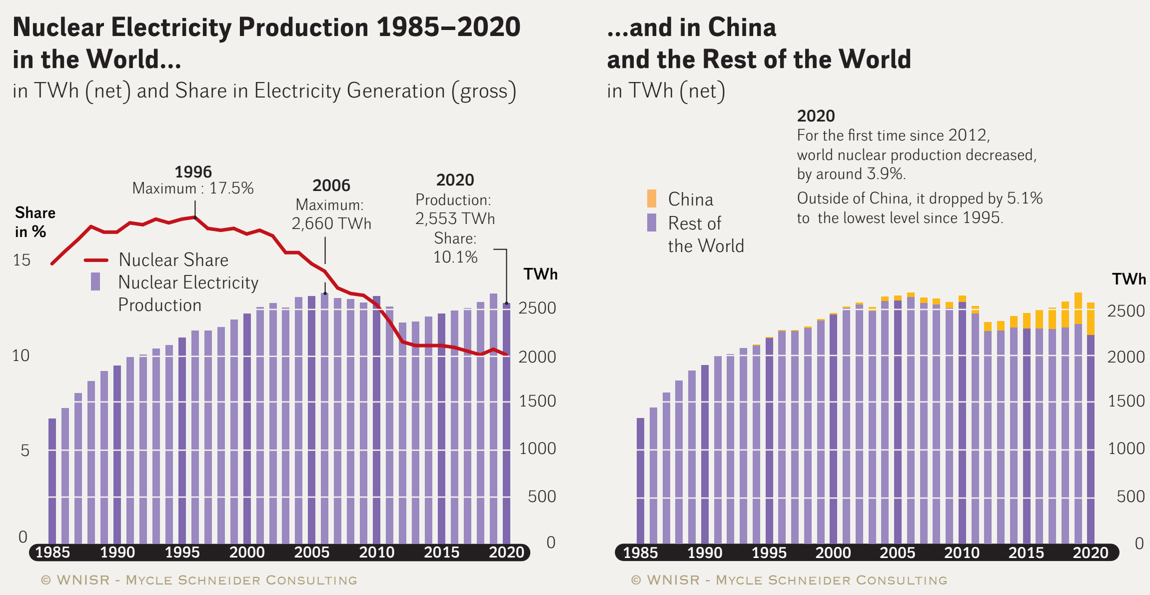
In 2020, there were eight countries that increased their nuclear share (including the two newcomer countries Belarus and UAE; see Figure 2)—versus 12 in 2019—nine decreased their nuclear shares, and 16 remained at a constant level (change of less than 1 percentage point). Besides the two newcomer countries, four countries (Argentina, China, Pakistan, Russia) achieved their largest ever nuclear production, as in 2019, two of these countries started up new units (China and Russia), Argentina's record was as a result of a full year of operation of a reactor that was restarted in 2019 after a four-and-a-half-year outage, and Pakistan increased productivity after a mediocre year.

34 - If not otherwise noted, all nuclear capacity and electricity generation figures based on International Atomic Energy Agency (IAEA), Power Reactor Information System (PRIS) online database, see https://prisweb.iaea.org/Home/Pris.asp. Production figures are net of the plant's own consumption unless otherwise noted, from https://pris.iaea.org/PRIS/WorldStatistics/NuclearShareofElectricityGeneration.aspx.

35 - BP, "Statistical Review of World Energy 2021 – 70th edition", 17 June 2020, see https://www.bp.com/content/dam/bp/business-sites/en/global/corporate/pdfs/energy-economics/statistical-review/bp-stats-review-2021-full-report.pdf, accessed 16 July 2021.

36 - Ibidem.

Figure 1 · Nuclear Electricity Generation in the World... and China



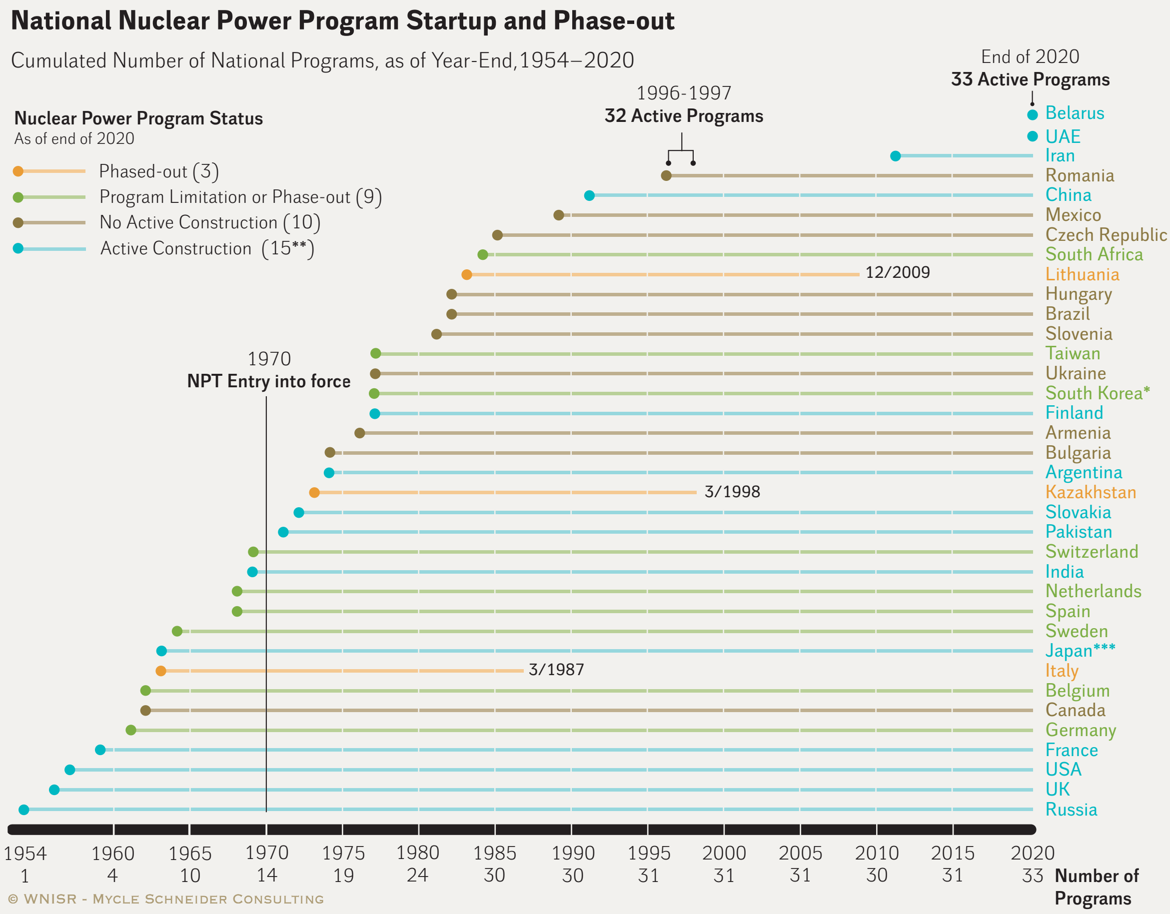
Sources: WNISR, with BP, IAEA-PRIS, 2021[37]

The following noteworthy developments for the year 2020 illustrate the continuous volatile operational situation of the individual national reactor fleets (see country-specific sections for details):

- **Argentina** boosted output by 26 percent—the second year in a row with a 20+ percent increase—after Embalse returned to service following a long refurbishment-outage and Atucha-1 generated more power than in any year over the past 12 years, and despite a bad year for Atucha-2 with a load factor below 40 percent.
- **Armenia**'s single reactor at Medzamor increased generation by almost 26 percent.
- **Belgium**'s nuclear fleet keeps undergoing large variations in generation. Output plunged by 21 percent after a 52-percent increase in 2019 following a 32-percent plunge in 2018 due to additional outages for maintenance, repair, and upgrade.
- **China** started up only two new units in 2020, just as in 2019, with nuclear generation increasing only 4.4 percent, the lowest increase since 2009.
- **France**'s nuclear generation decreased by 12 percent, remaining for the fifth year in a row below the 400 TWh mark. Output dropped to the lowest level in 27 years (see France Focus).
- **Germany** closed one reactor (Philippsburg-2) at the end of 2019 and the national nuclear power generation dropped accordingly by 14 percent in 2020.
- **Japan** had restarted nine reactors after all of them were down in 2014. But after a progressive increase in output, nuclear generation plunged again in 2020, by over 34 percent. A major reason were four reactors that were forced to shut down because they did not meet the regulator's deadline for security upgrades.

37 - WNISR for World Nuclear Industry Status Report, BP stands for BP plc.

Figure 2 · History of National Nuclear Power Programs



Source: WNISR, with IAEA-PRIS, 2021

Notes

This figure only displays countries with operating or once operating reactors.

* Although it has a phaseout policy, South Korea has four reactors under construction as of 1 July 2021.

** Including South Korea listed in the category "Program Limitation or Phase-out".

*** Japan is counted here among countries with "active construction"—however it is possible that the only project under active construction (Shimane-3) will be abandoned.

- **South Korea** increased nuclear production by 10 percent—mainly due to a full-year production of a reactor started up in April 2019—following a 9 percent increase in 2019 and a 10-percent decline in 2018.
- **South Africa**'s nuclear generation declined by 15 percent after a 28-percent increase in 2019 and a 30 percent drop in 2018.
- **Sweden**'s nuclear output dropped by 26.5 percent, partly due to the closure of one reactor (Ringhals-2).
- The **U.K.** nuclear generation decreased by another 10.5 percent following a 14 percent decline in 2019, due to long outages of some of its ageing reactors. Since 2016, annual production has dropped by 30 percent.

- In the **U.S.,** following the all-time high in 2019, nuclear electricity generation dropped (by 2.4 percent) below the 800 TWh mark for the first time since 2015. As four reactors were closed in 2019–2020, it is possible that the country has seen "peak nuclear" and will not get back to earlier production levels.

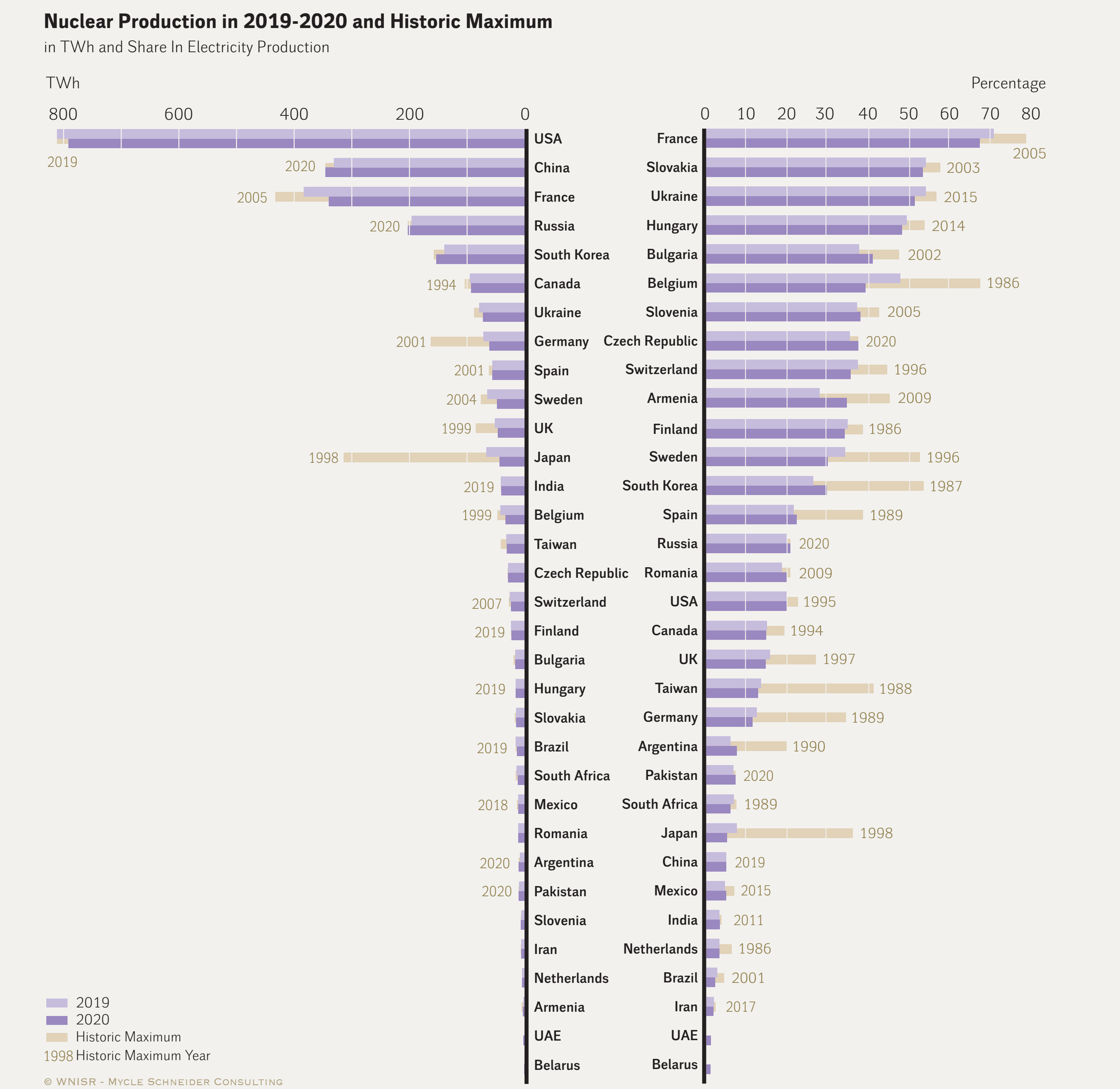
Similar to previous years, in 2020, the "big five" nuclear generating countries—by rank, the U.S., China, France, Russia and South Korea—generated 72 percent of all nuclear electricity in the world (see Figure 3, left side).

In 2002, China held position 15, in 2007 it was tenth, before reaching third place in 2016. In 2020—earlier than anticipated due to the mediocre performance of the French fleet—China became the second largest nuclear generator in the world, a position that France held since the early 1980s.

In 2020, the top three countries, the U.S., China and France, accounted for 58 percent of global nuclear production, underscoring the concentration of nuclear power generation in a very small number of countries.

In many cases, even where nuclear power generation increased, the addition is not keeping pace with overall increases in electricity production, leading to a nuclear share below the respective historic maximum (see Figure 3, right side). Only three countries, the Czech Republic, Pakistan, and Russia reached new historic peak shares of nuclear in their respective power mix, all three small increases, +2.1 percentage points for the Czech Republic (reaching a share of 37.3 percent) and +0.5 percentage points for Pakistan (attaining 7.1 percent) and +0.9 percentage point for Russia (reaching 20.6 percent). China maintained the 4.9 percent share, a maximum it first reached in 2019.

Figure 3 · Nuclear Electricity Generation and Share in Global Power Generation



Sources: IAEA-PRIS, and national sources for France and Switzerland, compiled by WNISR, 2021

OPERATION, POWER GENERATION, AGE DISTRIBUTION

Since the first nuclear power reactor was connected to the Soviet power grid at Obninsk in 1954, there have been two major waves of startups. The first peaked in 1974, with 26 grid connections in that year. The second reached a historic maximum in 1984 and 1985, just before the Chernobyl accident, reaching 33 grid connections in each year. By the end of the 1980s, the uninterrupted net increase of operating units had ceased, and in 1990 for the first time the number of reactor closures[38] outweighed the number of startups.

The 1991–2000 decade produced far more startups than closures (52/30), while in the decade 2001–2010, startups did not match closures (32/37). Furthermore, after 2000, it took a whole decade to connect as many units as in a single year in the middle of the 1980s (see Figure 4).

Between 2011 and 2020, the startup of 63 reactors—of which 37 (59 percent) in China alone—outpaced by only two the closure of 61 units over the same period.

Over the two decades 2001–2020, there were 95 startups and 98 closures in the world. As there were 47 startups and no closures in China over the period, the 98 closures outside China were matched by only 48 startups, a drastic decline by 50 units over the period (see Figure 5).

As larger units were started up (totaling 85.5 GW) than closed (totaling 59 GW) the net nuclear capacity added worldwide over the 20-year period was 26.5 GW. However, since China alone added 45 GW, the net capacity outside China declined by over 20 GW.

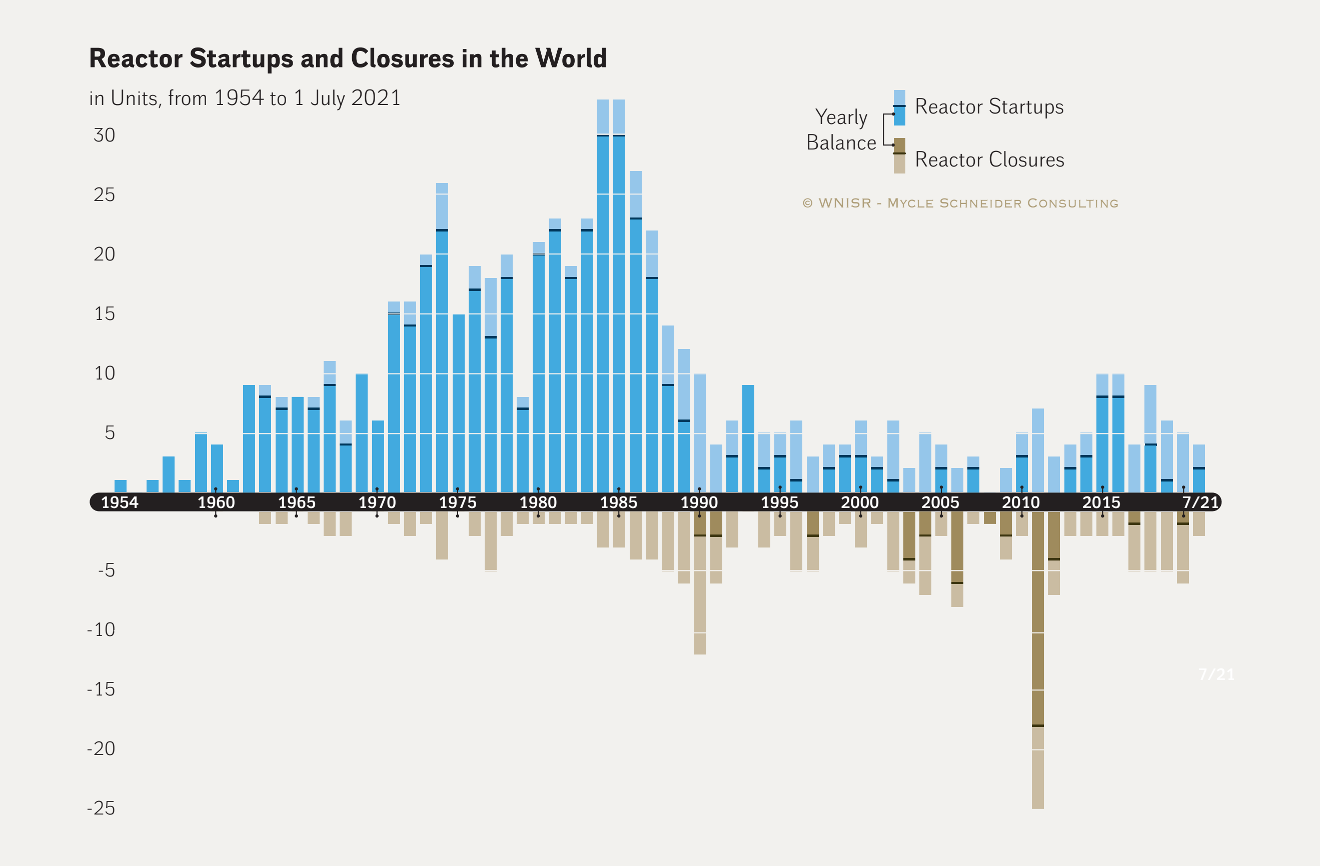
After the startup of 10 reactors in each of the years 2015 and 2016, only four units started up in 2017, of which three in China and one in Pakistan (built by Chinese companies). In 2018, nine reactors generated power for the first time, of which seven in China and two in Russia.

In 2019, six units were connected to the grid, of which three in Russia, two in China and one in South Korea, while five units were closed, of which two in the U.S., and one each in Germany, Sweden and Switzerland.

In 2020, five units were commissioned, two in China and one each in Belarus, Russia and the United Arab Emirates (UAE). At the same time, six units were closed including two each in France and the U.S. and one each in Russia and Sweden. Four new units were connected to the world's power grids in the first half of 2021, including two in China, while two reactors were closed, one each in the U.S. and Taiwan. (See Figure 5).

38 - With WNISR2019 we have introduced "closure" as general term for permanent shutdown, in order to avoid confusion with the use of "shutdown" for provisional grid disconnections for maintenance, refueling, upgrading or due to incidents. WNISR considers closure from the moment of grid disconnection—and not from the moment of the industrial, political or economic decision—and as the units have not generated power for several years, in WNISR statistics, they are closed in the year of their latest power generation.

Figure 4 · Nuclear Power Reactor Grid Connections and Closures in the World



Sources: WNISR, with IAEA-PRIS, 2021

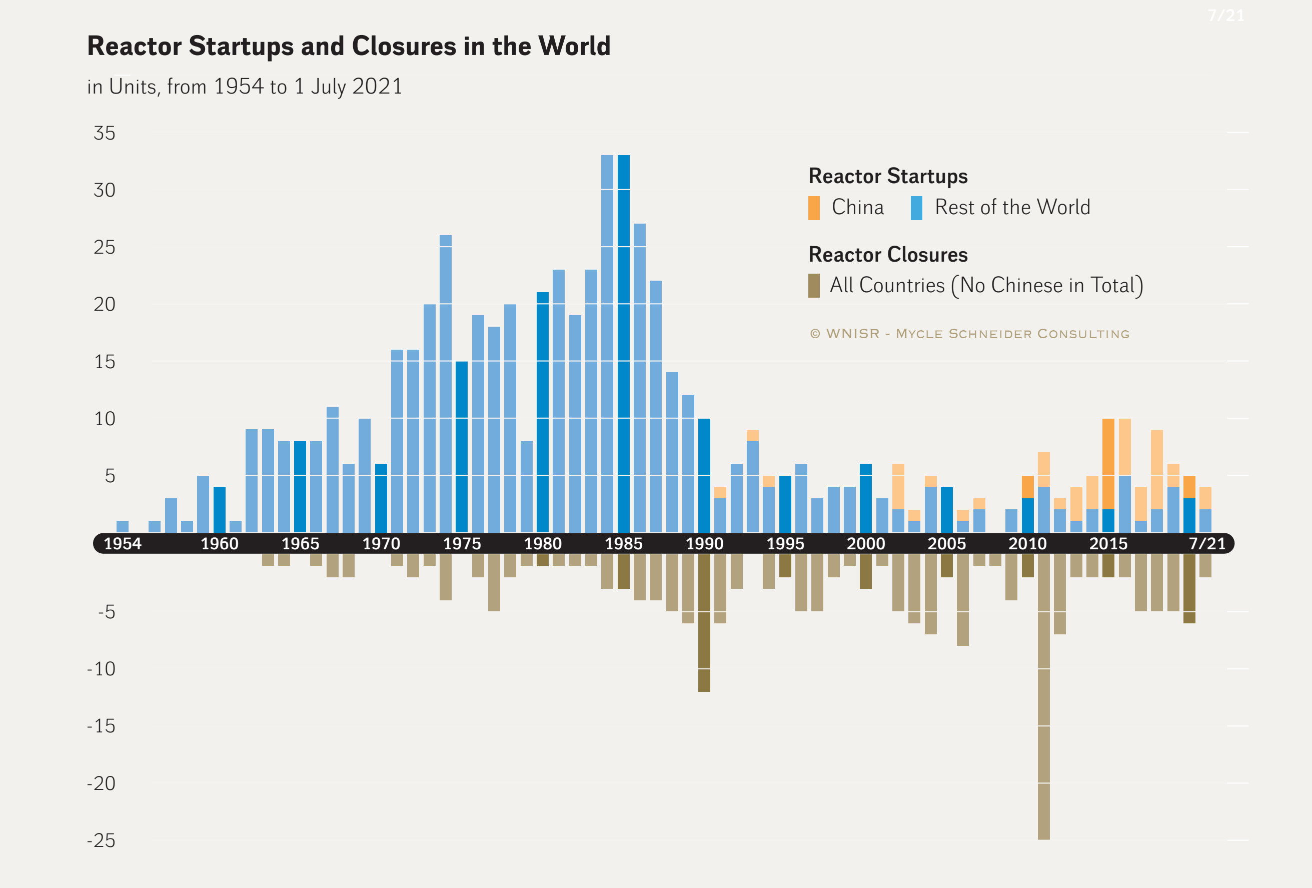
Notes:
As of 2019, WNISR is using the term "Closed" instead of "Permanent Shutdown" for reactors that have ceased power production, as WNISR considers the reactors closed as of the date of their last production. Although this definition is not new, it had not been applied to all reactors or fully reflected in the WNISR database; this applies to known/referenced examples like Superphénix in France, which had not produced in the two years before it was officially closed or the Italian reactors that were de facto closed prior to the referendum in 1987, or some other cases. Those changes obviously affect many of the Figures relating to the world nuclear reactor fleet (Startup and Closures, Evolution of world fleet, age of closed reactors, amongst others.)

As of mid-2021, the International Atomic Energy Agency (IAEA) continues to count 33 units in Japan in its total number of 443 reactors "in operation" in the world. That is a significant drop of eight compared to mid-2019.[39] No nuclear electricity was generated in Japan between September 2013 and August 2015, and as of 1 July 2021, only six reactors were operating. Nuclear plants provided only 5.1 percent of the electricity in Japan in 2020 versus 7.5 percent in 2019. It is the first time since all of the Japanese fleet came to a halt in 2014 following the events of 3/11 that the nuclear output is declining again (for details see Japan Focus).

The WNISR will keep reiterating its call for an appropriate reflection in world nuclear statistics of the unique situation in Japan. The attitude taken by the IAEA, the Japanese government, utilities, industry and many research bodies as well as other governments and organizations to continue considering the entire stranded reactor fleet in the country as "in operation" or "operational" is misleading.

39 - IAEA, "Power Reactor Information System", International Atomic Energy Agency, Undated, see https://pris.iaea.org/pris/CountryStatistics/CountryDetails.aspx?current=JP, accessed 22 July 2021.

Figure 5 · Nuclear Power Reactor Grid Connections and Closures – The Continuing China Effect



Sources: WNISR, with IAEA-PRIS, 2021

The IAEA does have a reactor-status category called "Long-term Shutdown" or LTS.[40] Under the IAEA's definition, a reactor is considered in LTS, if it has been shut down for an "extended period (usually more than one year)", and in early period of shutdown either restart is not being "aggressively pursued" or "no firm restart date or recovery schedule has been established". The IAEA currently lists zero reactors anywhere in the LTS category.

The IAEA criteria are vague and hence subject to arbitrary interpretation. What exactly are *extended* periods? What is *aggressively* pursuing? What is a *firm* restart date or recovery schedule? Faced with this dilemma, the WNISR team in 2014 decided to create a new category with a simple definition, based on empirical fact, without room for speculation: "Long-term Outage" or LTO. Its definition:

> A nuclear reactor is considered in Long-Term Outage or LTO if it has not generated any electricity in the previous calendar year and in the first half of the current calendar year. It is withdrawn from operational status retroactively from the day it has been disconnected from the grid.

When subsequently the decision is taken to close a reactor, the closure status starts with the day of the last electricity generation, and the WNISR statistics are retroactively modified accordingly.

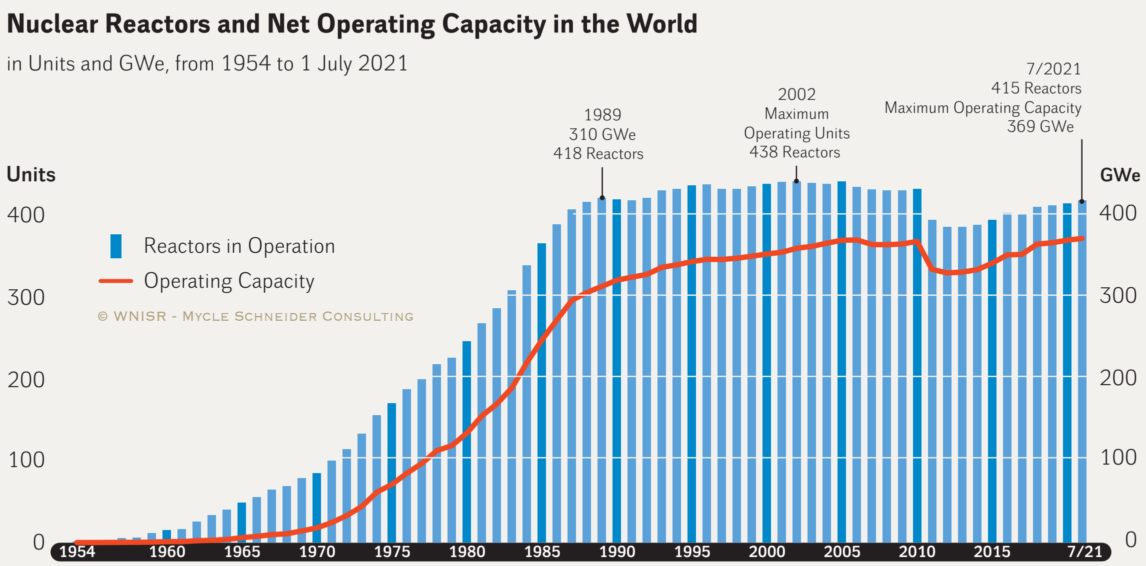
40 - See IAEA Glossary, at www.iaea.org/pris/Glossary.aspx, accessed 22 July 2021.

Applying this definition to the world nuclear reactor fleet, as of 1 July 2021, leads to classifying 26 units in LTO—all considered "in operation" by the IAEA—five less than in WNISR2020, of which 24 in Japan (no change) and one each in India (Madras-1) and in South Korea (Hanbit-4).

Two of the reactors in LTO in WNISR2020 were closed in the U.K. (Dungeness-B1 and -B2), one each was restarted in China (CEFR), Japan (Mihama-3), South Korea (Hanbit-3), and the U.K. (Hunterston-B1). One new reactor entered the LTO category in Japan (Ikata-3).

As of 1 July 2021, a total of 415 nuclear reactors were operating in 33 countries, up seven units from the situation in mid-2020 but still two below the status as of mid-2019.[41] The current world fleet has a total nominal electric net capacity of 369 GW, up by 7 GW (+1.9 percent) from one year earlier, representing a new peak just above the former record of 367 GW in 2006. The number of operating reactors remains by three below the figure reached in 1989 and by 23 below the 2002 peak (see Figure 6).

Figure 6 · World Nuclear Reactor Fleet, 1954–2021



Sources: WNISR, with IAEA-PRIS, 2021

Note
Changes in the database regarding closing dates of reactors or LTO status slightly change the shape of this graph from previous editions. In particular, the previous "maximum operating capacity" of 2006 (overtaken in July 2019) is now at 367 GW.

For many years, the net installed capacity has continued to increase more than the net number of operating reactors. This is a result of the combined effects of larger units replacing smaller ones. (In 1989, the average size of an operational nuclear reactor was about 740 MW, while that number has increased to almost 890 MW in 2021). Technical alterations raised capacity at existing plants resulting in larger electricity output, a process known as uprating.[42] In the U.S. alone, the Nuclear Regulatory Commission (NRC) has approved 170 uprates since 1977.

41 - +9 startups +4 restart –1 new LTO –5 closures.

42 - Increasing the capacity of nuclear reactors by equipment upgrades e.g. more powerful steam generators or turbines.

The cumulative approved uprates in the U.S. total 8 GW, the equivalent of eight large reactors. These include six minor uprates (<2 percent of reactor capacity) approved since mid-2020.[43]

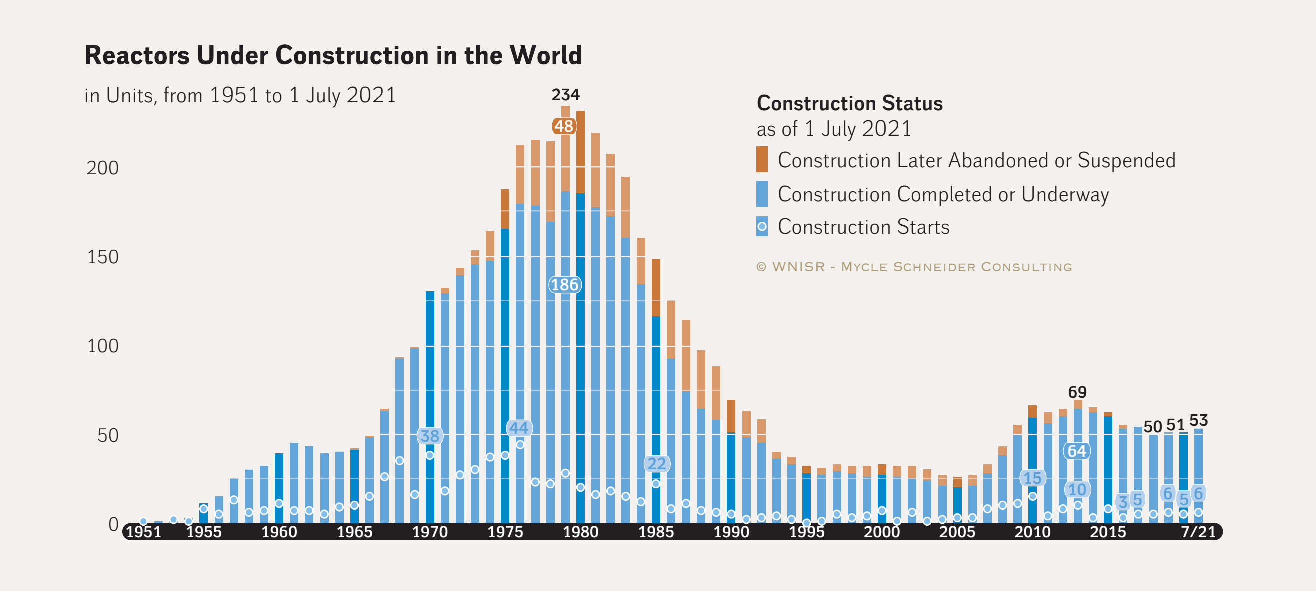
A similar trend of uprates and major overhauls in view of lifetime extensions of existing reactors has been seen in Europe. The main incentive for lifetime extensions is economic but this argument is being increasingly challenged as backfitting costs soar and alternatives become cheaper.

OVERVIEW OF CURRENT NEW-BUILD

As of 1 July 2021, 53 reactors are considered as under construction, one more than WNISR reported a year ago, but 16 fewer than in 2013 (five of those units have subsequently been abandoned). The number includes 18 units or one third being built in China.

Four in five reactors are built in Asia or Eastern Europe. In total, 17 countries are building nuclear plants, the same as reported in WNISR2020 (see Table 1). However, only four countries have construction ongoing at more than one site (see Annex 4, Figure 7 for details). Since mid-2020, ten new construction sites were launched worldwide, including seven in China. One construction start took place in each of India (Kudankulam-5), Russia (Brest-OD-300) and Turkey (Akkuyu-3).

Figure 7 · Nuclear Reactors "Under Construction" in the World (as of 1 July 2021)



Sources: WNISR, with IAEA-PRIS, 2021

Notes:

This figure includes construction of two CAP1400 reactors at Rongcheng/Shidaowan, although their construction has not been officially announced (see China Focus). At Shidao Bay, the plant under construction since 2012 has actually two reactors on the site and is therefore counted as two units as of WNISR2020.

43 - U.S.NRC, "Approved Applications for Power Uprates", U.S. Nuclear Regulatory Commission, Updated 5 February 2021, see http://www.nrc.gov/reactors/operating/licensing/power-uprates/status-power-apps/approved-applications.html, accessed 22 July 2021.

The number of 53 reactors listed as under construction by mid-2021 compares poorly with a peak of 234—totaling more than 200 GW—in 1979. However, many (48) of those projects listed in 1979 were never finished (see Figure 7). The year 2005, with 26 units under construction, marked a record low since the early nuclear age in the 1950s.

Compared to the situation described a year ago, the total capacity of the 53 units under construction in the world as of mid-2021 increased by just 0.5 GW to 54 GW, with an average unit size of 1,020 MW.

Table 1 - Nuclear Reactors "Under Construction" (as of 1 July 2021)[44]

Country	Units	Capacity (MW net)	Construction Start	Grid Connection	Units Behind Schedule
China	18	17 062	2012 - 2021	2021 - 2027	4
India	7	5 194	2004 - 2021	2022 - 2026	6
South Korea	4	5 360	2012 - 2018	2022 - 2025	4
Russia	3	2 650	2018 - 2021	2022 - 2026	0
Turkey	3	3 342	2018 - 2021	2024 - 2026	1
UAE	3	4 035	2013 - 2015	2021 - 2023	3
Bangladesh	2	2 160	2017 - 2018	2023 - 2024	0
Slovakia	2	880	1985 - 1985	2021 - 2023	2
UK	2	3 260	2018 - 2019	2026 - 2027	2
USA	2	2 234	2013	2022 -2023	2
Argentina	1	25	2014	2024	1
Belarus	1	1 110	2014	2022	1
Finland	1	1 600	2005	2022	1
France	1	1 600	2007	2023	1
Iran	1	1 196	1976	2024	1
Japan	1	1 325	2007	2025	1
Pakistan	1	1 014	2016	2022	1
Total	**53**	**54 047**	**1976 - 2021**	**2021 - 2027**	**31**

Sources: Various, compiled by WNISR, 2021

Notes:

This table does not contain suspended or abandoned constructions.

This table includes construction of two CAP1400 reactors at Rongcheng/Shidaowan, although their construction has not been officially announced (see China Focus). At Shidao Bay, the plant under construction since 2012 has two reactors on the site and is therefore counted as two units as of WNISR2020.

44 - For further details, see Annex 4 – Nuclear Reactors in the "World Under Construction".

CONSTRUCTION TIMES

Construction Times of Reactors Currently Under Construction

A closer look at projects presently listed as "under construction" illustrates the level of uncertainty and problems associated with many of these projects, especially given that most builders assume a five-year construction period to begin with:

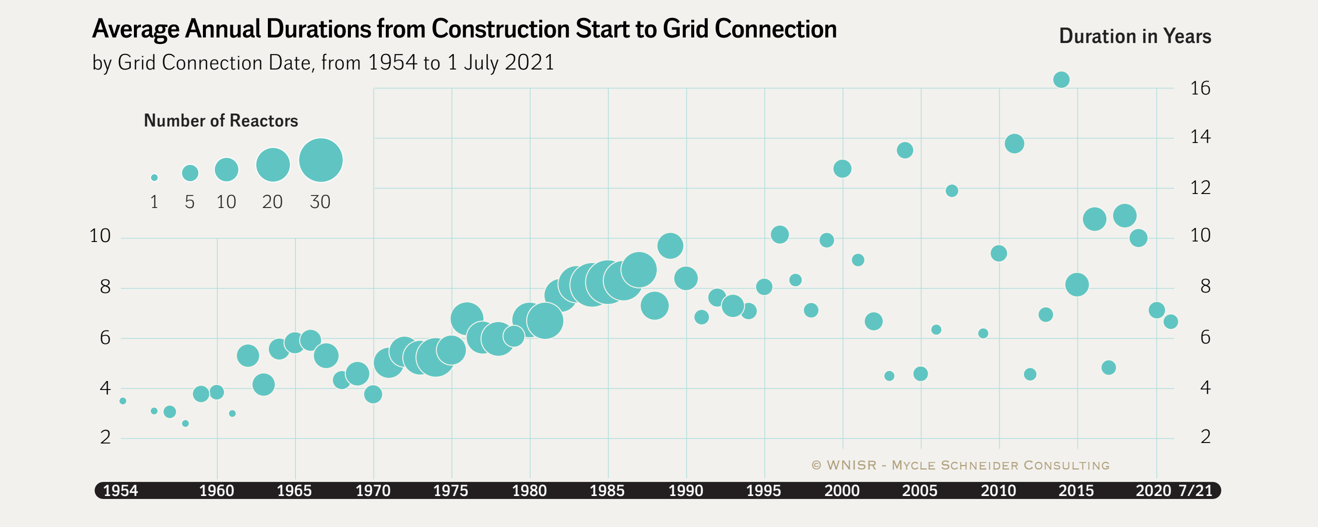
- As of 1 July 2021, for the 53 reactors being built an average of seven years have passed since construction start—slightly lower than the mid-2020 average of 7.3 years— and many remain far from completion.
- *All* reactors under construction in at least 12 of the 17 countries have experienced mostly year-long delays. At least 31 (58.5 percent) of the building projects are delayed. Most of the units which are nominally being built on-time were begun within the past three years or have not yet reached projected startup dates, making it difficult to assess whether or not they are on schedule. Particular uncertainty remains over construction sites in Bangladesh, China, Russia, and Turkey.
- Of the 31 reactors clearly documented as behind schedule, at least 13 have reported *increased* delays and four have reported *new* delays over the past year.
- WNISR2019 noted a total of 13 reactors scheduled for startup in 2020 but only three of these did so, while the other 10 were delayed at least into 2021. The COVID-19 pandemic clearly influenced some of the commissioning schedules.
- Construction start of two projects dates back 36 years, Mochovce-3 and -4 in Slovakia, and their startup has been further delayed, currently to late 2021 and 2023. Bushehr-2 originally started construction in 1976, that is 45 years ago, and resumed construction in 2019 after a 40-year-long suspension. Grid connection is currently scheduled for 2024.
- Five additional reactors have been listed as "under construction" for a decade or more: the Prototype Fast Breeder Reactor (PFBR) and Kakrapar-4 in India, the Olkiluoto-3 (OL3) reactor project in Finland, Shimane-3 in Japan, and Flamanville-3 (FL3) in France. The Finnish and French projects have been further delayed this year, grid connections of the Indian units are likely to be postponed again, and the Japanese reactor does not even have a provisional startup date.

The actual lead time for nuclear plant projects includes not only the construction itself but also lengthy licensing procedures in most countries, complex financing negotiations, site preparation and other infrastructure development.

Construction Times of Past and Currently Operating Reactors

Since the beginning of the nuclear power age, there has been a clear global trend towards increasing construction times. National building programs were faster in the early years of nuclear power, when units were smaller and safety regulations were less stringent. As Figure 8 illustrates, construction times of reactors completed in the 1970s and 1980s were quite homogenous, while in the past two decades they have varied widely.

Figure 8 · Average Annual Construction Times in the World



Sources: WNISR, with IAEA-PRIS, 2021

The 11 units completed in 2018–2020 by the Chinese nuclear industry took on average 7.1 years to build, while the six Russian projects took a mean 15 years from first construction start to grid connection, with Rostov-4 taking 35 years from construction start to finally generate power (see The Construction Saga of Rostov Reactors 3 and 4).

The case of the twin "floating" reactors Akademik-Lomonosov is particularly interesting. These are small 30-MW reactors meant to demonstrate a precursor to a new generation of Small Modular Reactors (SMRs), smaller, cheaper, and faster to build. However, construction has taken longer than any other reactor that has come on-line over the three-year period (with the exception of Rostov-4) and about four times as long as originally projected; a little before construction of the ship began in 2007, Rosatom announced that the plant would begin operating in October 2010[45], which finally happened in December 2019. Not surprisingly, the "nuclear barge" has become more expensive, from an initial estimate of around 6 billion rubles (US$$_{2007}$232 million)[46] to at least 37 billion rubles as of 2015 (US$$_{2015}$740 million),[47] or close to US$25,000 per installed kilowatt, almost twice as costly as the most expensive Generation III reactors.[48]

45 - Rosatom, "The first offshore nuclear heat and electrical power plant of small capacity is planned to operate in October 2010 in Severodvinsk (Arkhangelsk district)", Press Release, 15 December 2006; and IPFM, "Global Fissile Material Report 2007—Developing the technical basis for policy initiatives to secure and irreversibly reduce stocks of nuclear weapons and fissile materials", Second Report of the International Panel on Fissile Materials, Program on Science and Global Security, Princeton University, 1 October 2007, see http://fissilematerials.org/publications/2007/10/global_fissile_material_report_1.html, accessed 3 September 2020.

46 - *WNN*, "Russian floating reactor construction starts", 17 April 2007, see https://www.world-nuclear-news.org/Articles/Russian-floating-reactor-construction-starts, accessed 3 September 2020.

47 - Charles Digges, "New documents show cost of Russian floating nuclear power plant skyrockets", Bellona, 25 May 2015, see http://bellona.org/news/nuclear-issues/2015-05-new-documents-show-cost-russian-nuclear-power-plant-skyrockets, accessed 28 December 2015.

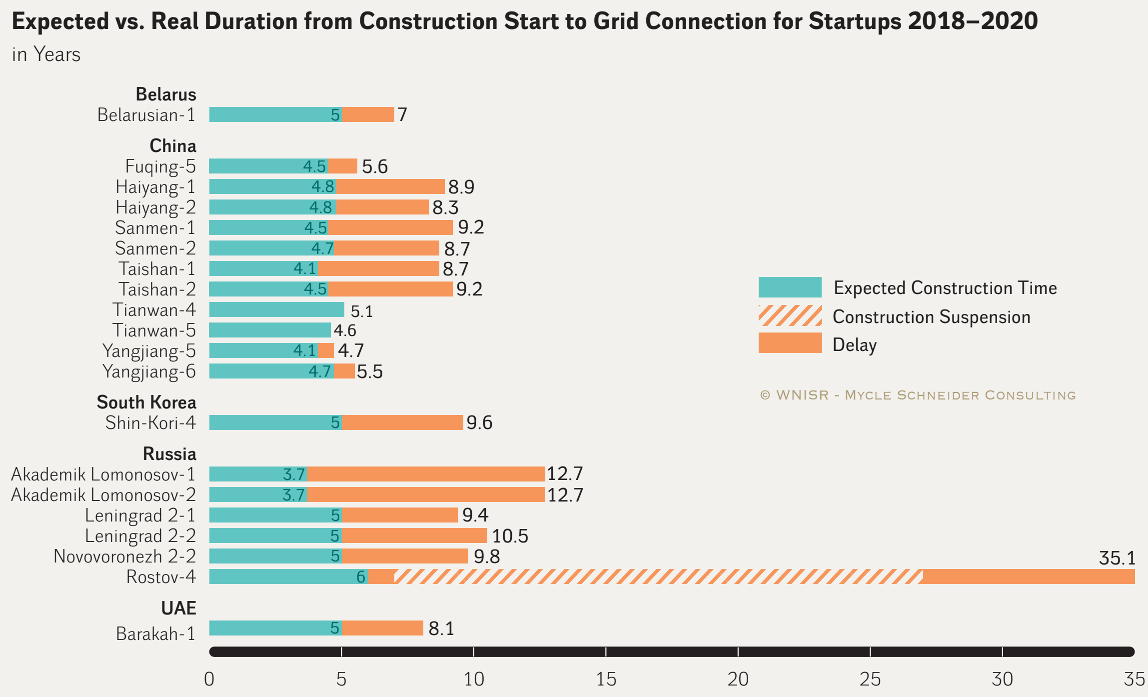
48 - The current cost estimate—including financing costs—of the Flamanville-3 EPR is about US$13,700/kW (see France Focus).

The mean time from construction start to grid connection for the five reactors started up in 2020 was 7.2 years, a clear improvement over the 9.9 years in 2019 and 10.9 years in 2018. In the case of the four units connected in the first half of 2021, the duration was 6.7 years.

While mean construction times have been improving more recently, over the three years 2018-2020, only two of 20 units started up on-time, and those are Tianwan-4 and -5 in China, a Russian-designed but mainly Chinese-built VVER-1000 (model V-428M), that the designers claim to belong to Gen III classification, but few details are known. The two Chinese units Yangjiang-5 and -6 were completed with minor delays in 4.7 and 5.5 years respectively. These are ACPR1000 reactors, designed by China General Nuclear Corp. (CGN) that claims contain at least ten improvements making them a Gen III design.[49]

Leaving the epic Rostov-4 case aside, the other units that started up in China (four AP1000s, two EPRs), the two large reactors in Russia (Leningrad 2-1 and Novovoronezh 2-2) and the one in South Korea (Shin-Kori-4) all experienced years-long delays and roughly doubled their respective planned construction time to 8.3–9.8 years, while the two floating reactors took with 12.7 years about four times as long to complete as planned (see Figure 9).

Figure 9 · Delays for Units Started Up 2018–2020



Sources: WNISR with IAEA-PRIS, 2021

Note

Expected construction time is based on grid connection data provided at construction start when available; alternatively, best estimates are used, based on commercial operation, completion, or commissioning information.

49 - Caroline Peachey, "Chinese reactor design evolution", *NEI*, 22 May 2014, see https://www.neimagazine.com/features/featurechinese-reactor-design-evolution-4272370/, accessed 14 August 2019.

The longer-term perspective confirms that short construction times remain the exceptions. Ten countries completed 63 reactors over the decade 2011–2020—of which 37 in China alone—after an average construction time of 10 years (see Table 2). That is two countries more (Belarus, UAE) than for the decade 2010–2019 with otherwise exactly the same numbers.

Table 2 – Duration from Construction Start to Grid Connection 2011–2020

Construction Times of 63 Units Started-up 2011–2020				
Country	Units	Construction Time (in Years)		
		Mean Time	Minimum	Maximum
China	37	6.1	4.1	11.2
Russia	10	18.7	8.1	35.1
South Korea	5	6.4	4.2	9.6
India	3	11.5	8.7	14.2
Pakistan	3	5.4	5.2	5.6
Argentina	1	33.0	33.0	
Belarus	1	7.0	7.0	
Iran	1	36.3	36.3	
UAE	1	8.1	8.1	
USA	1	42.8	42.8	
World	63	9.9	4.1	42.8

Sources: Various, compiled by WNISR, 2021

CONSTRUCTION STARTS & CANCELLATIONS

The number of annual construction starts[50] in the world peaked in 1976 at 44, of which 11 projects were later abandoned. In 2010, there were 15 construction starts—including 10 in China—the highest level since 1985 (see Figure 10 and Figure 11). That number dropped to five in 2020—including four in China—while building started on six units—including three in China—in the first half of 2021. Like most of the construction projects of the past decades, it was government owned or controlled companies that launched all the 11 reactors over the past 18 months.

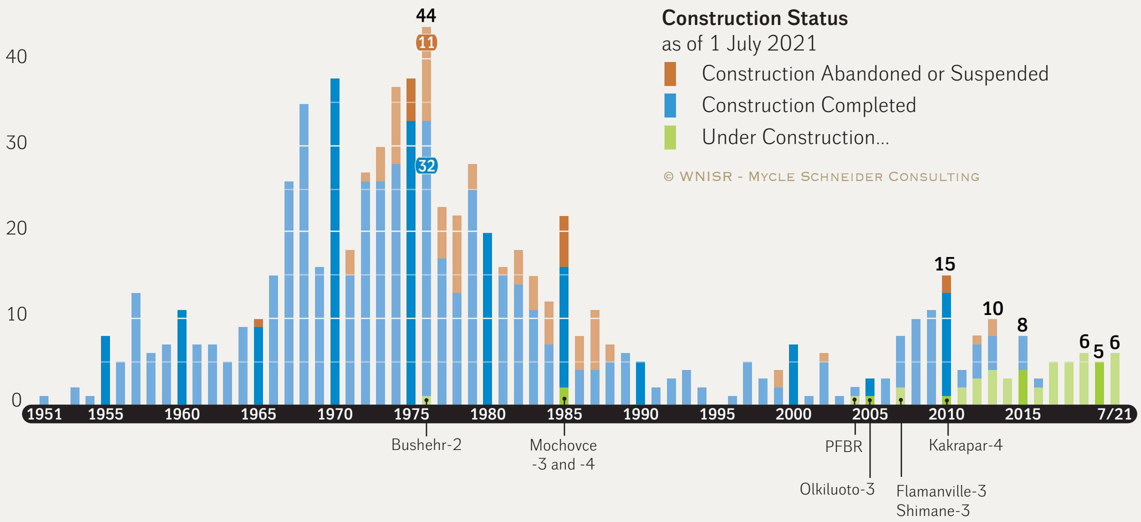
Seriously affected by the Fukushima events, China did not start any construction in 2011 and 2014 and began work only on eight units in total in 2012 and 2013. While Chinese utilities started building six more units in 2015, the number shrank to two in 2016, only a demonstration fast reactor in 2017, none in 2018, but four in 2019 (see Figure 11). While this increase apparently is a sign of the restart of commercial reactor building in China, the level continues to remain far below expectations. The five-year plan 2016–2020 had fixed a target of 58 GW operating and 30 GW under construction by 2020. As of the end of 2020, China had 49 units with 47.5 GW operating, one reactor in LTO (CEFR) and 17 units with 16 GW under construction, far from the original target.

50 - Generally, a reactor is considered under construction with the beginning of the concreting of the base slab of the reactor building. Site preparation work, excavation and other infrastructure developments are not included.

Figure 10 · Construction Starts in the World

Construction Starts of Nuclear Reactors in the World

in Units, from 1951 to 1 July 2021



Sources: WNISR, with IAEA-PRIS, 2021

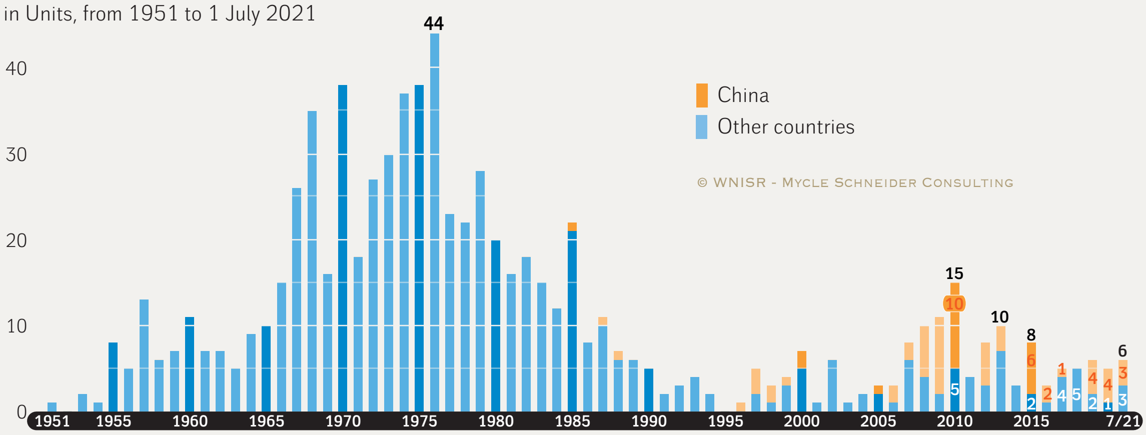
Notes:

Construction of Bushehr-2, started in 1976, was considered abandoned in earlier versions of this figure. As construction was restarted in 2019, it now appears as "Under Construction". The Chinese project at Shidao Bay-1 is considered as two reactors, and construction starts in 2012 reflect this change.

Figure 11 · Construction Starts in the World/China

Construction Starts of Nuclear Reactors in the World

in Units, from 1951 to 1 July 2021



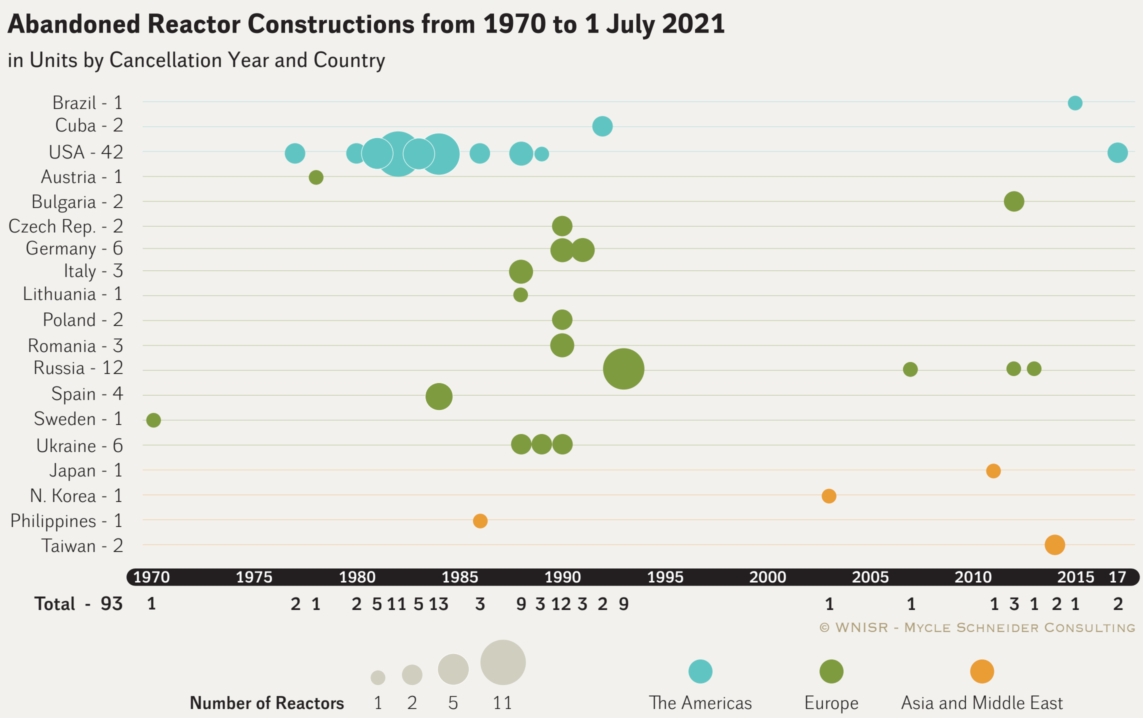
Sources: WNISR, with IAEA-PRIS, 2021

Over the decade 2011–2020, construction began on 57 reactors in the world, of which three have been abandoned (Baltic-1 in Russia, V.C. Summer-2 and -3 in the U.S.). With 18 units, one third of the ongoing building projects are located in China. As of mid-2021, only 15 of the 54 units have started up, while 39 remain under construction.

Experience shows that simply having an order for a reactor, or even having a nuclear plant at an advanced stage of construction, is no guarantee of ultimate grid connection and power production. The abandonment of the two V.C. Summer units at the end of July 2017 after four years of construction and following multi-billion-dollar investment is only the latest example in a long list of failed nuclear power plant projects.

French Alternative Energies & Atomic Energy Commission (CEA) statistics through 2002 indicate 253 "cancelled orders" in 31 countries, many of them at an advanced construction stage (see also Figure 12). The United States alone accounted for 138 of these order cancellations.[51]

Figure 12 · Cancelled or Suspended Reactor Constructions



Sources: WNISR, with IAEA-PRIS, 2021

Note: This graph only includes constructions that had officially started with the concreting of the base slab of the reactor building.

Of the 783 reactor constructions launched since 1951, at least 93 units in 19 countries had been abandoned or are suspended, as of 1 July 2021. This means that 12 percent or one in eight nuclear constructions have been abandoned.

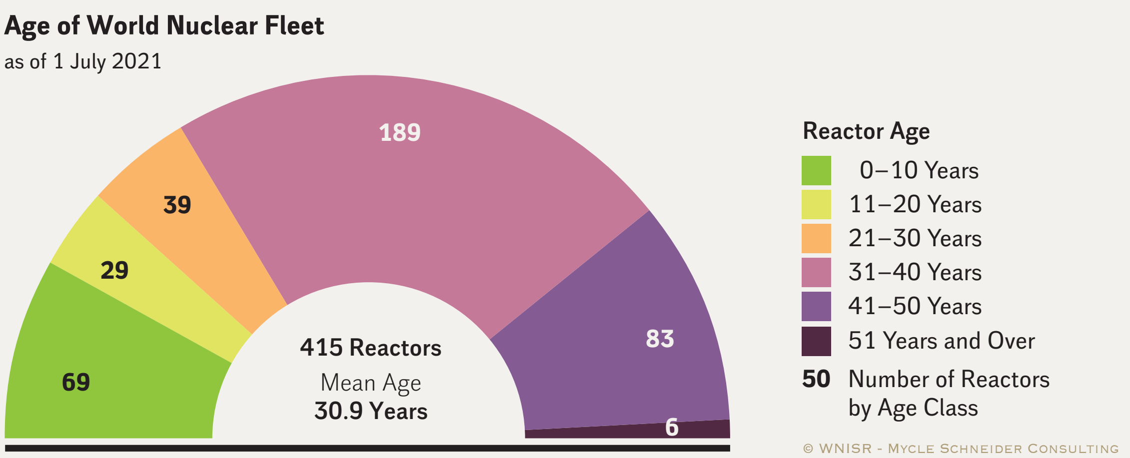
Close to three-quarters (66 units) of all cancelled projects were in four countries alone—the U.S. (42), Russia (12), Germany and Ukraine (six each). Some units were 100-percent completed—including Kalkar in Germany and Zwentendorf in Austria—before the decision was taken not to operate them.

51 - CEA, "Elecnuc—Nuclear Power Plants in the World", French Alternatives Energies and Atomic Energy Commission, 2002. The section "cancelled orders" has disappeared after the 2002 edition.

OPERATING AGE

In the absence of significant, successful new-build over many years, the average age (from grid connection) of operating nuclear power plants has been increasing since 1984 and as of mid-2021 it is standing at 30.9 years, up from 30.7 years in mid-2020 (see Figure 13).[52]

Figure 13 · Age Distribution of Operating Reactors in the World



Sources: WNISR, with IAEA-PRIS, 2021

A total of 278 reactors, two-thirds of the world's operating fleet, have operated for 31 or more years, including 89—more than one in five—for 41 years or more.

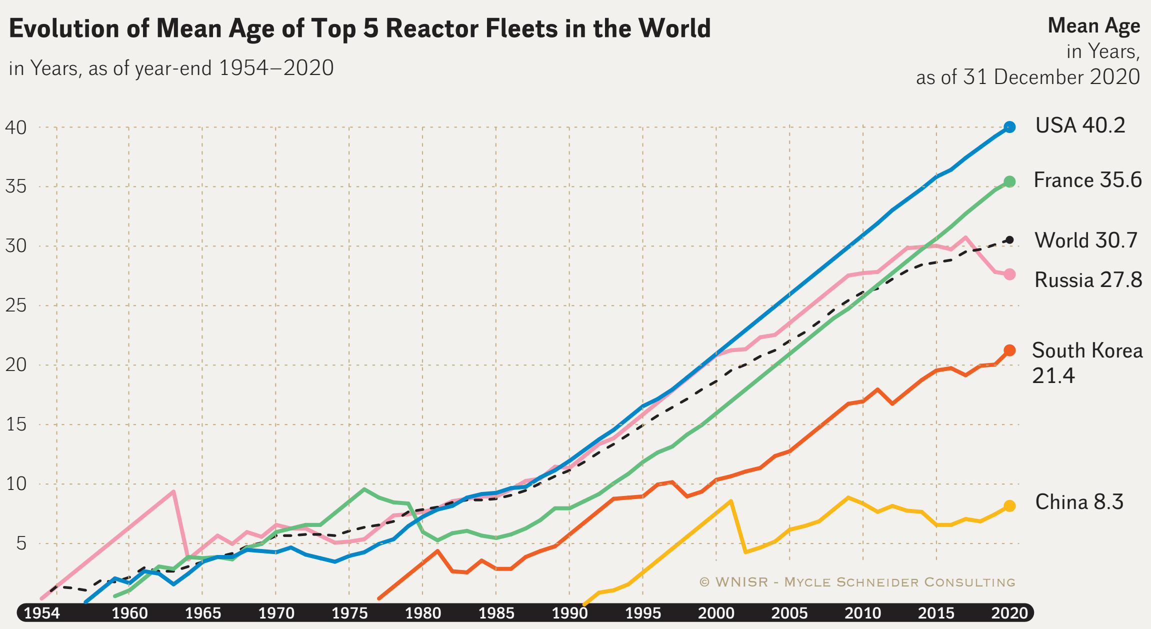
In 1990, the average age of the operating reactors in the world was 11.3 years, in 2000, it was 18.8 years and stood at 26.3 years by 2010. The leading nuclear nation is also leading the age pyramid. The U.S. has passed the 40-year average age in 2020. France's fleet exceeds 35 years. Russia inversed the curve starting in 2016 and its average fleet age of 27.8 years as of the end of 2020 remains 2.4 years below the 2015-peak. South Korea's reactors at 21.4 years remain half as old as the U.S. fleet, and China is the obvious newcomer with an average fleet age of just 8.3 years. (See Figure 14).

Many nuclear utilities envisage reactor lifetimes of beyond 40 years up to 60 and even 80 years. In the U.S., reactors are initially licensed to operate for 40 years, but nuclear operators can request a license renewal from the Nuclear Regulatory Commission (NRC) for an additional 20 years. An initiative to allow for 40-year license extensions in one step was terminated after NRC staff had recommended in June 2021 to "discontinue the activity to consider regulatory and other changes to enable license renewal for 40 years".[53]

52 - WNISR calculates reactor age from grid connection to final disconnection from the grid. In WNISR statistics, "startup" is synonymous with grid connection and "closure" with withdrawal from the grid. In order to have a better image of the fleet and ease calculations, the age of a reactor is considered to be 1 between the first and second grid connection anniversaries. For some calculations, we also use operating years: the reactor is in its first operating year until the first grid connection anniversary, when it enters the second operating year.

53 - NRC, Division of New and Renewed Licenses, "Closure of Activity to Consider License Renewal for 40 Years of Additional Nuclear Power Plant Operation", Office of Nuclear Reactor Regulation, U.S.NRC, 22 June 2021, see https://www.nrc.gov/docs/ML2111/ML21117A007.pdf, accessed 11 August 2021.

Figure 14 · Reactor-Fleet Age of Top 5 Nuclear Generators



Sources: WNISR, with IAEA-PRIS, 2021

As of mid-2021, 97 U.S. units had received a 20-year license extension, no further applications were under NRC review. Nine units with renewed licenses were closed early, and two applications for three reactors were withdrawn as Crystal River was closed and the other two at Diablo Canyon will close when their current license expires in 2024–2025 (see United States Focus). Three additional applications for four reactors are expected in 2021–2023.[54]

So far, the NRC has granted Subsequent Renewed Operating Licenses to six reactors, which permit operation from 60 to 80 years. A further seven reactors have their applications still under review.[55]

Only eight of the 40 units that have been closed in the U.S. had reached 40 years on the grid. All eight had obtained licenses to operate up to 60 years but were closed much earlier mainly for economic reasons. In other words, at least one fourth of the 133 reactors connected to the grid in the U.S. at any point in time never reached their initial design lifetime of 40 years. None of those already closed had reached yet 50 years of operation. The mean age at closure of those 40 units was 22 years.

On the other hand, of the 93 currently operating plants, 44 units have already operated for 41 years or more (of six have been on the grid for 50 years or more); thus, half of the units with license renewals have entered the lifetime extension period, and that share is growing rapidly with the mid-2021 mean age of the U.S. operational fleet exceeding 40 years (see Figure 34 and United States Focus).

54 - NRC, "Status of License Renewal Applications and Industry Activities", Updated 13 March 2019, see http://www.nrc.gov/reactors/operating/licensing/renewal/applications.html, accessed 23 August 2020.

55 - NRC, "Status of Subsequent License Renewal Applications", as of 4 August 2021, see https://www.nrc.gov/reactors/operating/licensing/renewal/subsequent-license-renewal.html, accessed 11 August 2021.

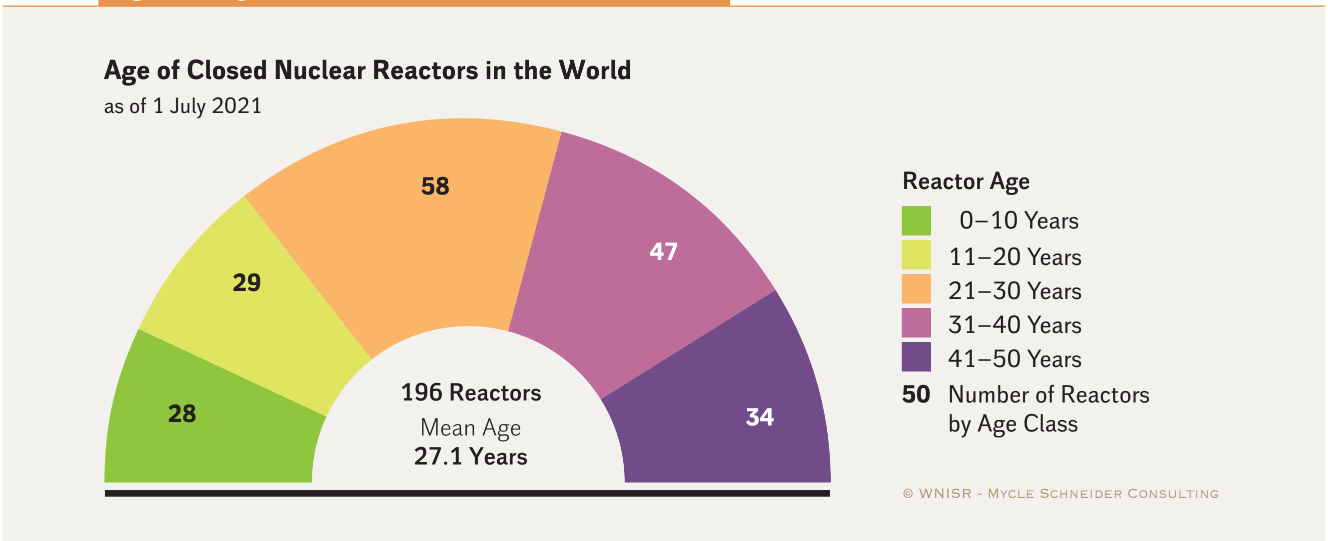
Many countries have no specific time limits on operating licenses. In France, for example, reactors must undergo in-depth inspection and testing every decade against reinforced safety requirements. The French reactors have operated for 36 years on average, and most of them have completed the process with the French Nuclear Safety Authority (ASN) evaluating each reactor allowing them to operate for up to 40 years, which is the limit of their initial design age. However, the ASN assessments are years behind schedule. For economic reasons, the French state-controlled utility Électricité de France (EDF) clearly prioritizes lifetime extension to 50 years over large-scale new-build.

EDF's approach to lifetime extension has been reviewed by ASN and its Technical Support Organization (TSO). In February 2021, ASN granted a conditional generic agreement to lifetime extensions of the 32 reactors of the 900 MW series. However, lifetime extensions beyond 40 years require site-specific licensing procedures involving public inquiries in France.

Recently commissioned reactors and the ones under construction in South Korea do or will have a 60-year operating license from the start. EDF will certainly also aim for a 60-year license for its Hinkley Point C units in the U.K.

In assessing the likelihood of reactors being able to operate for 50 or 60 years, it is useful to compare the age distribution of reactors that are currently operating with those that have already closed (see Figure 13 and Figure 15). The age structure of the 196 units already closed (seven more than one year ago) completes the picture. In total, 77 of these units operated for 31 years or more, and of those, 33 reactors operated for 41 years or more. Many units of the first-generation designs only operated for a few years. The mean age of the closed units is about 27 years.

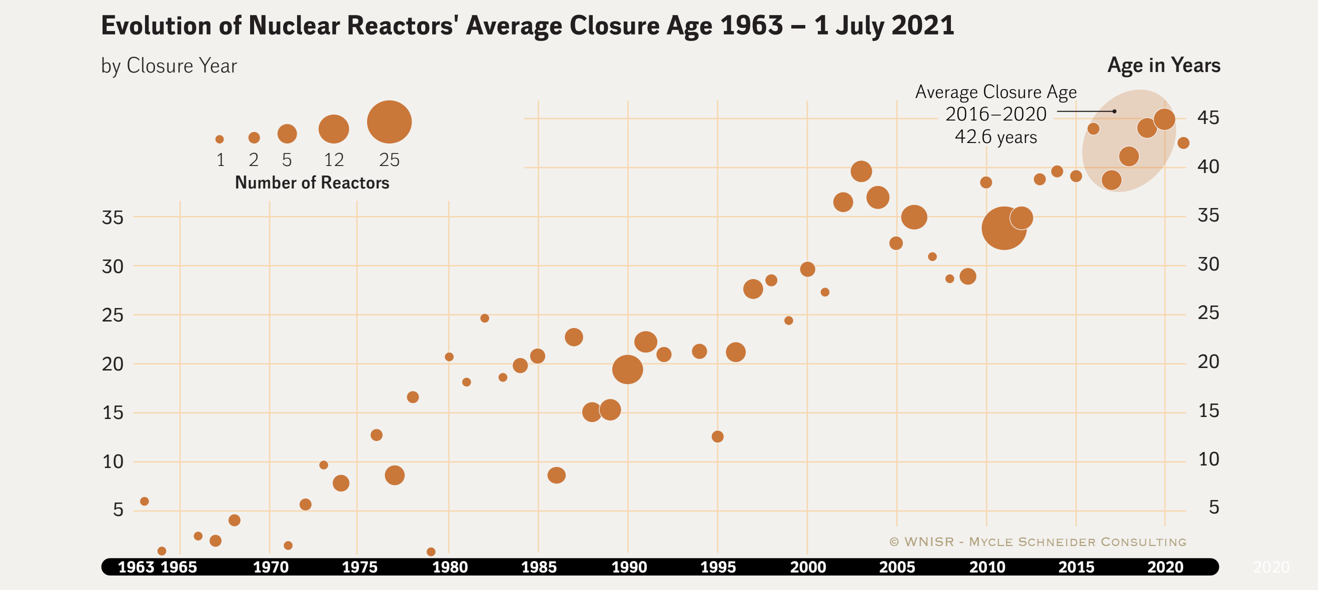
Figure 15 · Age Distribution of Closed Nuclear Power Reactors



Sources: WNISR, with IAEA-PRIS, 2021

To be sure, the operating time prior to closure has clearly increased continuously. The mean age at closure of the 23 units taken off the grids between 2016 and 2020 was 42.6 years (see Figure 16).

Figure 16 · Nuclear Reactor Closure Age



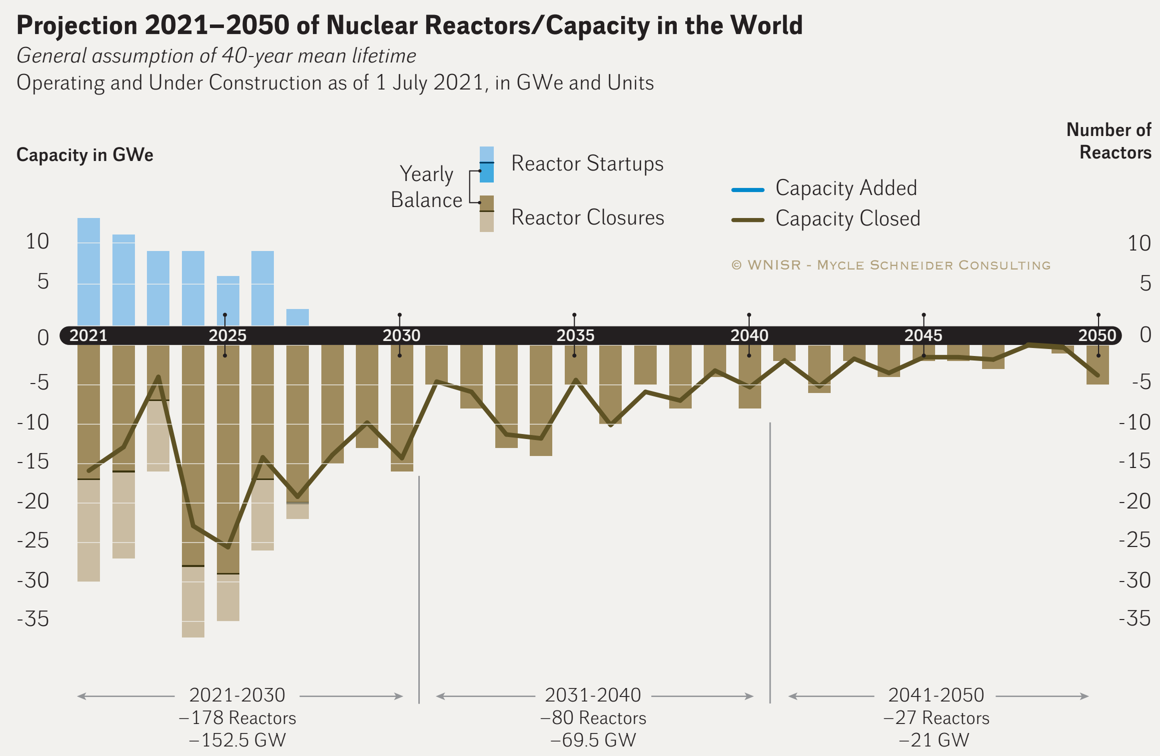
Sources: WNISR, with IAEA-PRIS, 2021

As a result of the Fukushima nuclear disaster (elsewhere referred to as 3/11), questions have been raised about the wisdom of operating older reactors. The Fukushima Daiichi units (1 to 4) were connected to the grid between 1970 and 1974. The license for Unit 1 had been extended for another 10 years in February 2011, just one month before the catastrophe began. Four days after the accidents in Japan, the German government ordered the closure of eight reactors that had started up before 1981, two of which were already closed at the time and never restarted. The sole selection criterion was operational age. Other countries did not adopt the same approach, but clearly the 3/11 events in Japan had an impact on previously assumed extended lifetimes in other countries, including in Belgium, Switzerland and Taiwan. Some of the main nuclear countries closed their respective then oldest unit before age 50, including Germany at age 37, South Korea at 40, Sweden at 46 and the U.S. at 49. France closed its two oldest units in spring 2020 at age 43.

LIFETIME PROJECTIONS

Nuclear operators in many countries continue to implement or prepare for lifetime extensions. As in previous years, WNISR has created two lifetime projections. A first scenario (40-Year Lifetime Projection, see Figure 17), assumes a general lifetime of 40 years for worldwide operating reactors—not including reactors in Long-Term Outage (LTO).

Figure 17 · The 40-Year Lifetime Projection



Sources: Various sources, compiled by WNISR, 2021

Notes pertaining to Figure 17, Figure 18 and Figure 19.

Those figures include one Japanese reactor (Shimane) and two Chinese 1400 MW-units at Shidao Bay, for which the startup dates were arbitrarily set to 2025 and 2024, as there are no official dates.

The restart of two reactors (Mihama-3 and CEFR) from LTO prior to 7/2021 appears as "startup". Potential restarts or closures amongst the 26 reactors in LTO as of 1 July 2021 are not represented here.

The figures take into account "early retirements" of three reactors in the U.S.; the early retirement as of 2021 for four Exelon reactors recently announced to close in September and November of this year, is not taken into account due to uncertainties; in the case of four additional reactors, the reversal of early retirements has been maintained although some are likely to be repealed, and others might be added (see United States Focus); the figures also take into account political decisions to close reactors prior to 40 years (Germany, South-Korea).

In the case of reactors that have reached 40 years of operation prior to 2021, the 40-Year projection also uses the end of their licensed lifetime (including 6 reactors licensed for 80 years in the U.S.)

In the case of French reactors that have reached 40 years of operation prior to 2021 (startup before 1981), we use the deadline for their 4th periodic safety review (visite décennale) as closing date in the 40-year projection. For all those that have already passed their 3rd periodic safety review, the scheduled date of their 4th periodic safety review is used in the PLEX projection, regardless of their startup date.

The 40-year number corresponds to the design lifetimes of most operating reactors. Some countries have legislation or policy (Belgium, South Korea, Taiwan) in place that limit operating lifetime, for all or part of the fleet, to 40 or 50 years. Recent designs, mostly reactors under construction, have a design lifetime of 60 years (e.g. APR1400, EPR). For the 99 reactors that have passed the 40-year lifetime, we assume they will operate to the end of their licensed, extended operating time.

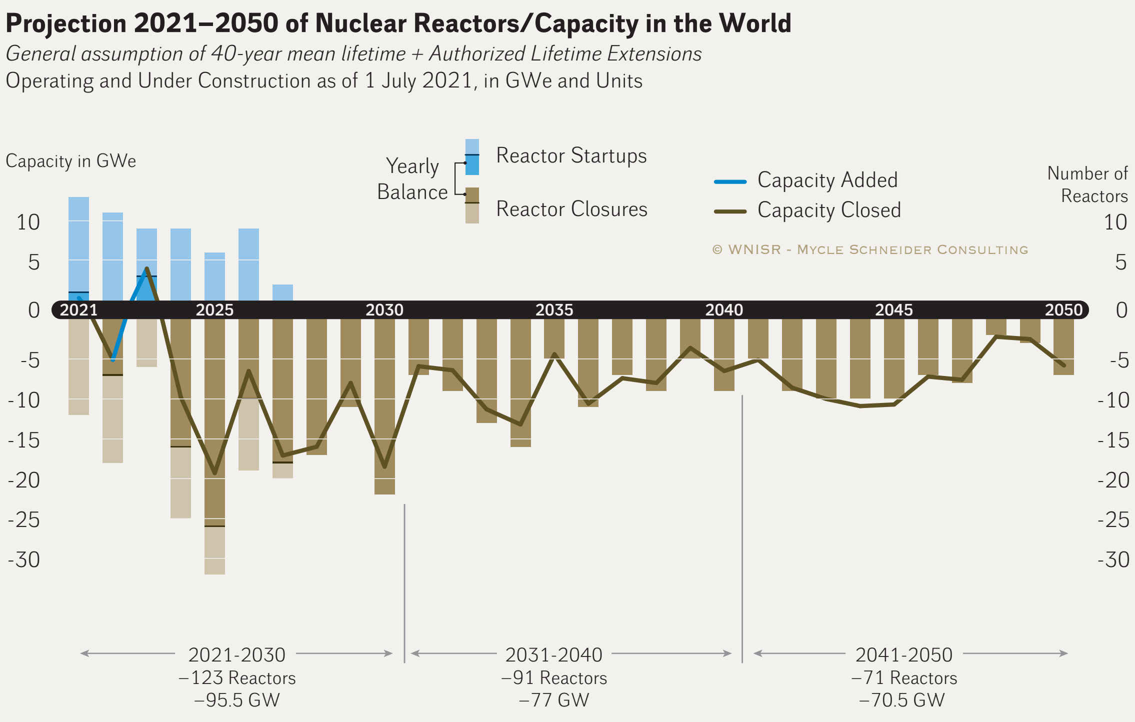
A second scenario (Plant Life Extension or PLEX Projection, see Figure 18) takes into account *all* already-authorized lifetime extensions.

The lifetime projections allow for an evaluation of the number of plants and respective power generating capacity that would have to come online over the next decades to offset closures and simply maintain the same number of operating plants and level of capacity, if all units were closed after a lifetime of 40 years.

Considering all units under construction scheduled to have started up and not including potential early closure of the four units at Byron and Dresden sites in the U.S.,[56] 17 additional reactors (compared to the end of 2020 status) would have to be commissioned or restarted prior to the end of 2021 in order to maintain the status quo of operating units. Without additional startups, installed nuclear capacity would decrease by 15.9 GW by the end of 2021.

In the decade to 2030, in addition to the units currently under construction, 178 new reactors (152.6 GW)—18 units or 15 GW per year—would have to be connected to the grid to maintain the status quo, almost three times the rate achieved over the past decade (63 startups between 2011 and 2020).

Figure 18 · The PLEX Projection (not including LTOs)



Sources: Various sources, compiled by WNISR, 2021

56 - Darren Sweeney, "Exelon CEO says closing nuclear plants 'right economic decision' absent support", *S&P Global*, 4 August 2021, see https://www.spglobal.com/marketintelligence/en/news-insights/latest-news-headlines/exelon-ceo-says-closing-nuclear-plants-right-economic-decision-absent-support-65881124, accessed 7 August 2021.

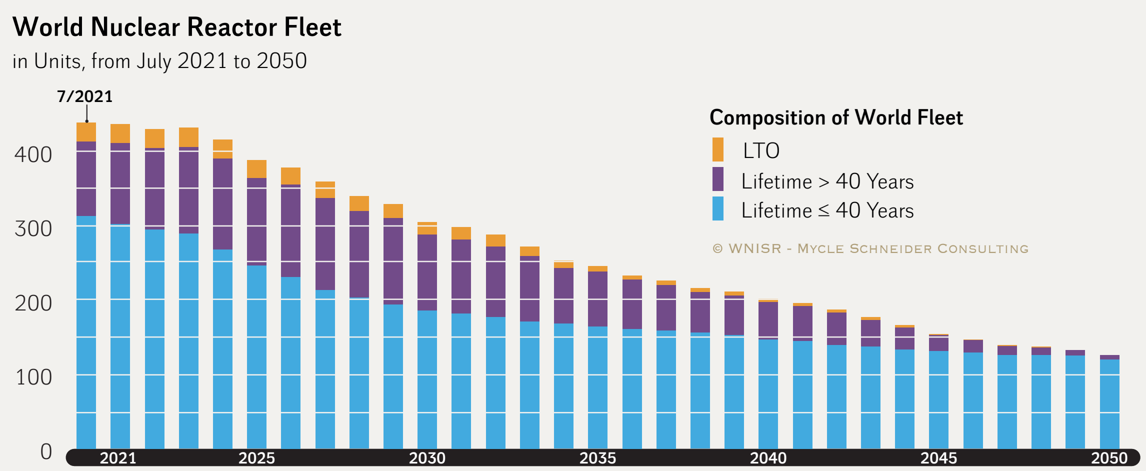
The stabilization of the situation by the end of 2021 is only possible because most reactors will likely not close at the end of the year, regardless of their age. As a result, the number of reactors in operation will likely continue to stagnate at best, unless—beyond restarts—lifetime extensions become the rule worldwide. Such generalized lifetime extensions—far beyond 40 years—are clearly the objective of the nuclear power industry, and, especially in the U.S., there are numerous more or less successful attempts to obtain subsidies for uneconomic nuclear plants in order to keep them on the grid (see United States Focus).

Developments in Asia, including in China, do not fundamentally change the global picture. Reported ambitions for China's targets for installed nuclear capacity have fluctuated in the past. While construction starts have picked up speed again, Chinese medium-term ambitions appear significantly lower than anticipated in the pre-3/11 era.

Every year, WNISR also models a scenario in which all currently licensed lifetime extensions and license renewals (mainly in the U.S.) are maintained, and all construction sites are completed. For all other units, we have maintained a 40-year lifetime projection, unless a firm earlier or later closure date has been announced. By the end of 2021, the net number of operating reactors and operating capacity would remain almost stable (+ 1 unit / + 0.3 GW, not including the potential early closure of the four units at Byron and Dresden in the U.S.).

In the decade to 2030, the net balance would turn negative as soon as 2024, and an additional 123 new reactors (95.3 GW)—one unit or 0.8 GW per month—would have to start up or restart to replace closures. The PLEX-Projection would still mean, in the coming decade, a need to double the annual building rate of the past decade from six to twelve (see Figure 17, Figure 18 and the cumulated effect in Figure 19).

Figure 19 · Forty-Year Lifetime Projection versus PLEX Projection



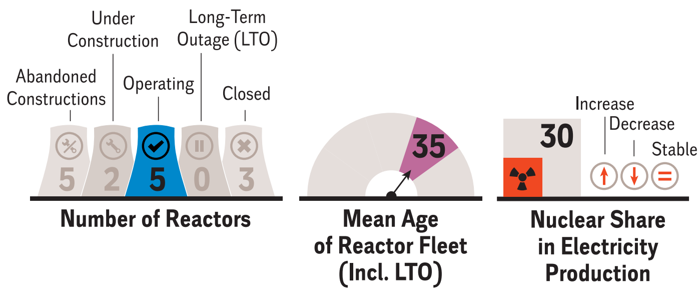
Sources: Various sources, compiled by WNISR, 2021

Note: This figure illustrates the trends, and the projected composition of the current world nuclear fleet, taking into account existing reactors (operating and in LTO) and their closure dates (40-years Lifetime vs authorized Lifetime Extension) as well as the 53 reactors under construction as of 1 July 2021. The graph does *not represent a forecasting of the world nuclear fleet over the next three decades as it does not speculate about future constructions.*

In the meantime, construction starts have been on a declining trend for a decade. Between 2011 and 2015, a total of 33 constructions were launched around the world, of which 14 in China (and three later abandoned), thus an average of six units per year were launched and sustained. Between 2016 and 2020, constructions started at only 24 units, of which 11 in China, thus an average of less than five construction starts per year, significantly less than half than of the building rate needed according to the PLEX Projection over the coming decade just to maintain the current number of operating reactors in the world.

FOCUS COUNTRIES

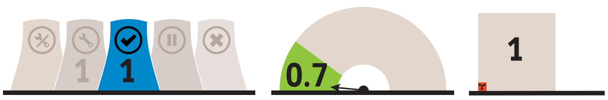
These "quick view" indicators will be used in the country sections throughout the report.



The following chapter offers an in-depth assessment of ten countries: Belarus, China, Finland, France, India, Japan, South Korea, Taiwan, United Kingdom (U.K.) and the United States (U.S.). They represent one third of the nuclear countries, two thirds of the global reactor fleet and four of the world's five largest nuclear power producers. For other countries' details, see Annex 1.

Unless otherwise noted, data on the numbers of reactors operating and under construction and their capacity (as of mid-2021) and nuclear's share in electricity generation in 2020 are from the International Atomic Energy Agency's Power Reactor Information System (IAEA-PRIS) online database.[57] Historical maximum figures indicate the year that the nuclear share in the power generation of a given country was the highest since 1986, the year of the Chernobyl disaster.

BELARUS FOCUS



Construction started in November 2013 at Belarus's first nuclear reactor at Ostrovets power plant, also called Belarusian-1. Construction of a second 1200 MWe AES-2006 reactor started at the same site in June 2014. The first unit was completed and connected to the grid on 3 November 2020 and reached full power in January 2021.[58] The first few weeks of operation reignited the international controversy around the project, and according to the Lithuanian Government three incidents of equipment failure occurred in the first month (later confirmed by Belarus), including in the voltage transformer, the cooling system, and a steam noise absorber.[59] On 2 June 2021, Belarusian-1 received a commercial operating license.[60]

The European Commission issued a statement saying "It is regrettable that Belarus has decided to start the commercial operation of the Astravets [Ostrovets] nuclear power plant, without addressing all the safety recommendations contained in the 2018 EU stress test report. As the

57 - IAEA-PRIS, "Nuclear Share of Electricity Generation in 2020", see https://pris.iaea.org/PRIS/WorldStatistics/NuclearShareofElectricityGeneration.aspx. Some of the figures indicated by the IAEA are not updated (e.g. the given 2020-number for France is wrong as it simply reissues the 2019-number, while the share has dropped significantly) or are very different from national statistics, which WNISR uses in those cases.

58 - *NEI*, "Unit 1 of the Belarusian nuclear plant brought to 100% capacity", 14 January 2021, see https://www.neimagazine.com/news/newsunit-1-of-the-belarusian-nuclear-plant-brought-to-100-capacity-8453244/, accessed 1 May 2021.

59 - Andrew Rettman, "Lithuania warns EU leaders on Belarus nuclear incidents", *EUobserver*, 11 December 2020, see https://euobserver.com/foreign/150358, accessed 1 May 2021.

60 - Gosatomnadzor, "License for the Operation of Belarusian NPP Power Unit No. 1 is issued", 2 June 2021, see http://gosatomnadzor.mchs.gov.by/en/novosti/353948/, accessed 30 July 2021.

Commission has repeatedly stated, all peer review recommendations should be implemented by Belarus without delay."[61]

The State Inspectorate for Nuclear Energy Safety of Lithuania (Vatesi) commented: "The fact of issuing a licence does not change the position of Vatesi, that it is necessary to suspend the operation of the Belarusian NPP, resolve nuclear safety problems and take the necessary measures to improve its safety."[62]

In October 2011, a contract was signed between the Belarus Nuclear Power Plant Construction Directorate, and Russia's AtomStroyExport (ASE). It defines the main terms of the general contract for the construction of two reactors as a turnkey project to be carried out by ASE, with the first unit then scheduled to be commissioned in 2017 and the second in 2018.[63]

The Russian and Belarusian governments agreed that Russia would lend up to US$10 billion for 25 years to finance 90 percent of the project. In July 2012, the contract was signed for the construction of the two reactors for an estimated cost of US$10 billion, including US$3 billion for new infrastructure to accommodate the remoteness of Ostrovets in northern Belarus.[64] Under the terms of the loan agreement Belarus should begin to repay the loan no later than 1 April 2021. Furthermore, the current loan rate for Belarus is a fixed 5.23 percent a year for half of the selected funds and "six-month LIBOR[65] in dollars (now 1.72 percent) plus 1.83 percent per annum" for the other half. Belarus has also proposed increasing the repayment period from 25 years (counting from the date of opening a credit line in 2011) to 35 years, but this has so far been rejected by the Russian counterparts. In March 2021, the Russia-Belarusian loan agreement was adjusted, and the loan extended by two years, until the end of 2022. In addition, a fixed interest rate on the loan is set at 3.3 percent a year, and the start date of the repayment of the principal debt on the loan has been deferred from 1 April 2021 to 1 April 2023.[66]

The project assumes liability for the supply of all fuel and repatriation of spent fuel for the life of the plant. The fuel is to be reprocessed in Russia and the separated wastes returned to Belarus. Information is not available on the fate of the plutonium extracted during reprocessing, but it is likely to remain in Russia.

It is difficult to estimate what the final construction price will be. On the one hand, President Lukashenko has said that cost would be below US$10 billion, but refused to reveal the actual number stating: "It is a commercial secret. The contract price shouldn't be made public."[67] Other sources suggest that the cost of the project has increased by 26 percent, to

61 - European Commission, "Statement by Commissioner Simson on the Astravets nuclear power plant in Belarus", 2 June 2021, see https://ec.europa.eu/commission/commissioners/2019-2024/simson/announcements/statement-commissioner-simson-astravets-nuclear-power-plant-belarus_en, accessed 12 August 2021.

62 - *NEI*, "Issue of operating licence for Belarus unit 1 prompts protests from Lithuania", 8 June 2021, see https://www.neimagazine.com/news/newsissue-of-operating-licence-for-belarus-unit-1-prompts-protests-from-lithuania-8803313, accessed 30 July 2021.

63 - *WNN*, "Contract signed for Belarusian reactors", 11 October 2011, see https://www.world-nuclear-news.org/Articles/Contract-signed-for-Belarusian-reactors, accessed 1 May 2021.

64 - *NIW*, "Belarus, Aided by Russia and Broke, Europe's Last Dictatorship Proceeds With NPP", 28 September 2012.

65 - The London Interbank Offered Rate (LIBOR) is a benchmark interest rate at which major global banks lend to one another in the international interbank market for short-term loans.

66 - *NEI*, "Russia amends terms for Belarus NPP loan agreement", 29 March 2021, see https://www.neimagazine.com/news/newsrussia-amends-terms-for-belarus-npp-loan-agreement-8633297/, accessed 1 May 2021.

67 - *BelTA*, "Belarusian nuclear power plant to cost less than $10bn", 19 April 2019, see https://eng.belta.by/president/view/belarusian-nuclear-power-plant-to-cost-less-than-10bn-120494-2019/, accessed 1 May 2021.

56 billion Russian rubles [US$750 million] in 2001-prices.[68] The uncertainty of the actual costs is compounded by the high volatility of exchange rates.

The project is the focus of international opposition and criticism, with formal complaints from the Lithuanian government[69] that has published a list of fundamental problems of the project. These include claims of major construction issues, doubts about the site suitability and accusations of non-compliance with some of its public engagement obligations according to the Espoo Convention. Belarus was in 2017 found in non-compliance with the Aarhus Convention for harassing members of civil society campaigning against the project.[70] Then, in February 2019, a meeting of the Espoo Convention voted by 30 to 6 that Belarus had violated the convention's rules while choosing Ostrovets as the site for a nuclear power plant.[71]

The Belarussian government, in order to allay European concerns about Ostrovets, submitted the project to a post-Fukushima nuclear stress test and produced a national report, which was submitted to peer-review by a commission from the European Nuclear Safety Regulators Group (ENSREG) and the European Commission. In July 2018, the European Commission announced that the ENSREG report had been presented to the Belarussian authorities and the executive summary was made public, which concludes that "although the report is overall positive, it includes important recommendations that necessitate an appropriate follow up". For example, on the topic of assessment of severe accident management, it says, "the overall concept of practical elimination of early and large releases should be more explicitly reflected in an updated plant safety case." It also gave recommendations for better seismic robustness.[72]

The Belarus authorities have not responded to the peer-review report and in June 2019 the Council of the European Union stated, "The Commission and ENSREG have been calling upon Belarus to swiftly prepare and present a National Action Plan to address the peer-review findings and recommendations, in line with the practice followed for previous stress tests within the EU and with third countries. At the moment of preparation of this report, the Commission and ENSREG are still awaiting reception of this plan."[73] The Lithuanian President has called upon the European Commission to take all possible actions to ensure the safety of the power plant and in March 2020, the Belarus nuclear regulator discussed the national action plan with ENSREG.[74] A follow-up mission of ENSREG in February 2021 to discuss the (lack of) implementation of the stress-test recommendations was downscaled due to the COVID

68 - *Charter 97*, "Astravets NPP Becomes 12 Billion More Expensive In One Day", 30 December 2016, see https://charter97.org/en/news/2016/12/30/236059/, accessed 1 May 2021.

69 - Bryan Bradley, "Lithuania Urges Belarus to Halt Nuclear Project on Safety Issues", *Bloomberg*, 20 August 2013, see https://www.bloomberg.com/news/articles/2013-08-20/lithuania-urges-belarus-to-halt-nuclear-project-on-safety-issues, accessed 1 May 2021.

70 - Economic Commission for Europe, "Findings and recommendations with regard to communication ACCC/C/2014/102 concerning compliance by Belarus", Economic and Social Council, United Nations, presented at Meeting of the Parties to the Convention on Access to Information, Public Participation in Decision-making and Access to Justice in Environmental Matters – 58th Meeting 10-13 September 2017, Adopted by the Compliance Committee 18 June 2017, Distributed 24 July 2017, see https://www.unece.org/fileadmin/DAM/env/pp/compliance/CC-58/ece.mp.pp.c.1.2017.19.e.pdf, accessed 1 May 2021.

71 - *NIW*, "Briefs – Belarus", 15 February 2019.

72 - ENSREG, "Belarus Stress Tests Peer Review–Executive Summary", June 2018, see http://www.ensreg.eu/sites/default/files/attachments/hlg_p2018-36_156_belarus_stress_test_prt_report_-_executive_summary_0.pdf, accessed 12 August 2021.

73 - European Atomic Energy Community, "Report on the implementation of the obligations under the Convention on Nuclear Safety – 8th Review Meeting of the Contracting Parties", Council of the European Union, 19 June 2019, see https://data.consilium.europa.eu/doc/document/ST-10365-2019-ADD-1/en/pdf, accessed 1 May 2021.

74 - *BelTA*, "Fulfillment of national action plan in wake of Belarusian nuclear power plant stress tests reviewed", 11 March 2020, see https://atom.belta.by/en/belaes_en/view/fulfillment-of-national-action-plan-in-wake-of-belarusian-nuclear-power-plant-stress-tests-reviewed-10573/, accessed 1 May 2021.

pandemic and was to be followed by a larger mission in May-June 2021[75], but had not been reported as of mid-August 2021.

In February 2021, the European Parliament passed a resolution on Ostrovets, which "encourages the Commission to work closely with the Belarusian authorities in order to suspend the starting process until all EU stress test recommendations are fully implemented and all necessary safety improvements are in place".[76]

Belarus has historically been an importer of electricity from Russia and Ukraine. Lithuania is trying to get its neighbors to follow the ban on nuclear power from Belarus and will use the Espoo ruling to add weight to its claim. In February 2020, the Governments of Estonia, Latvia and Lithuania put out a joint declaration that they would oppose electricity purchases from the nuclear power plant.[77] In addition, in May 2020, the Lithuanian Parliament passed a resolution "on Energy Independence and the Threat Posed by the Astravyets Nuclear Power Plant" proposing that the government take technical means to block electricity from Belarus.[78] The sale of electricity to the West will be vital for the economics of the project, as increasing domestic consumption or even sale back to Russia will raise significantly lower revenues, due to lower prices. The inability to export the power will lead to significant overcapacity and consequently President Alexander Lukashenko has said that the government needed to devise ways to get the population to use more electricity, including retrofitting houses for electric heating and installing more water boilers.[79]

In November 2020, following the first production of power from Unit 1, Lithuanian transmission system operator Litgrid ceased all power trading with Belarus.[80] However, trading did restart, and Lithuania is seeking a permanent solution. In March the Government proposed a new trilateral methodology for power trade with Russia to its Baltic neighbors with the hope that this would lead to a blockade of electricity from Belarus.[81] It is foreseen that the Baltic states will be synchronized with the West-European electricity grid in 2025, delinking the region from its dependency on Russian and Belarusian electricity.[82]

75 - *BelTA*, "Belarus to host ENSREG mission in May-June", 15 February 2021, see https://eng.belta.by/economics/view/belarus-to-host-ensreg-mission-in-may-june-137467-2021/, accessed 4 May 2021.

76 - European Parliament, "European Parliament Resolution of 11 February 2021 on the Safety of the nuclear power plant in Ostrovets (Belarus)", 2021/2511(RSP), 11 February 2021, see https://www.europarl.europa.eu/doceo/document/TA-9-2021-0052_EN.html, accessed 1 May 2021.

77 - Dominik Istrate, "Baltic States will not buy energy from Belarus NPP", *Emerging Europe*, 13 February 2020, see https://emerging-europe.com/news/baltic-states-will-not-buy-energy-from-belarus-npp/, accessed 1 May 2021.

78 - Sniegė Balčiūnaitė, "Lithuanian parliament ups the ante on Belarus nuclear plant", *LRT*, 5 May 2020, see https://www.lrt.lt/en/news-in-english/19/1175343/lithuanian-parliament-ups-the-ante-on-belarus-nuclear-plant, accessed 1 May 2021.

79 - Gary Peach, "Belarus Prepares Reactor Launch Despite Covid-19 Surge", *NIW*, 29 May 2020.

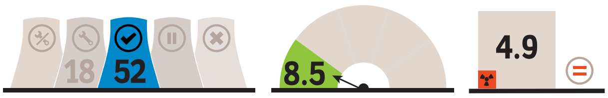
80 - Andrius Sytas, "Lithuania stops Baltics power trade with Belarus, Russia over nuclear plant", *Reuters*, 3 November 2020, see https://www.reuters.com/article/litgrid-belarus-idUSKBN27J2CA, accessed 1 May 2021.

81 - *The Baltic Times*, "Lithuania expects to agree with neighbors by July on Belarus' nuclear power blockade", 2 March 2021, see https://www.baltictimes.com/lithuania_expects_to_agree_with_neighbors_by_july_on_belarus__nuclear_power_blockade/, accessed 1 May 2021.

82 - Evelin Szőke, "Baltic states' mega project of synchronisation to receive 720 mln euros of EU support", *CEENERGYNEWS*, 5 October 2020, see https://ceenergynews.com/electricity/baltic-states-mega-project-of-synchronisation-to-receive-720-mln-euros-of-eu-support/, accessed 4 May 2021.

Following the start of commercial operation Lithuania initiated a legal process to take control of power interconnections with Belarus. The Lithuania government hopes that restricting electricity exports will delay the commercial operation of Belarus-2.

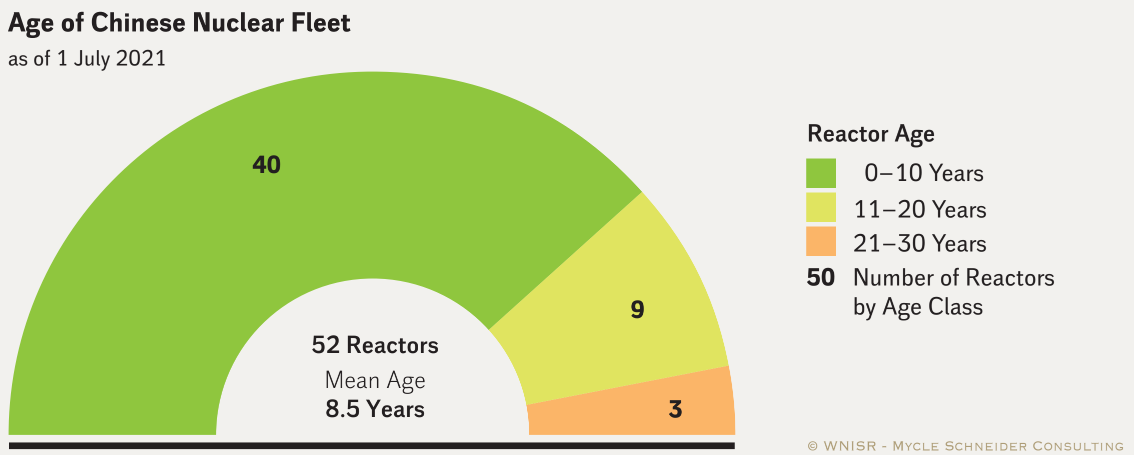
CHINA FOCUS



As of mid-2021, China had 52 operating reactors, including the China Experimental Fast Reactor (CEFR) that was reconnected to the grid after a Long-Term Outage (LTO). Nuclear plants generated 345 TWh in 2020, which is 4.4 percent more than in 2019, the lowest annual growth rate since 2009. Nuclear plants provided a stable 4.9 percent of the electricity in the country.

China operates by far the youngest large nuclear fleet in the world with 40 units, or almost four in five, having been connected to the grid within the past ten years (see Figure 20).

Figure 20 · Age Distribution of Chinese Nuclear Fleet



Sources: WNISR with IAEA-PRIS, 2021

As reported in WNISR2020, there continues to be uncertainty about the future path of nuclear power in China. While the nuclear industry in China and elsewhere are advocating for a large buildup of nuclear reactors in China, the government seems to be cautious. In July 2020, it was reported that the "National Energy Administration (NEA) provided no details of new nuclear construction in its recent 2020 National Energy Work Guiding Opinions, unlike in previous years" and "the State Council, has mentioned almost nothing about newbuilds in its government work plan".[83]

Despite announcing ambitious plans for carbon emissions reduction, the 2021–2025 five-year plan released in March 2021 only announced a goal of 70 GW total nuclear capacity by the end

83 - C.F. Yu, "Beijing's Silence On Further Newbuilds", *NIW*, 13 July 2020.

of 2025.[84] This goal should be seen in light of China missing the earlier 2020-target of 58 GW in operation plus 30 GW under construction, with only 47.5 GW constructed and less than 16 GW under construction at year-end. Also to be considered for context is the 2010 recommendation from the China Nuclear Energy Association (CNEA) calling upon the government to set a goal of 70 GW of nuclear power for 2020.[85] During the deliberations over the five-year plan in 2020, the nuclear industry reportedly took "a back seat to renewables" with leading nuclear developers shifting their business strategies "away from nuclear toward solar".[86]

More significant for the future of nuclear energy is the disappointment expressed by nuclear officials at this goal, calling on the government to accelerate development.[87] The government's caution might be similar to the pause in construction and other decisions made in the aftermath of the multiple nuclear accidents at Fukushima.[88] The *Xinhua* publication of the government's new emission goals, for example, showed that the government only called for "active and well-ordered steps to develop nuclear energy on the basis of ensuring its safe use".[89] In January 2021, China's energy regulator acknowledged "concerns about 'quality management'...noting that some reactor projects had been launched without adequate preparation".[90]

A further reason for uncertainty has been the ongoing anticorruption campaign. In October 2020, the top nuclear official in China's National Energy Administration (NEA) was indicted for misconduct.[91] According to a listing in *Nuclear Intelligence Weekly* (*NIW*)[92], this was the fifth indictment of an NEA chief and the 12th among its senior officials, in eight years; at least a dozen nuclear executives have been indicted since 2018, including the former chairman of China General Nuclear Technology Development Co. More recently, an executive at China National Nuclear Corporation (CNNC) has been under investigation for graft.[93] This official was "previously an executive at an asset-management firm under China Nuclear Engineering & Construction Corporation", which merged with CNNC in 2018, when he was "promoted to deputy chief economist at CNNC, managing costs in that capacity".[94]

84 - *Xinhua*, "China pledges solid efforts on peaking carbon emissions, carbon neutrality", 5 March 2021; and David Stanway, "China should speed nuclear development to meet carbon goals: industry legislators", *Reuters*, 8 March 2021, see https://www.reuters.com/article/uk-china-parliament-nuclearpower-idUKKBN2B00C0, accessed 29 August 2021.

85 - David Stanway, "China nuclear body recommends 2020 target of 70 GW", *Reuters*, 24 November 2010, see https://www.reuters.com/article/china-nuclear-idUSBJI00247420101124, accessed 23 May 2021.

86 - C.F. Yu, "China: Beijing's Silence on Further Newbuilds", *NIW*, 23 October 2020.

87 - David Stanway, "China should speed nuclear development to meet carbon goals: industry legislators", *Reuters*, 8 March 2021, op. cit.

88 - Amy King and M.V. Ramana, "The China Syndrome? Nuclear Power Growth and Safety After Fukushima", *Asian Perspective*, 2015, see http://journals.rienner.com/doi/abs/10.5555/0258-9184-39.4.607, accessed 29 August 2021.

89 - *Xinhua*, "China Pledges Solid Efforts on Peaking Carbon Emissions, Carbon Neutrality", March 2021; and *NEI*, "China's new Five-Year Plan aims for carbon neutrality by 2060 ", 9 March 2021, see https://www.neimagazine.com/news/newschinas-new-five-year-plan-aims-for-carbon-neutrality-by-2060-8584788, accessed 29 August 2021.

90 - David Stanway, "China Should Speed Nuclear Development to Meet Carbon Goals: Industry Legislators", *Reuters*, March 2021, op. cit.

91 - C.F. Yu, "Top NEA Nuclear Official Indicted on Corruption Charges", *NIW*, 30 October 2020.

92 - Ibidem.

93 - *Caixin*, "Senior Nuclear Official Falls Under Graft Probe", 22 April 2021, see https://www.caixinglobal.com/2021-04-22/senior-nuclear-official-falls-under-graft-probe-101697524.html, accessed 23 May 2021.

94 - Shunsuke Tabeta, "Xi ramps up purge of former military-industrial chiefs", *Nikkei Asia*, 11 May 2021, see https://asia.nikkei.com/Politics/Xi-ramps-up-purge-of-former-military-industrial-chiefs, accessed 23 May 2021.

Of the 18 reactors under construction by mid-2021, two have been ongoing since 2012 (Shidao Bay 1-1 and 1-2), three have been ongoing since 2015 (Fangchenggang-3, Hongyanhe-6, and Fuqing-6), one since 2016 (Fangchenggang-4), one since 2017 (Xiapu-1), four since 2019 (Taipingling-1, Zhangzhou-1, Shidao Bay 2-1 and 2-2), and four since 2020 (Taipingling-2, Sanaocun-1, Xiapu-2 and Zhangzhou-2); three started construction during the first half year of 2021 (Changjiang-3, Tianwan-7, and Xudabao-3). Notably, there are no AP1000 reactors under construction, with the State Council reportedly rejecting arguments by AP1000 proponents in September 2020.[95] This is likely a result of the experience with the projects at Haiyang and Sanmen reported in earlier issues of WNISR.

The startup of at least four reactors is delayed. When construction of Hongyanhe-6 started in 2015, it was scheduled to begin operating in 2020.[96] In January 2020, China General Nuclear Power Corporation (CGN) announced that operation of Hongyanhe-6 was delayed by at least six months to 2022.[97] Fuqing-6 was scheduled to be completed in 2020; it is now expected to start up later in 2021.[98] However, since most of the units started building after 2016 and information on the respective construction status is not always available, it is difficult to assess the exact construction status.

The most prominent among the delayed reactors are the twin High Temperature Gas Cooled Reactor (HTGR) units (Shidao Bay 1-1 and 1-2) under construction since December 2012. The builder and operator of the units announced at that time that construction would "take 50 months, with 18 months for building, 18 months for installation and 14 months for pre-commissioning".[99] We are now past more than twice that time period and the reactors still have not commenced operation. According to an update from January 2021, hot testing of the reactors had started, and the units were scheduled to start up later this year.[100]

Well before these construction delays, the cost of electricity from Shidao Bay had been projected to be 40 percent higher than that from light water reactors.[101] The poor economic prospects might be driving China National Nuclear Corp. (CNNC), one of the partners in the Shidao Bay 1 project, to start plans for building larger HTR units to take advantage of economies of scale. In November 2020, CNNC put out a tender soliciting technology partners to construct two 600 MW HTR units.[102] It is hard to imagine that even this increase in scale would make HTRs competitive; estimates by the Idaho National Laboratory in the U.S. suggest that the costs for fuel fabrication, operations, and maintenance alone would be three times

95 - C. F. Yu and Phil Chaffee, "Does the Rise of the Hualong-One Rule Out Further AP1000s?", *NIW*, 11 September 2020.

96 - *WNN*, "Grid connection for Hongyanhe 4", 1 April 2016, see https://www.world-nuclear-news.org/NN-Grid-connection-for-Hongyanhe-4-0104164.html, accessed 27 May 2020.

97 - CGN, "Inside Information - Operation Briefings for the Fourth Quarter of 2019", 6 January 2020, see http://en.cgnp.com.cn/encgnp/c20191226/202001/917f4904f06d4826be1ae98e96780703/files/0627a0191ddb4a07bcfe0b4764a196e4.pdf, accessed 12 January 2020.

98 - *WNN*, "Construction milestones at new Chinese units", 5 January 2017, see http://www.world-nuclear-news.org/NN-Construction-milestones-at-new-Chinese-units-0501175.html, accessed 28 February 2017.

99 - David Dalton, "China Begins Construction Of First Generation IV HTR-PM Unit", *NucNet*, 7 January 2013, see http://www.nucnet.org/all-the-news/2013/01/07/china-begins-construction-of-first-generation-iv-htr-pm-unit, accessed 10 January 2013.

100 - *WNN*, "Hot functional testing of HTR-PM reactors starts", 4 January 2021, see https://www.world-nuclear-news.org/Articles/Hot-functional-testing-of-HTR-PM-reactors-starts, accessed 4 January 2021.

101 - C. F. Yu, "CNEC-CFHI Deal — Boosting the HTGR Or Chinese Manufacturing?", *NIW*, 9 September 2016.

102 - C.F. Yu, "CNNC Rolls Out Additional HTGR Plans", *NIW*, 13 November 2020.

the corresponding costs for light water reactors.[103] CNNC's interest in the HTGR is therefore puzzling, especially in light of the failure of the first HTR-PM project to meet schedules and cost estimates.

China's hopes for nuclear reactor exports also seem to be fading away. During the past decade, the Fukushima accidents were used by Chinese officials to argue that the country had a comparative advantage; in 2013, a former Administrator at the CNEA stated "history has given China an opportunity to overtake the world's nuclear energy and nuclear technology powers".[104] In 2016, CNNC's president announced that "China aims to build 30 overseas nuclear power units… by 2030".[105] That goal is clearly beyond reach today and most agreements that China had entered into with various countries "have not progressed much past the signing stage".[106] The country has no firm export prospects except to Pakistan.

Accordingly, CGN has simply abandoned any export ambition over the coming years, and states in a May-2020 supplement to the 2019-Annual Report[107]:

> In view of the recent international development trend of nuclear power, the Company has neither determined any specific targets for overseas market exploration, nor commenced any overseas projects, and does not expect to have any overseas investment projects in the next few years. As a result, the proceeds specified to be used for overseas market exploration in the Prospectus have not been utilized. Given the orderly progression of the Company's construction of nuclear power projects under construction, in order to increase the efficiency of use of proceeds and reduce capital deposition, on May 20, 2020, the Company, as approved by the 2019 Annual General Meeting, has changed the use of the remaining unused proceeds. Accordingly, approximately RMB966.739 million [US$152 million] of the unused proceeds to be used for overseas market exploration as specified in the Prospectus will instead be entirely utilized for the construction of Fangchenggang Units 3 and 4, and the interests and exchange income thereby generated will also be used for the construction of Fangchenggang Units 3 and 4.

In the meantime, renewable energy capacity in China continues to grow rapidly. According to the International Renewable Energy Agency (IRENA), total installed renewable capacity increased by nearly 18 percent in the past year, going from 759 GW in 2019 to 894 GW in 2020.[108] The largest component of that expansion was in wind capacity, which increased from 210 GW in 2019 to 282 GW in 2020, of which offshore capacity is 9 GW; solar capacity went from 205 GW in 2019 to 254 GW in 2020.

103 - Edwin Lyman, "'Advanced' Isn't Always Better—Assessing the Safety, Security, and Environmental Impacts of Non-Light-Water Nuclear Reactors", Union of Concerned Scientists, March 2021, p.88, see https://www.ucsusa.org/resources/advanced-isnt-always-better, accessed 29 August 2021.

104 - David Stanway, "Analysis: China needs Western help for nuclear export ambitions", *Reuters*, 17 December 2013, see http://www.reuters.com/article/us-nuclear-britain-china-analysis-idUSBRE9BG06B20131217, accessed 25 February 2017.

105 - *Xinhua*, "China plans 30 overseas nuclear power units by 2030", as published by *China.org.cn*, 1 March 2016, see http://www.china.org.cn/china/2016-03/01/content_37910282.htm, accessed 25 August 2021.

106 - C.F. Yu, "Is CGN's Setback Overseas Reason to Merge With CNNC?", *NIW*, 18 September 2020.

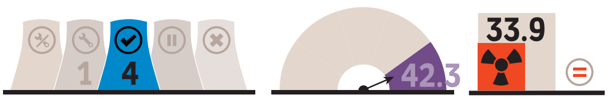
107 - CGN Power, "Supplemental Announcement—Additional Information to the 2019 Annual Report and Update on the Use of Proceeds", 22 July 2020, see http://en.cgnp.com.cn/encgnp/c20191226/202007/fd443aa37fd140c488117b43cdfab7a5/files/48d54962a0a44d9c8a7f5ec50a0a18d0.pdf, accessed 29 May 2021.

108 - IRENA, "Renewable Capacity Statistics 2021", International Renewable Energy Agency, March 2021, see https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2021/Apr/IRENA_RE_Capacity_Statistics_2021.pdf, accessed 5 May 2021.

In comparison, with two reactors starting up, installed nuclear capacity increased by 2 GW in 2020. According to provisional numbers, this is by far the lowest increase in all major sources of power with hydropower going up by 13 GW and thermal (coal) power expanding by 56 GW.[109] The reasons for the expansion of coal have been traced to a number of incentives.[110] Investment trends, according to the China Electricity Council, are also important. When 2020 is compared with 2019, investment in completed thermal power projects has declined by 27 percent and nuclear energy projects by 23 percent, whereas investment in completed hydro power and wind power projects went up by 19 percent and 71 percent respectively.[111]

When it comes to power generation trends, wind and solar plants injected 467 TWh and 261 TWh to the grid respectively, according to the China Electricity Council.[112] In 2020, electricity generated by wind turbines exceeded the nuclear output by 28 percent, and solar energy represented over 70 percent of nuclear energy's contribution.

FINLAND FOCUS



Finland operates four units which in 2020 supplied 22.4 TWh of electricity, compared with 22.9 TWh in 2019 which was the highest production ever in the country. The nuclear share represented 33.9 percent of the nation's electricity in 2020, compared to 34.7 percent in 2019, and a peak of 38.4 percent in 1986.

Finland's fifth reactor, the 1.6 GW EPR at Olkiluoto (OL3), which has been under construction since August 2005, was originally scheduled to begin operations in 2009, and as previously, during the past year has suffered further delays. In mid-2020, the schedule was for grid connection at the end of January 2021 and commercial operation by 31 May 2021, 16 years after construction start and 12 years later than originally planned.[113] These target dates were not achieved, and the plant is now scheduled to be connected to the grid in October 2021.[114]

Finland has adopted different nuclear technologies and suppliers, as two of its operating reactors are modified VVER-V213 built by Russian contractors at Loviisa, while two are AAIII, BWR-2500 built by Asea Brown Boveri (ABB) at Olkiluoto. The OL3 EPR contractor is AREVA. The average age of the four operating reactors is 42.3 years. In January 2017, operator TVO (Teollisuuden Voima Oyj) filed an application for a 20-year license extension for Olkiluoto-1 and -2 (OL1, OL2), which were connected to the grid in 1978 and 1980 respectively.[115] On

109 - China Electricity Council, "2020 electricity & other energy statistics (preliminary)", *China Energy Portal*, 22 January 2021 (in Chinese and English), see https://chinaenergyportal.org/2020-electricity-other-energy-statistics-preliminary/, accessed 5 May 2021.

110 - Lauri Myllyvirta, "A New Coal Boom in China—New Coal Plant Permitting and Proposals Accelerate", Briefing, Centre for Research on Energy and Clean Air, June 2020, see https://energyandcleanair.org/publications/coal-power-projects-accelerate-after-covid-19-lockdown-a-new-coal-boom-in-china/, accessed 7 May 2021.

111 - China Electricity Council, "2020 Electricity & Other Energy Statistics (Preliminary)", Chine Energy Portal, January 2021, op. cit.

112 - Ibidem.

113 - Roger Fry, "TVO reporte le démarrage d'Olkiluoto 3 (1,6 GW) à mai 2021", *Montel*, 2 July 2020 (in French), see https://www.montelnews.com/fr/story/tvo-reporte-le-dmarrage-dolkiluoto-3-16-gw-%C3%A0-mai-2021/1128407, accessed 13 July 2021.

114 - TVO, "The terms of the OL3 EPR project completion have been agreed", 17 May 2020, see https://www.tvo.fi/en/index/news/pressreleasesstockexchangereleases/2021/thetermsoftheol3eprprojectcompletionhavebeenagreed.html, accessed 13 July 2021.

115 - TVO, "New operating license applied for Olkiluoto 1 and 2 plant units", Press Release, 26 January 2017, see https://www.tvo.fi/en/index/news/pressreleasesstockexchangereleases/2017/hNRykwgEO.html, accessed 13 July 2021.

20 September 2018, the Cabinet approved the lifetime extension for both units to operate until 2038.[116]

A "severe abnormal event" occurred at the OL2 reactor on 10 December 2020, that led to reactor shut down.[117] What the Finnish radiation and nuclear safety regulator Säteilyturvakeskus (STUK) called an exceptional safety event, with a rise in radiation levels inside the containment, caused a full-scale emergency response at STUK and at Olkiluoto. As of mid-2021, the situation was stable and the unit in a safe state. TVO and STUK reported that there was no radioactive release to the environment.[118] The event cause was confirmed on 11 December 2020 due to a fault in the purification system in the primary circuit when filter material caused a temporary rise of the radiation levels in the circuit. According to STUK there was no nuclear fuel damage.[119]

In March 2014, Russian state nuclear operator Rosatom, through subsidiary company RAOS Voima Oy, completed the purchase of 34 percent of the Finnish company Fennovoima for an undisclosed price,[120] and then in April 2014 a "binding decision to construct" a 1200 MW AES-2006 reactor was announced. A construction license for the reactor was expected in 2021[121] and construction was to begin in the same year, with operation of the plant currently scheduled for 2028. Progress was made during the past year according to Fennovoima, in particular its near completion of the safety review, however, there have been revisions to the construction start and completion dates.

In April 2021, Fennovoima reported that it had moved significantly towards being granted a construction license by the end of 2021.[122] However, three weeks later it reported that it was now aiming for a license in summer 2022. In its updated application to STUK for a construction license on 28 April 2021, it reported construction start now scheduled for 2023, and commercial operation by 2029.[123] Construction of Hanhikivi-1 is now ten years behind the original schedule.[124] Estimated costs for the project have increased from €6.5–7 billion (US$7.7-8.3 billion) to €7–7.5 billion (US$8.3–8.8 billion).[125] The construction contract with

116 - TVO, "Finnish Government Approves Extension Of Operating Licences For OL1 And OL2 Plant Units", Press Release, 20 September 2018, see https://www.tvo.fi/en/index/news/pressreleasesstockexchangereleases/2018/h7tODvf1I.html, accessed 13 July 2021.

117 - STUK, "The abnormal operational occurrence at Olkiluoto nuclear power plant – the unit is stable", 10 December 2020, see https://www.stuk.fi/web/en/-/the-abnormal-operational-occurrence-at-olkiluoto-nuclear-power-plant-the-unit-is-stable, accessed 13 July 2021.

118 - STUK, "The unit 2 at Olkiluoto will be shut down to a cold state so that the cause of the fault can be determined - the situation is stable", 10 December 2020, see https://www.stuk.fi/web/en/-/the-unit-2-at-olkiluoto-will-be-shut-down-to-a-cold-state-so-that-the-cause-of-the-fault-can-be-determined-the-situation-is-stable, accessed 13 July 2021.

119 - STUK, "The event at Olkiluoto nuclear power plant yesterday caused no threat to the safety of people or environment", 11 December 2020, see https://www.stuk.fi/web/en/-/the-event-at-olkiluoto-nuclear-power-plant-yesterday-caused-no-threat-to-the-safety-of-people-or-environment, accessed 13 July 2021.

120 - Fennovoima, "Rosatom acquired 34% of Fennovoima", Press Release, 27 March 2014.

121 - *WNN*, "Fennovoima changes spur progress with Hanhikivi project", 25 March 2020, see https://world-nuclear-news.org/Articles/Hanhikivi-project-progresses-following-Fennovoima, accessed 13 July 2021.

122 - Fennovoima, "Fennovoima's year 2020", 7 April 2021, see https://www.fennovoima.fi/sites/default/files/media/documents/Fennovoimas_Year_2020_report.pdf, accessed 13 July 2021.

123 - Fennovoima, "Fennovoima updates the Construction License Application", Press Release, 28 April 2021, see https://www.fennovoima.fi/en/press-releases/fennovoima-updates-construction-license-application, accessed 13 July 2021.

124 - *NEI*, "Fennovoima issues progress report on Hanhikivi" 26 March 2020, see https://www.neimagazine.com/news/newsfennovoima-issues-progress-report-on-hanhikivi-7839412, accessed 13 July 2021.

125 - Fennovoima, "Fennovoima updates the Construction License Application", 28 April 2021, op. cit.

RAOS Project Oy is a fixed-priced contract, so costs are due to expenses from Fennovoima's own operations. A Review by STUK of the licensing documentation to be submitted as part of the Preliminary Safety Analysis Report for the reactor is underway but has experienced further delays.[126]

Olkiluoto-3 (OL3)

In December 2003, Finland became the first country in Western Europe to order a new nuclear reactor since 1988. AREVA NP, then a joint venture owned 66 percent by AREVA and 34 percent by Siemens, was contracted to build the European Pressurized Reactor (EPR) at OL3 under a fixed-price, turnkey contract with the utility TVO. Siemens quit the consortium in March 2011 and announced in September 2011 that it was abandoning the nuclear sector entirely.[127] After the 2015 technical bankruptcy of the AREVA Group, in which the cost overruns of Olkiluoto had played a large part, the majority shareholder, the French Government, decided to integrate the reactor-building division under "new-old name" Framatome into a subsidiary majority-owned by state utility EDF.

However, EDF made it clear that it would not take over the billions of euros' liabilities linked to the costly Finnish AREVA adventure.[128] Thus, it was decided that the financial liability for OL3 and associated risks stay with AREVA S.A. after the sale of AREVA NP and the creation of a new company AREVA Holding, now named Orano, that will focus on nuclear fuel and waste management services, very similar to the old COGEMA. In July 2017, the French Government confirmed that it had completed its €2 billion (US$$_{2018}$2.3 billion) capital increase,[129] most of which was to cover the costs to AREVA of the OL3 investment.

The OL3 project was financed essentially on the balance sheets of the Finland's leading firms and heavy energy users as well as a number of municipalities under a unique arrangement that makes them liable for the plant's indefinite capital costs for an indefinite period, whether or not they get the electricity—a capex "take-or-pay contract"—in addition to the additional billions incurred by AREVA under the fixed price contract.

OL3 construction started in August 2005, with operations planned from 2009. However, that date—and other dates—passed.

From the beginning, the OL3 project was plagued with countless management and quality-control issues. Not only did it prove difficult to carry out concreting and welding to technical specifications, but the use of sub-contractors and workers from over 50 nationalities made communication and oversight extremely complex (see previous WNISR editions).

126 - STUK, "Supervision of Fennovoima's nuclear power plant project January – April 2021", 30 April 2021, see https://www.stuk.fi/stuk-valvoo/ydinturvallisuus/stukin-kolmannesvuosiraportointi/uusien-hankkeiden-valvonta, accessed 13 July 2021.

127 - *WNN*, "Siemens quits the nuclear game", 19 September 2011, see https://world-nuclear-news.org/Articles/Siemens-quits-the-nuclear-game, accessed 13 July 2021

128 - Jean-Michel Bezat, "EDF pose ses conditions au rachat des réacteurs d'Areva", *Le Monde*, 19 May 2015.

129 - Jean-Michel Belot and Richard Lough, "Areva says French state completes two billion-euro capital increase", *Reuters*, 12 July 2017, see https://www.reuters.com/article/us-arevasa-capital-idUSKBN19X2S9, accessed 13 July 2021.

After further multiple delays, TVO announced in June 2018 that grid connection was planned for May 2019 with "regular electricity generation" in September 2019.[130] In April 2019, fuel loading was pushed further to August 2019. TVO's plans for grid connection in October 2019 and electricity generation by January 2020 were considered by WNISR2019 as highly optimistic.[131]

In July 2019, TVO announced that it had once again delayed operations for OL3 by six months.[132] The startup date was moved to July 2020 by nuclear plant supplier the AREVA-Siemens Consortium. TVO announced that nuclear fuel was scheduled to be loaded into the reactor in January 2020 and the first connection to the grid was to be in April 2020. By November 2019, the revised schedule for OL3 start had slipped a further six weeks, according to TVO.[133] The delays were reported to be due to final verification of the mechanical, electrical and Instrumentation and Control (I&C) systems.

In December 2019, the AREVA-Siemens Consortium informed TVO[134] that OL3 would be connected to the grid in November 2020 with regular electricity generation from March 2021.[135] Nuclear fuel loading was planned for June 2020. The delays were reported to be due to slow progress of system tests and shortcomings in spare-part deliveries.[136] Among other things in the tests of auxiliary diesel generators some faulty components were found.[137]

On 8 April 2020, TVO announced that it had applied to the regulator STUK, for approval for fuel loading.[138] It was expected to take two months. At the same time, TVO revealed that "a significant amount of measures [were] taken to prevent the spreading of the coronavirus epidemic (COVID-19) in order to minimize the effects of pandemic risk to the project. The coronavirus pandemic may have significantly added uncertainty to the progress of the project."[139] As a consequence, fuel loading would not take place in June 2020 as planned, and "it is possible that the regular electricity production will be delayed respectively. AREVA-Siemens consortium will update the schedule for OL3 EPR unit as soon as spreading and effects of the coronavirus pandemic are known."[140]

130 - TVO, "OL3 EPR's regular electricity generation starts in September 2019", Press Release, 13 June 2018, see https://www.tvo.fi/en/index/news/pressreleasesstockexchangereleases/2018/hAZ2olOtQ.html, accessed 13 July 2021.

131 - *WNN*, "TVO starts work to resolve Olkiluoto 3 vibration issue", 23 May 2019, see https://www.world-nuclear-news.org/Articles/TVO-starts-work-to-resolve-Olkiluoto-3-vibration-i, accessed 13 July 2021.

132 - TVO, "OL3 EPR's regular electricity generation starts in July 2020", Press Release, 17 July 2019, see https://www.tvo.fi/en/index/news/pressreleasesstockexchangereleases/2019/h3BCeyaya.html, accessed 13 July 2021.

133 - TVO, "Plant supplier updates the schedule of OL3 project", Press Release, 8 November 2019, see https://www.tvo.fi/en/index/news/pressreleasesstockexchangereleases/2019/hoaOkf1fA.html, accessed 13 July 2021.

134 - *YLE*, "Olkiluoto 3 reactor delayed yet again, now 12 years behind schedule", 20 December 2019, see https://yle.fi/uutiset/osasto/news/olkiluoto_3_reactor_delayed_yet_again_now_12_years_behind_schedule/11128489, accessed 13 July 2021.

135 - TVO, "OL3 EPR's regular electricity generation starts in March 2021", Press Release, 19 December 2019, see https://www.tvo.fi/en/index/news/pressreleasesstockexchangereleases/2020/ol3eprsregularelectricitygenerationstartsinmarch2021.html, accessed 13 July 2021.

136 - Ibidem.

137 - *YLE*, "Olkiluoto 3 reactor delayed yet again, now 12 years behind schedule", 20 December 2019, see https://yle.fi/uutiset/osasto/news/olkiluoto_3_reactor_delayed_yet_again_now_12_years_behind_schedule/11128489, accessed 13 July 2021.

138 - TVO, "TVO has submitted OL3 EPR unit nuclear fuel loading permission application", Press Release, 8 April 2020, see https://www.tvo.fi/en/index/news/pressreleasesstockexchangereleases/2020/tvohassubmittedol3eprunitnuclearfuelloadingpermissionapplication.html, accessed 13 July 2021.

139 - Ibidem.

140 - Ibidem.

These delays and uncertainties prompted a revision downwards of TVO's credit rating by Standard & Poor's, with the timing and effect on OL3 commissioning "unclear" and

> with expectations (…) that this will further increase project costs and postpone TVO's deleveraging, increasing the risk that the AREVA (not rated) is unable to maintain sufficient funds for related obligations, including the two-year guarantee period. The negative outlook reflects the risk that TVO's financial flexibility could diminish as a result of weaker counterparties or additional delays that could further increase already-high financial leverage.[141]

With the delay in fuel loading, and in a further sign of potential and additional financial risks for delay in OL3 commissioning, credit rating agency Fitch revised TVO's outlook from stable to negative, and stated that, "A significant delay could be negative for TVO's cash flow as the company has to service debt related to OL3".[142] The agency noted:

> There is a risk that the settlement agreement signed with the supplier consortium (AREVA NP, AREVA GmbH, Siemens AG (A/Stable) and AREVA Group's parent AREVA SA) in March 2018 would not protect TVO from financial impacts should the start of power production be delayed beyond June 2021, because the consortium has not yet assigned a new date for the fuel loading. After this date, TVO would not be entitled to penalty payments from the supplier consortium under the settlement agreement anymore.[143]

As reported by WNISR2019 (see WNISR2019 – Finland Focus), TVO and AREVA-Siemens signed a settlement agreement in March 2018, which states that TVO would receive compensation of €450 million (US$515 million) from the supplier consortium. The settlement further includes a penalty mechanism, under which the supplier consortium pays additional penalties to TVO in case of further delays beyond 2019. However, these are capped at €400 million (US$458 million), which were reached in June 2021. With delays beyond June 2021, the agreement does not cover the financial impact on TVO. It was reported in April 2020, that AREVA was currently making arrangements in order to secure funding until the end of the project (including the guarantee period).[144]

In March 2021, fuel was finally loaded into the OL3 reactor, with grid connection announced in mid-May 2021 for October 2021.[145] By the end of July 2021, startup had already been pushed back by another month to November 2021, "due to turbine overhaul".[146]

141 - TVO, "Standard & Poor's has downgraded TVO's long term credit rating to BB", 15 April 2020, see https://www.tvo.fi/en/index/news/pressreleasesstockexchangereleases/2020/standardpoorshasdowngradedtvoslongtermcreditratingtobb.html, accessed 13 July 2021.

142 - Fitch, "Fitch Revises Teollisuuden Voima Oyj's Outlook to Negative; Affirms at 'BBB-'", 20 April 2020, see https://www.fitchratings.com/research/corporate-finance/fitch-revises-teollisuuden-voima-oyj-outlook-to-negative-affirms-at-bbb-20-04-2020, accessed 13 July 2021.

143 - Ibidem.

144 - Ibidem; and TVO, "OL3 EPR's schedule work continues", 2 July 2020, see https://www.tvo.fi/en/index/news/pressreleasesstockexchangereleases/2020/ol3eprsscheduleworkcontinues.html, accessed 13 July 2021.

145 - TVO, "The terms of the OL3 EPR project completion have been agreed", 17 May 2021, see https://www.tvo.fi/en/index/news/pressreleasesstockexchangereleases/2021/thetermsoftheol3eprprojectcompletionhavebeenagreed.html, accessed 22 August 2021.

146 - TVO, "The regular electricity production of the OL3 EPR will be postponed for a month due to turbine overhaul", 30 July 2021, see https://www.tvo.fi/en/index/news/pressreleasesstockexchangereleases/2021/theregularelectricityproductionoftheol3eprwillbepostponedforamonthduetoturbineoverhaul.html, accessed 22 August 2021.

On 17 May 2021, TVO announced that it had reached a consensus settlement agreement with the Areva–Siemens consortium.[147] Negotiations had been underway since summer 2020 on the terms of the OL3 EPR project-completion. Critical to the goal was agreement for an additional €600 million to be made available from the AREVA companies' trust mechanism as of the beginning of January 2021. Other key issues agreed included that both parties are to cover their own costs from July 2021 until end of February 2022, and that in case the consortium companies do not complete the OL3 EPR project until the end of February 2022, they would pay additional compensation for delays, depending on the date of completion. Fitch reported that it may revise TVO's outlook from negative to stable.[148]

Faulty Pressurizer Safety Relief Valves

On 9 July 2020, when yet another potentially significant delay was announced in commissioning of OL3, STUK reported that defects in the pressurizer safety relief valves had been identified.[149] The valve on which the leak was found was mechanically damaged and after further checks similar cracks were detected in two of five other valves. STUK announced that the problem was serious and should be fully investigated before proceeding with nuclear fuel loading. The Sierion valves were disassembled, removed from OL3 and returned to the German manufacturer for detailed analysis.

Pressurizer safety relief valves are F1A classified (must-not-fail) because it is necessary to reach a controlled state under Plant Condition Category (PCC) conditions. The EPR valves are required to perform vital functions in both routine and accident conditions.[150]

The safety relief valves type VS99 (Sierion) installed in OL3 were manufactured by the German company Sempell,[151] and their quality was confirmed in 2016–2017 by Erlangen Center owned by Framatome. As a result of the discovery, Sempell valves installed in the EPRs at Taishan-1 and -2 in China and Flamanville-3 in France are to be investigated. Sempell valves are also due to be installed in the Hinkley Point C EPRs. As of early July 2020, the only disclosure from TVO was that "cracks were detected in the pilot valves of the pressurizer safety relief valves".[152]

147 - *NEI*, "TVO and Areva-Siemens reach consensus on OL3", 20 May 2021, see https://www.neimagazine.com/news/newstvo-and-areva-siemens-reach-consensus-on-ol3-8757426, accessed 13 July 2021.

148 - Fitch, "Agreed Terms of OL3 Completion Reduce Negative Rating Pressure on TVO", 31 May 2021, see https://www.fitchratings.com/research/corporate-finance/agreed-terms-of-ol3-completion-reduce-negative-rating-pressure-on-tvo-21-05-2021, accessed 13 July 2021.

149 - onOZE, "Ponowne wstrzymanie budowy bloku elektrowni jadrowej Olkiluoto-3", 9 July 2020 (in Finnish), see https://onoze.pl/2020/07/09/ponowne-wstrzymanie-budowy-bloku-elektrowni-jadrowej-olkiluoto-3/, accessed 13 July 2021.

150 - UK-EPR, "Fundamental Safety Overview — Volume 2: Design and Safety — Chapter E: The Reactor Coolant System and Related Systems — Section E.4.5. Pressuriser Relief Line", 2007, see http://www.epr-reactor.co.uk/ssmod/liblocal/docs/V3/Volume%202%20-%20Design%20and%20Safety/2.E%20-%20The%20Reactor%20Coolant%20System%20and%20Related%20Systems/2.E.4/2.E.4.5%20-%20Pressuriser%20Relief%20Line%20-%20v2.pdf, accessed 13 July 2021.

151 - Emerson, "Sempell Nuclear Valves Secure leak-tight performance and 100% reliability for high pressure, high temperature applications", Sempell Nuclear Product Brochure, VCPBR-03316-EN, 2017.

152 - TVO, "TVO Newsletter—Respirator masks worn at OL3", 2 July 2020, see https://uutiset.tvo.fi/g/l/290020/0/0/2652/1012/7, accessed 13 July 2021.

In October 2020, STUK confirmed that the damage to the safety release valves had been caused by stress corrosion cracking.[153] The valves would be required to be repaired before nuclear fuel loading, and would be eventually required to be replaced.

STUK granted a fuel loading permit for the OL3 EPR on 26 March 2021.[154] It started on 27 March 2021.[155]

OL3 was considered by the nuclear industry as a showcase for next-generation reactor technology with TVO and AREVA predicting 56 months to completion. In September 2020, after confirming further delays to the operation date for OL3, the project Director, Jouni Silvennoinen, said he would not guess the total costs and losses and that in terms of the project being a failure, "We do not comment."[156]

Over a decade ago WNISR considered that the project could lead to a crisis,[157] which has turned out to be rather accurate as its total construction time to commercial operation on the current schedule of February 2022, will be 212 months or 13 years behind schedule.

153 - Leila Fernández Thévoz and Wilhelm Zakrisson, "Fissures sur les soupapes de l'EPR Olkiluoto 3 – régulateur", *Montel*, 23 October 2020 (in French), see https://www.montelnews.com/fr/news/1160611/fissures-sur-les-soupapes-de-lepr-olkiluoto-3--rgulateur, accessed 1 August 2021.

154 - STUK, "STUK: The third nuclear reactor of Olkiluoto received the fuel loading permit", Press Release, 26 March 2021, see https://www.stuk.fi/web/en/-/stuk-the-third-nuclear-reactor-of-olkiluoto-received-the-fuel-loading-permit, accessed 14 July 2021.

155 - TVO, "Teollisuuden Voima Oyj Interim Report January–March 2021", Press Release, 22 April 2021, see https://www.tvo.fi/en/index/news/pressreleasesstockexchangereleases/2021/teollisuudenvoimaoyjinterimreportjanuary-march2021.html, accessed 14 July 2021.

156 - *Iltalehti*. "OL3-ydinvoimala ei valmistu sitten millään – kyseessä täydellinen epäonnistuminen? 'Emme kommentoi'" ["Then the OL3 nuclear power plant will not be completed at all - is it a complete failure? 'We do not comment'"] 4 September 2020 (in Finnish), see https://www.iltalehti.fi/talous/a/c92d4524-8a93-4626-bda2-0d3f41d4bf8f, accessed 13 July 2021.

157 - WNISR, "The World Nuclear Industry Status Report 2009", August 2009, see https://www.worldnuclearreport.org/-2009-.html; and Steve Thomas, "The EPR in Crisis", Public Services International Research Unit, Business School, University of Greenwich, London, November 2010, see https://gala.gre.ac.uk/id/eprint/4699/3/(ITEM_4699)_THOMAS_2010-11-E-EPR.pdf, both accessed 13 July 2021.

FRANCE FOCUS

This report constitutes a Copernican moment for the energy world. From now on, we have the confirmation that moving towards 100% renewable electricity is technically possible. This is a major conceptual evolution and a revolution for our collective representation concerning our electricity mix.[158]

Barbara Pompili
Minister for the Ecological Transition
Comments on a joint IEA-RTE report
27 January 2021

Introduction

The year 2020 was particularly difficult for the French nuclear sector. The COVID-19 pandemic impacted the industry not only by reducing electricity consumption and increasing costs, but the operation of nuclear power plants was significantly impacted by the repeated reshuffling of the outage schedules. Output plunged to the lowest level in 27 years. While no reactor has been shut down explicitly due to the impact of COVID-19, nuclear power has turned out very sensitive to effects, like the need to have very large numbers of workers on-site during refueling and maintenance outages.

The credit-rating agencies did not wait for year-end and in June 2020 downgraded EDF to BBB+ (lower medium grade) notably because of "lower-than-expected availability of nuclear reactors". However, due to the "likelihood of government support", EDF is awarded three notches over its "Stand Alone Credit Profile", which is now lowered BB+ (non-investment grade or "junk"). EDF's U.K. subsidiary EDF Energy was downgraded to "junk".[159]

"Without civil nuclear no military nuclear,
without military nuclear no civil nuclear."

President Emmanuel Macron

At the end of 2020, President Emmanuel Macron visited the Creusot Forge that had been fighting for several years with a scandalous history of irregularities and falsifications in the documentation of thousands of forged pieces spanning over several decades (see Nuclear Power and Criminal Energy). He gave a symbolic speech that was meant to reinforce the unconditional support of the French state to the struggling nuclear industry, civil and military. "Our energy and ecological future", "our economic and industrial future", "the strategic

158 - André Joffre, "100% EnR, c'est possible : Barbara Pompili salue la publication du rapport de l'AIE et de RTE et évoque un moment copernicien", *Tecsol Blog*, 28 January 2021 (in French), see https://tecsol.blogs.com/mon_weblog/2021/01/100-enr-cest-possible-barbara-pompili-salue-la-publication-du-rapport-de-laie-et-de-rte-et-évoque-un.html, accessed 26 July 2021.

159 - *Standard & Poor's*, "French Utility EDF Downgraded To 'BBB+' On Prolonged Operational Weakness, Lower Output Due To COVID-19; Outlook Stable", 22 June 2020.

future of France" are all depending on the nuclear industry.[160] In brief, the quality of life, the independence, *la grandeur de la France* all depend on the nuclear sector.

The French President insisted heavily on the interdependencies between the civil and military branches of the nuclear industry:

> The sector is living of its complementarities and moreover it should be conceived in its complementarities. And it is also because of that that we need to constantly think in the long term, the capacity to preserve our technical, technological, and industrial competences on the entire sector to protect our sovereign production capacities, civil as well as military. The one is not possible without the other.[161] Without civil nuclear no military nuclear, without military nuclear no civil nuclear.[162]

The President mentioned the "Creusot Affair" only in passing, "four and a half years after these moments of doubt". However, he also stated:

> As it is very difficult to say today which, nuclear [power] or renewable energies, will be the best technology to replace our existing nuclear fleet in 2035, we therefore need to look at the entire range of possibilities. (…) First, we need to study the technical feasibility of an electricity mix with a very high level of renewables. A report commissioned from the International Energy Agency [IEA] and RTE [Réseau de Transport d'Électricité] will be published early next year.[163]

Indeed, the joint IEA-RTE report was released in January 2021 and found "no insurmountable technical barriers to move towards a mix with very high shares of variable renewable energy", that is 85–90 percent by 2050 and 100 percent by 2060.[164] However, the study sees four areas where additional developments seem necessary: Power system strength; adequacy and flexibility resources to cope with the variability of wind and solar PV; operational reserves; and grid development.[165]

The IEA-RTE working group is carrying out a series of follow-up assessments including a full system-cost analysis and extensive modeling of the European power sector. The work is scheduled to be completed before the end of 2021.

The conflicting signals between the affirmation of the traditional government support for the "all-nuclear" approach and the fine-tuning of an "all-renewables" feasibility analysis are likely to provide ample substance for debate well into 2022 with the first round of the presidential election scheduled for 10 April.

160 - Élysée, "Notre avenir énergétique et écologique passe par le nucléaire. Déplacement du Président Emmanuel Macron sur le site industriel de Framatome", French Government, 8 December 2020 (in French), see https://www.elysee.fr/emmanuel-macron/2020/12/08/deplacement-du-president-emmanuel-macron-sur-le-site-industriel-de-framatome, accessed 13 May 2021.

161 - French original: "L'un ne va pas sans l'autre."

162 - Élysée, "Notre avenir énergétique et écologique passe par le nucléaire. Déplacement du Président Emmanuel Macron sur le site industriel de Framatome", French Government, December 2020, op. cit.

163 - Ibidem.

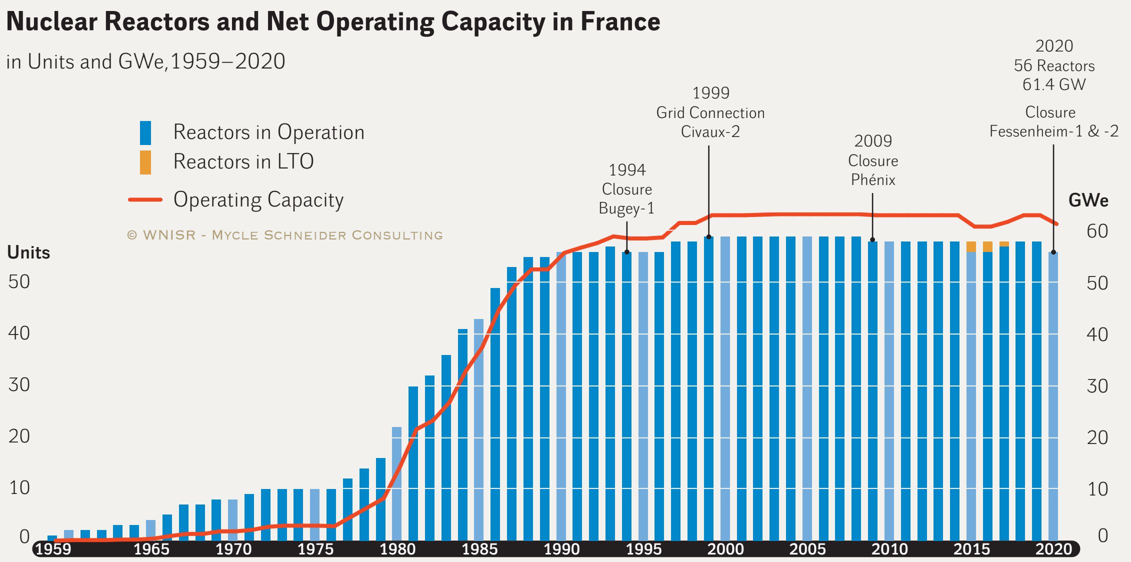
164 - RTE-IEA, "RTE and IEA publish study on the technical conditions necessary for a power system with a High Share of Renewables in France Towards 2050", Press Release, 27 January 2021, see https://www.iea.org/news/rte-and-iea-publish-study-on-the-technical-conditions-necessary-for-a-power-system-with-a-high-share-of-renewables-in-france-towards-2050, accessed 2 September 2021.

165 - RTE-IEA, "Conditions and Requirements for the Technical Feasibility of a Power System with a High Share of Renewables in France Towards 2050", January 2021.

Worst Performance in Decades

Until the closure of the two oldest French units at Fessenheim in the spring of 2020, the French nuclear fleet had remained stable for 20 years, except for the closure of the 250 MW fast breeder Phénix in 2009 and for two units in LTO within the period 2015–2017 (see Figure 21).

Figure 21 · Operating Fleet and Capacity in France



Sources: WNISR with IAEA-PRIS, 2021

No new reactor has started up since Civaux-2 was connected to the French grid in 1999. The first and only PWR closed prior to Fessenheim was the 300 MW Chooz-A reactor, which was retired in 1991. The other closures were eight first generation natural-uranium gas-graphite reactors, two fast breeder reactors and a small prototype heavy water reactor (see Figure 22).

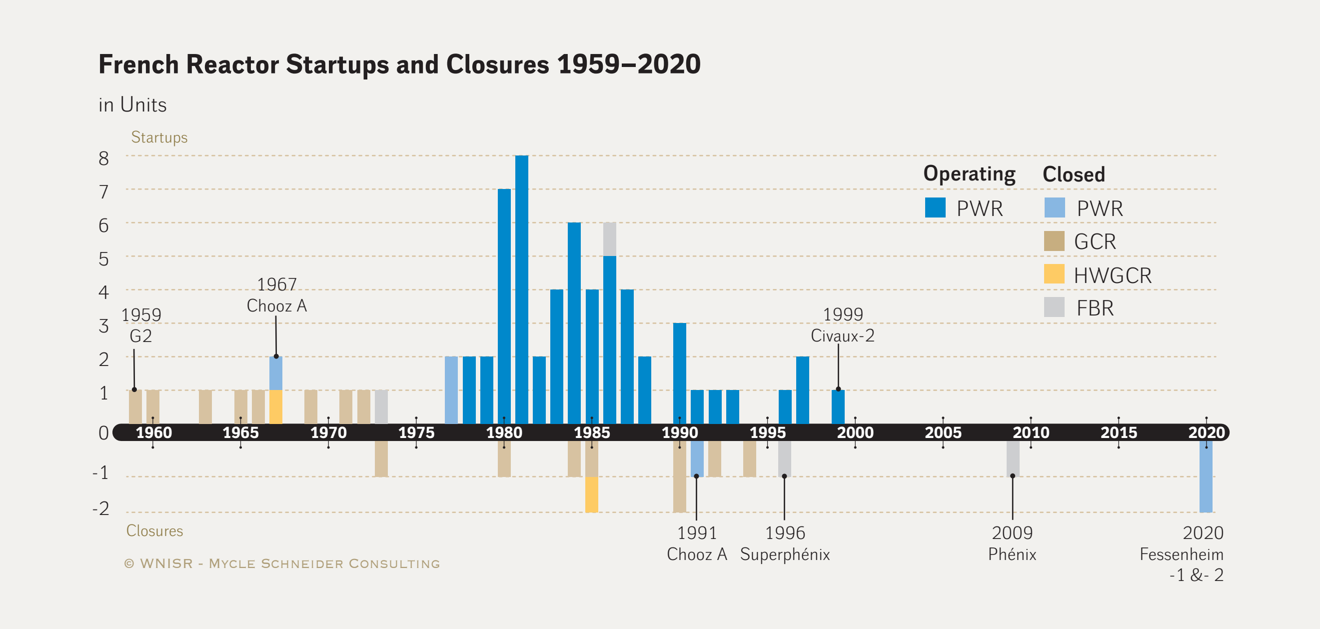
In 2020, the 58 operating reactors—including the two Fessenheim reactors closed in the first half of 2020[166]— produced 335.4 TWh, an 11.6 percent drop over the previous year.[167] The plunge of 44.1 TWh is larger than the total annual production of 21 smaller nuclear power generating countries, including Japan, or larger than the annual generation of two thirds of all nuclear countries. It is the fifth year in a row that generation remained below 400 TWh, partially due to the COVID-19 crisis in 2020. In 2005, nuclear generation peaked at 431.2 TWh.

Nuclear plants provided 67.1 percent of the country's electricity, 3.5 percentage points less than in 2019, the lowest share since 1985. According to RTE, the share peaked in 2005 at 78.3 percent (see Figure 23).

166 - All Pressurized Water Reactors (PWRs), 34 x 900 MW, 20 x 1300 MW, and 4 x 1400 MW.

167 - RTE, "Bilan Électrique 2020", Réseau de Transport d'Électricité, January 2021, see https://assets.rte-france.com/prod/public/2021-03/Bilan%20electrique%202020_0.pdf, accessed 2 September 2021.

Figure 22 · Startups and Closures in France

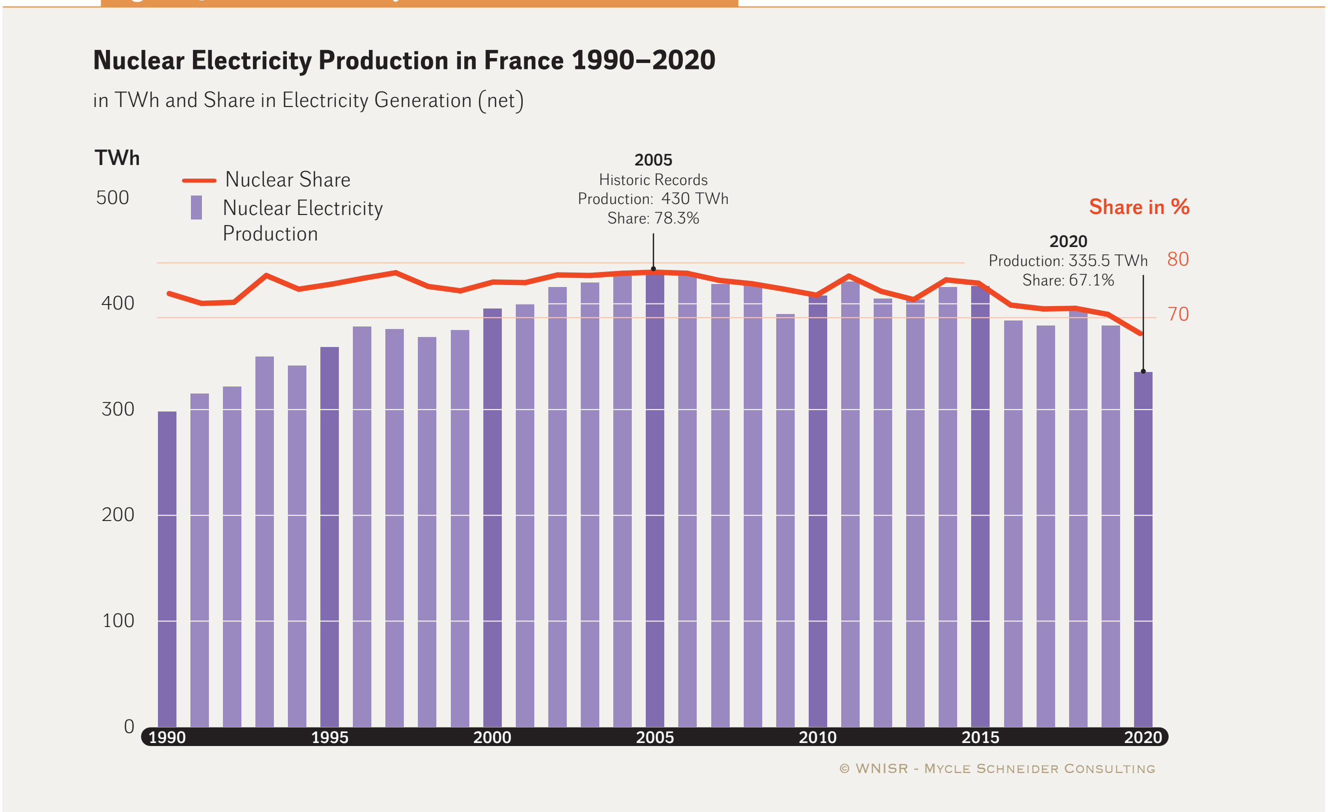


Sources: WNISR, with IAEA-PRIS, 2021

Notes:

PWR: Pressurized Water Reactor; GCR: Gas-Cooled Reactor; HWGCR: Heavy Water Gas Cooled Reactor; FBR: Fast Breeder Reactor.

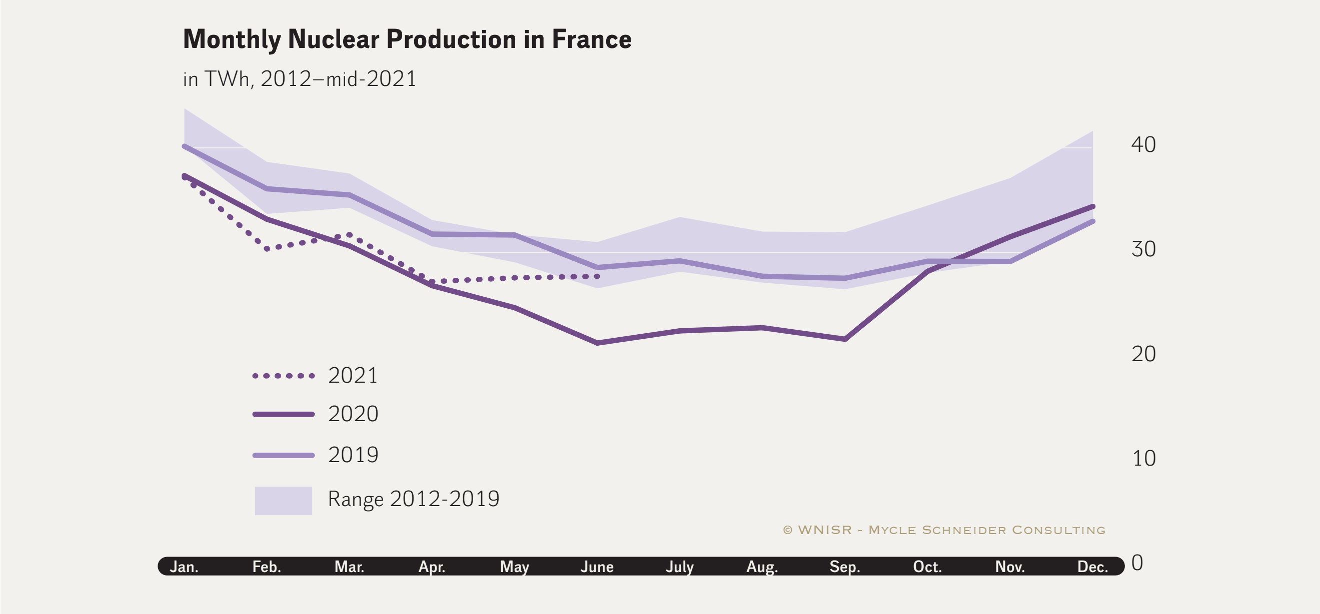
Figure 23 · Nuclear Electricity Production in France 1990–2020



Sources: RTE, 2000–2021

In the first half of 2021, nuclear production recovered to some degree but remained below the 2019-level and at the lower end of the 2012–2019 range (see Figure 24).

Figure 24 · Startups and Closures in France



Source: RTE, "Données Mensuelles", 2021

Nuclear plants provided 17 percent of final energy in France in 2020, with the largest share being covered by fossil fuels with 63 percent.

According to operator EDF, the negative impact relating to Covid-19 on 2020 generation is estimated to be approximately 33 TWh. In addition to the effects of the health crisis, the drop in power generation is due to the shutdown of the two Fessenheim reactors as well as:

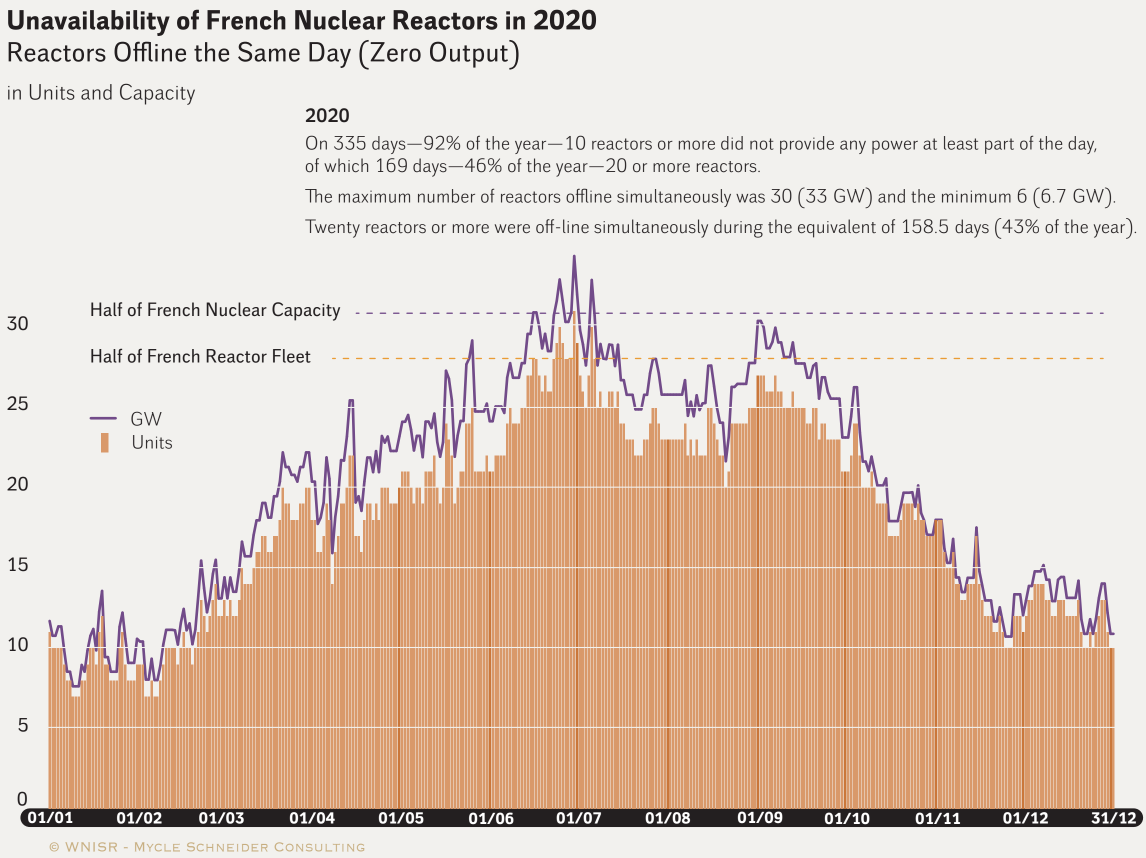
- The shutdown of Flamanville-2 (ten-year inspection) and Paluel-2 (Simple Reload Shutdown – SRS) which continued throughout the 2020 campaign, due to major technical issues. The end of 2020 and the beginning of 2021 saw the return of these two units to the grid.
- A significant technical complication on a shared radioactive effluent collection tank for Bugey-2 and -3, resulting in the extension of the ten-year inspection of Bugey-2 and the shutdown of Unit 3 (as well as the extension of its SRS);
- Exceptional incidents and large-scale contingencies (Flamanville-1 diesel – 10 TWh, Cattenom-1 power transmission station – 1.1 TWh):
- In addition, production losses were suffered at the Chooz power plant due to the low water levels in the river Meuse.[168]

168 - EDF, "Universal Registration Document 2020—Annual Financial Report", filed 15 March 2021, see https://www.edf.fr/en/the-edf-group/dedicated-sections/investors-shareholders/reference-documents, accessed 26 July 2021.

Nuclear Unavailability Review 2020

In 2020, the total duration of zero output of the French reactor fleet reached 6,465 reactor-days (up 885 days or 16 percent from the 5,580 reactor-days in 2019, following a 500-day or 10 percent increase in 2019 over 2018), an average of 115.5 days per reactor (up 19.3 days over 2019) or an outage ratio of about one third of the time, not including load following or other operational situations with reduced but above-zero output e.g. as a consequence of heat and drought. All 56 reactors were subject to outages ranging from 5–356 days (see Figure 25 and Figure 26).

Figure 25 · Reactor Outages in France in 2020 (in number of units and GWe)



Sources: RTE, compiled by WNISR, 2021[169]

Note: For each day in the year, this graph shows the total number of reactors offline, not necessarily simultaneously as all unavailabilities do not overlap, but on the same day. The two Fessenheim reactors closed in the first half of the year are not represented.

The unavailability analysis further shows[170]:

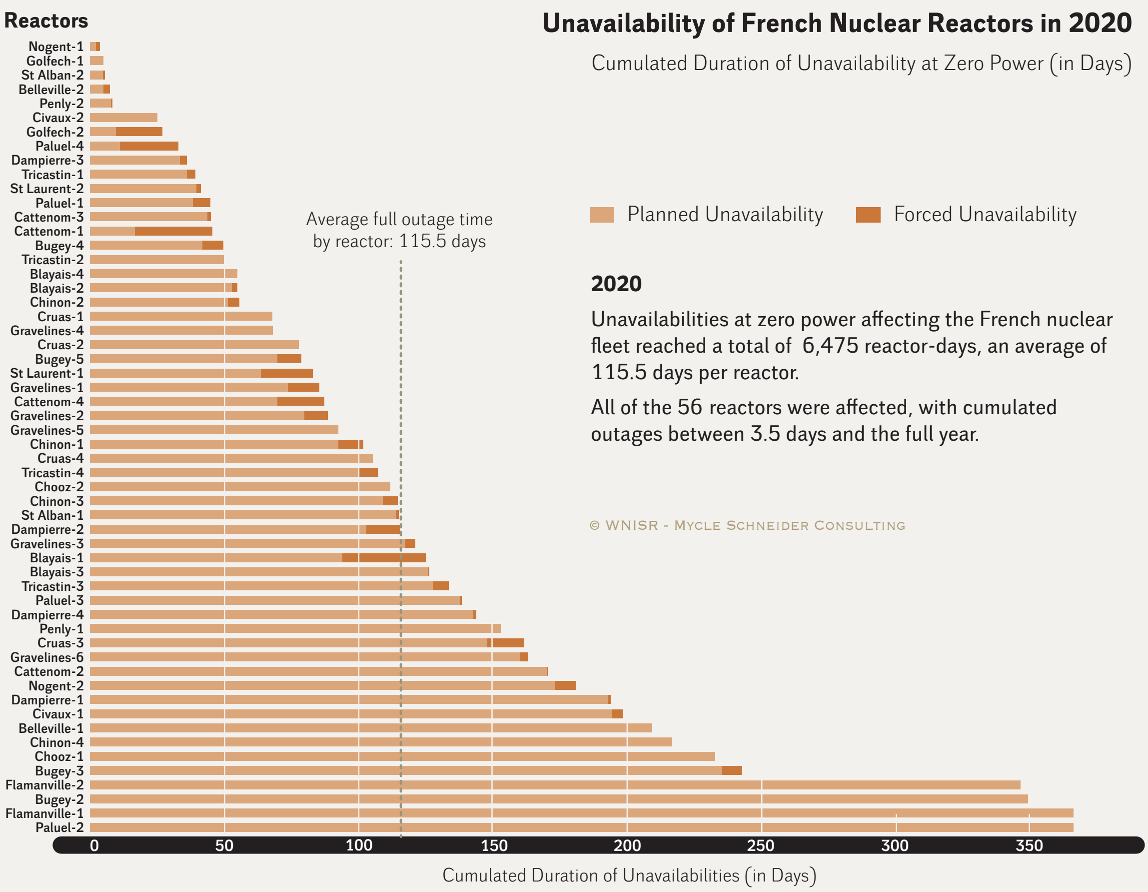
- On 13 days (4 percent of the year), 28 or more (30–34.4 GW) of the 56 units were down for at least part of the day.

169 - RTE, "Données des Indisponibilités de Production 2020", as of February 2021, see https://www.services-rte.com/en/download-data-published-by-rte.html?category=generation&type=unavailabilities.

170 - Note that the two Fessenheim reactors are not included in this analysis (unless explicitly mentioned), nor in the graphics.

- On 169 days (46 percent of the year, up from 26 percent in 2019), 20 or more units were shut down for at least part of the day.
- On 335 days (92 percent of the year, up from 83 percent in 2019), at least 10 units were down during the same day.
- At least six reactors (6.7 GW) were down (zero capacity) simultaneously at any day of the year.
- At least twenty reactors were offline simultaneously during the equivalent of 158.5 days.

Figure 26 · Forced and Planned Unavailability of Nuclear Reactors in France in 2020



Sources: compiled by WNISR, with RTE Data, EDF, "List of outages", 2020–2021

Notes:

This graph only compiles outages at zero power, thus excluding all other operational periods with reduced capacity >0 MW. Impact of unavailabilities on power production is therefore significantly larger.

"Planned" and "Forced" unavailabilities as declared by EDF.

The two Fessenheim reactors closed in the first half of the year are not represented.

EDF's declaration of "planned" vs. "forced" outages is grossly misleading. According to that classification, in 2020, 15 reactors did not have any "forced" outage, at eight units they lasted less than one day, and at 24 between one and ten days, just nine reactors fall in the range between 11 and 31 days of "forced" outage.

EDF considers an outage as planned whatever the number of extensions or its duration. In fact, WNISR analysis shows that in 2019 only one unit (Dampierre-3) restarted as planned after a long outage of 82 days. All other outages were extended beyond the original grid-reconnection dates. The unplanned delays ranged from 1.3 to 175 days. The additional unavailability added up to 1,705 days, an increase of 44 percent over the expected outage duration.

The Flamanville site was the worst performer. The two units finally restarted on 12 December 2020 (FL2) and 3 May 2021 (FL1), after 702-day and 593-day outages. Throughout the shutdown, EDF has labeled the outage for both units as "planned", a policy that does not help the public and decision-makers understand the real nature of plant management and performance by the largest nuclear operator in the world.

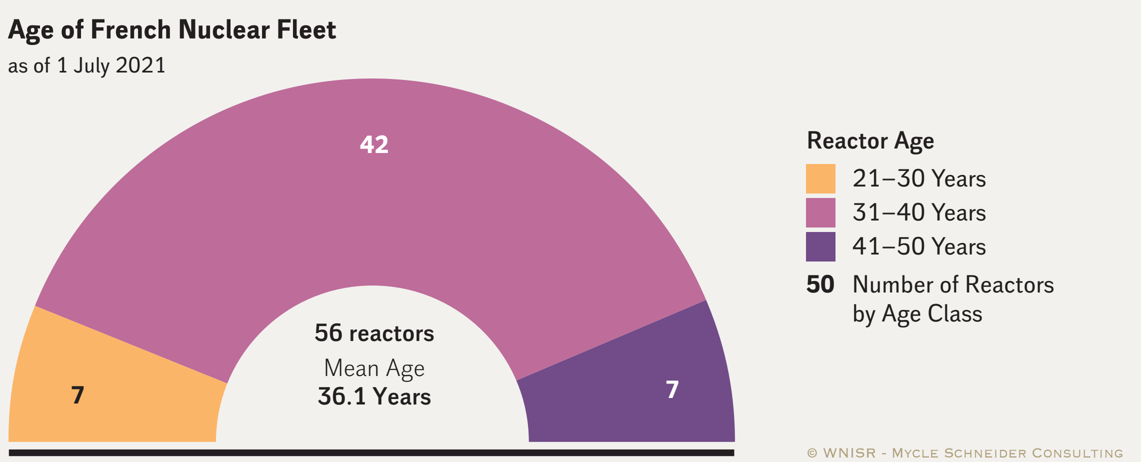
According to EDF, the outage schedule for the 2020 campaign "suffered significant upheaval due to the health crisis, requiring major adjustments to the work programmes, and causing disruption to preparation".[171] In particular:

> Some shutdowns were extended by more than 50 days, notably the partial inspections at Cattenom-2, Civaux-1, Cruas-3, Blayais-3, and Gravelines-6, and the ten-year inspection at Chinon-B4. These shutdowns, some of which began during the first lockdown, met with significant complications.[172]

Lifetime Extension, ASN's Conditional Generic Approval

By mid-2021, the average age of the 56 power reactors exceeds 36 years (see Figure 27). Lifetime extension beyond 40 years—49 operating units are now over 31 years old—requires significant additional upgrades. Also, relicensing will be subject to public enquiries reactor by reactor.

Figure 27 · Age Distribution of French Nuclear Fleet (by Decade)



Sources: WNISR, with IAEA-PRIS, 2021

171 - EDF, "Universal Registration Document 2020— Annual Financial Report", op. cit.

172 - For a diesel generator at Cattenom-2, on an ASG pump (steam generator auxiliary power supply] at Civaux-1, and on an RRA exchanger (shutdown cooling circuit) at Chinon-B4.

Operating costs have increased substantially over the past few years (see also previous WNISR editions). Outages that systematically exceed planned timeframes are particularly costly. EDF's net financial debt increased by €8 billion (US$9 billion) in 2019 and grew by another €1.2 billion (US$1.4 billion) in 2020 to a total of €42.3 billion (US$50 billion).[173]

Until 2022, the COVID-19 effects might add a total of €5–10 billion (US$6–12 billion) to the company's debt burden and increase the pressure for further cost savings.[174]

Investments for lifetime extensions will need to be balanced against the excessive nuclear share in the power mix, the stagnating or decreasing electricity consumption in France—it has been roughly stable for the past decade—and in the European Union (EU) as a whole, the shrinking client base due to successful competitors, and the energy efficiency and renewable energy production targets set at both the EU and the French levels.

EDF has been losing 100,000–200,000 clients *per month* for several years. As of the end of 2020, EDF's competitors had captured half of the commercial customers and 26 percent of the residential clients.[175] On 1 January 2021, EDF lost 300,000 non-residential customers in one go when the regulated tariffs for small commercial users were abolished.[176]

At the beginning of 2018, EDF claimed its power generating costs for existing reactors would be €32/MWh (US$38/MWh)—including nuclear operating and maintenance costs (€22/MWh or $US\$_{2018}$26/MWh including fuel at €5/MWh – $US\$_{2018}$6/MWh) and all anticipated upgrading costs for plant life extension to 50 years (10 €/MWh or $US\$_{2018}$12/MWh)—and would remain more economic than "any new alternative".[177]

However, there are serious questions about these numbers. Michèle Pappalardo, former senior representative of the Court of Accounts, remarked during the National Assembly's Inquiry-Committee hearings that EDF's calculation stopped mid-way in 2025, and recalled that the Court had calculated a total cost of €100 billion (US$117 billion) for the period 2014–2030.[178] That figure has been confirmed by EDF in the meantime.[179]

However, these estimates were based on the situation in early 2018, but EDF's performance in 2018–20 significantly deteriorated with unprecedented outage extensions, thus low production levels in a low-price, low-consumption market environment, which had not been factored into the 2018-cost calculations. The COVID-19 crisis led to a further deterioration of the situation and will have repercussions at least into 2022.

173 - EDF, "Consolidated Financial Statements at 31 December 2020", 13 April 2021, see https://www.edf.fr/sites/default/files/contrib/groupe-edf/espaces-dedies/espace-finance-en/financial-information/publications/financial-results/2020-annual-results/pdf/annual-results-2020-consolidated-financial-statements-20210218.pdf, accessed 26 July 2021.

174 - *Le Monde*, "'Mimosa', le nouveau plan d'économies d'EDF", 7 July 2020.

175 - CRE, "Les marchés de détail de l'électricité et du gaz naturel — Observatoire, 4E Trimestre 2020 (Données au 31/12/2020)", French Energy Regulatory Commission, March 2021 (in French), see https://www.cre.fr/Documents/Publications/Observatoire-des-marches/observatoire-des-marches-de-detail-de-l-energie-du-4eme-trimestre-2020, accessed 29 August 2021.

176 - CRE, "Délibération de la Commission de régulation de l'énergie du 18 mars 2021 portant communication sur le déroulé des échéances relatives à la fin partielle des tarifs réglementés de vente d'électricité et à la suppression des tarifs réglementés de vente de gaz naturel", Délibération 2021-84, French Energy Regulatory Commission, 18 March 2021.

177 - EDF, "Le parc nucléaire en exploitation en France : Exploitation, maintenance et Grand Carénage", 11 January 2018.

178 - Barbara Pompili, "Rapport d'enquête sur la sûreté et la sécurité des installations nucléaires—N° 1122 tome II", 28 June 2018 (in French), see http://www.assemblee-nationale.fr/15/rap-enq/r1122-tII.asp, accessed 19 July 2018.

179 - EDF, "Consolidated Financial Statements at 31 December 2020", op. cit.

EDF will likely seek lifetime extension beyond the 4th Decennial Safety Review (VD4) for most, if not all, of its remaining reactors. This is in line with the Government's pluriannual energy plan, which does not envisage any further reactor closures until 2023 (after the presidential elections) and only a limited number in the following years. This program will be limited to 900 MWe reactors, the oldest segment of the French nuclear fleet. The first reactor to undergo the VD4 was Tricastin-1 in 2019. Bugey-2 and -4 were scheduled in 2020, and Tricastin-2, Dampierre-1, Bugey-5 and Gravelines-1 in 2021… until the COVID-19 pandemic further disrupted the safety review schedule.

While the President of the Nuclear Safety Authority (ASN) judged the VD4-premiere on Tricastin-1 "satisfactory", he questioned whether EDF's engineering resources were sufficient to carry out similar extensive reviews simultaneously at several sites.[180] Beyond the human resource issue, the experience raises the question of affordability. EDF had scheduled an outage for Tricastin-1 of 180 days in 2019, which was extended by 25 days. Including further, unrelated unavailabilities, the reactor was in full outage during two thirds of the year (232 days).

EDF expects these VD4 outages to last six months, much longer than the average of three to four months experienced through VD2 and VD3 outages. However, as illustrated, many factors could lead to significantly longer outages. EDF, in fact, has already started negotiating with ASN for the workload to be split in two packages, with the supposedly smaller second one to be postponed four years after the VD4.[181]

On 23 February 2021, the ASN issued detailed generic requirements for plant life extension. Originally, these requirements were to be issued in 2016 but their release has been postponed several times, due to the need for extended and often unprecedented technical discussions. The general objective of ASN has been to bring the reactors "as close as possible" to the safety level required in new reactor designs, such as the EPR under construction in Flamanville. ASN notes in its 2019-Annual Report:

> The safety reassessment of these reactors and the resulting improvements must be carried out by comparison with the new-generation reactors, such as the EPR, the design of which meets significantly reinforced safety requirements.[182]

This is strikingly different from most other countries, where safety authorities merely request to maintain a given safety level. Accordingly, the key aspects of ASN's February 2021 decision were not the five short administrative articles but the two annexes setting the technical conditions and the timetable for work to be carried out. The challenge for operator EDF will be high, as ASN outlines:

180 - Bernard Doroszsuk, "Présentation du rapport annuel 2019 de l'Autorité de sûreté nucléaire (ASN) sur l'état de la sûreté nucléaire et de la radioprotection en France", ASN, Hearing before The Parliamentary Office for Scientific and Technological Assessment, French National Assembly, 28 May 2020, see http://videos.senat.fr/video.1628244_5ecf547f8a96f.audition-pleniere---autorite-de-surete-nucleaire?timecode=2963962, accessed 13 August 2020.

181 - ASN, "Réexamen périodique associé aux quatrièmes visites décennales des réacteurs du palier 900 MWe", Presentation at a meeting of the local information committee on the major energy facilities at Tricastin, Commission locale d'information des grands équipements énergétiques du Tricastin (CLIGEET), 4 July 2018 (in French), see https://www.ladrome.fr/sites/default/files/5.2_presentation_asn_vd4.pdf, accessed 23 March 2019.

182 - ASN, "ASN Report on the state of nuclear safety and radiation protection in France in 2019", 15 July 2020, see http://www.french-nuclear-safety.fr/Information/Publications/ASN-s-annual-reports/ASN-Report-on-the-state-of-nuclear-safety-and-radiation-protection-in-France-in-2019, accessed 17 August 2020.

> Over the coming five years, the nuclear sector will have to cope with a significant increase in the volume of work that is absolutely essential to ensuring the safety of the facilities in operation.
>
> Starting in 2021, four to five of EDF's 900 Megawatts electric (MWe) reactors will undergo major work as a result of their fourth ten-yearly outages. (...)
>
> All of this work will significantly increase the industrial workload of the sector, with particular attention required in certain segments that are under strain, such as mechanical and engineering, at both the licensees and the contractors.[183]

ASN has shown remarkable tolerance for extended timescales of refurbishments and upgrades in the past, e.g. many of the post-Fukushima measures have not yet been implemented. According to information provided by ASN to Greenpeace France on 3 March 2021 following a detailed questionnaire sent to ASN on 16 December 2020, none of the 56 French reactors were backfitted entirely according to ASN requests issued in 2012. Completion of the work program could take until 2039.[184]

And the implementation of work to be carried out as part of the lifetime extension beyond 40 years stretches over 15 years until 2036, when the last 900 MW reactor is supposed to be upgraded: Chinon B-4, connected to the grid in 1987, gets the 15-year delay to implement 15 of a total of 37 measures. The unit will have operated then for 49 years. This is not an exception; it is just the most recent operating 900 MW reactor. ASN has accepted similar timescales for all 32 of the 900 MW units. The French Nuclear Safety Authorities are flexible.

The Flamanville-3 EPR Saga Continued

The 2005 construction decision of Flamanville-3 (FL3) was mainly motivated by the industry's attempt to confront the serious problem of maintaining nuclear competence. Fifteen years later, ASN still drew attention to the "need to reinforce skills, professional rigorousness and quality within the nuclear sector".[185]

In December 2007, EDF started construction on FL3 with a scheduled startup date of 2012. The project has been plagued with design issues and quality-control problems, including basic concrete and welding difficulties similar to those at the Olkiluoto (OL3) project in Finland, which started construction two-and-a-half years earlier. These problems never stopped. In April 2018, it was discovered that the main welds in the secondary steam system did not conform with the technical specifications; so by the end of May 2018 EDF stated that repair

183 - ASN, "Abstracts ASN Report on the state of nuclear safety and radiation protection in France in 2020", May 2021, see http://www.french-nuclear-safety.fr/Information/Publications/ASN-s-annual-reports/ASN-Report-on-the-state-of-nuclear-safety-and-radiation-protection-in-France-in-2020, accessed 27 July 2021.

184 - Institute négaWatt, "Sûreté nucléaire – Les mesures de renforcement du parc nucléaire français, dix ans après la catastrophe de Fukushima", Report commissioned by Greenpeace France, March 2021, see https://cdn.greenpeace.fr/site/uploads/2021/03/Greenpeace-France-Les-mesures-de-renforcement-du-parc-nucl%C3%A9aire-fran%C3%A7ais-10-ans-apr%C3%A8s-Fukushima-Dossier-de-presse-mars-2021-1.pdf, accessed 23 August 2021.

185 - Ibidem.

work might again cause "a delay of several months to the start-up of the Flamanville 3 European Pressurized Water Reactor (EPR) reactor."[186]

In July 2020, EDF had stated that fuel loading would now be delayed to "late 2022" and construction costs re-evaluated at €12.4 billion, an increase of €1.5 billion over the previous estimate.[187] In addition to the overnight construction costs, as of December 2019, EDF indicated more than €4.2 billion ($US\$_{2019}$4.6 billion) was needed for various cost items, including €3 billion ($US\$_{2019}$3.3 billion) of financial costs. By 1 July 2023, the latest provisional date for the startup of the reactor, these additional costs could reach $€_{2015}$6.7 billion ($US\$_{2015}$7.4 billion). The latest construction cost estimate given by EDF of $€_{2015}$12.4 billion would represent about two thirds of the total thus estimated by the French Court of Accounts at $€_{2015}$19.1 billion ($US\$_{2020}$20 billion).[188]

On the basis of the updated cost estimates, the Court states that FL-3 electricity could possibly be generated at $€_{2015}$110–120/MWh (US$137–149/MWh).

All of these numbers do not take into account the COVID-19 effect, and EDF warned that the construction interruption at the Flamanville EPR "could result in further delays and additional costs".[189]

That is in addition to new technical issues. ASN notes in its 2020 Annual Report:

> The inspection of the EPR equipment has already revealed numerous deviations from the required level of quality. ASN therefore asked EDF to perform a quality review of the Flamanville EPR reactor equipment. With regard to the secondary circuits (main steam lines and steam generator feedwater lines), more than a hundred welds are concerned by deviations. (…)
>
> ASN is particularly attentive to operating experience feedback from the EPR reactors in Finland and China, which highlights certain subjects requiring specific investigation and examination. It notably concerns the stress corrosion on the pilot valves of the EPR reactor at Olkiluoto (Finland), as well as the anomalies on the power distributions in the EPR cores in Taishan (China).[190]

In March 2021, EDF notified ASN of a new problem. Back in 2006, EDF and Framatome changed the design of three nozzles—connections between pipes—and increased the diameter of the weld connecting the pieces, which are part of the primary circuit. ASN reports: "At the time, they did not identify the fact that the break size to be considered in the event of rupture of this weld now exceeded that considered in the safety studies."[191] EDF only detected this in 2013, but apparently did not communicate it to ASN, and, instead, "decided to process this anomaly by extending to these welds the break preclusion approach applied to the main primary system

186 - EDF, "Quality deviations on certain welds of the secondary circuit at the Flamanville EPR: the investigation continues", 31 May 2018, see https://www.edf.fr/en/the-edf-group/dedicated-sections/journalists/all-press-releases/quality-deviations-on-certain-welds-of-the-secondary-circuit-at-the-flamanville-epr-the-investigation-continues, accessed 7 June 2018.

187 - EDF, "Annual Financial Report 2019 – Universal Registration Document", March 2020, op. cit.

188 - Cour des Comptes, "La filière EPR", 9 July 2020. See WNISR2020 for excerpts from the report.

189 - EDF, "2020 Half-Year Results", Press Release, 30 July 2020.

190 - ASN, "Abstracts ASN Report on the state of nuclear safety and radiation protection in France in 2020", op. cit.

191 - ASN, "Flamanville EPR reactor: design anomaly on three main primary system nozzles", 18 March 2021, see http://www.french-nuclear-safety.fr/Information/News-releases/Flamanville-EPR-reactor-design-anomaly-on-three-main-primary-system-nozzles, accessed 27 July 2021.

pipes". This approach consists in reinforcing design and manufacturing requirements to practically exclude a break scenario that would call for the study and mitigation strategies of potential consequences. ASN has yet to issue a position statement on this latest problem.

Independent nuclear experts Manon Besnard and Yves Marignac, both members of several ASN advisory committees, issued a briefing on the nozzle problem expressing concern that "no procedure allowed ASN, for fifteen years, to identify" the issue. The "coincidental discovery" of the problem reinforces "the picture of the systemic crisis" in nuclear safety, they write.[192]

An EPR "New Model", an "EPR2"?

Various reports over the past few years indicated that EDF is pushing for an early decision on the construction of new EPRs. The trade journal *Contexte Énergie* has consulted a leaked study evaluating four scenarios of an electricity mix in 2050. EDF's Strategy Department concludes that the three scenarios combining renewables and nuclear power would "provide a better resilience" than an all-renewable option as they would avoid "betting on the maturity of certain technologies and on the capacity to mobilize very high potentials of renewables". They would also "allow to achieve the objectives at lower cost".[193] Consequently, the EDF study pushes for a decision to engage in the construction of six EPRs as early as 2021–22, thus *prior* to the presidential elections.

The leak of EDF's conclusions appears convenient in the interest of those wishing to follow suit, as it is impossible to assess the underlying hypotheses.

The government has asked EDF to "prepare a comprehensive file with the nuclear industry by mid-2021 relating to a programme of renewal of nuclear facilities in France". Studies for a new design termed EPR NM (New Model) or EPR2 are underway. EDF has "started to prepare economic and industrial proposals based on the EPR2 technology".[194]

ASN's technical support organization IRSN (Institut de Radioprotection et de Sûreté Nucléaire) issued several critical assessments of EDF's pre-design choices. ASN had requested EDF to take into account the crash of a military plane in the design and safety studies. IRSN concluded in a note released in December 2020 that "EDF's approach stays behind ASN's request", in particular that such a "crash does not entail an accident".[195] In another analysis published in March 2021, IRSN looks at a phenomenon identified in various EPRs in operation or under construction. Excessive vibrations have been identified in pipework connected to the pressurizer. IRSN stated that manufacturer "Framatome must identify the origin of the high vibrations and bring them back to a situation comparable to the one in the operating fleet." This should not exclude the development of a new design.[196]

192 - Manon Besnard and Yves Marignac, "Problème de piquages du circuit primaire de l'EPR de Flamanville", Institut négaWatt, 18 March 2021, Reviewed 2 April 2021 (in French), see https://www.institut-negawatt.com/fichiers/autres_documents/20210402-InstitutnegaWatt-Piquages-EPR-Flamanville-V2.pdf, accessed 29 August 2021.

193 - *Contexte Énergie*, "Info Contexte - L'étude qui permet à EDF de justifier la construction de nouveaux EPR", 19 March 2021.

194 - EDF, "Annual Financial Report 2019 – Universal Registration Document", March 2020, op. cit.

195 - IRSN, "Avis IRSN N°2020-00204", Institut de Radioprotection et de Sûreté Nucléaire, 16 December 2020.

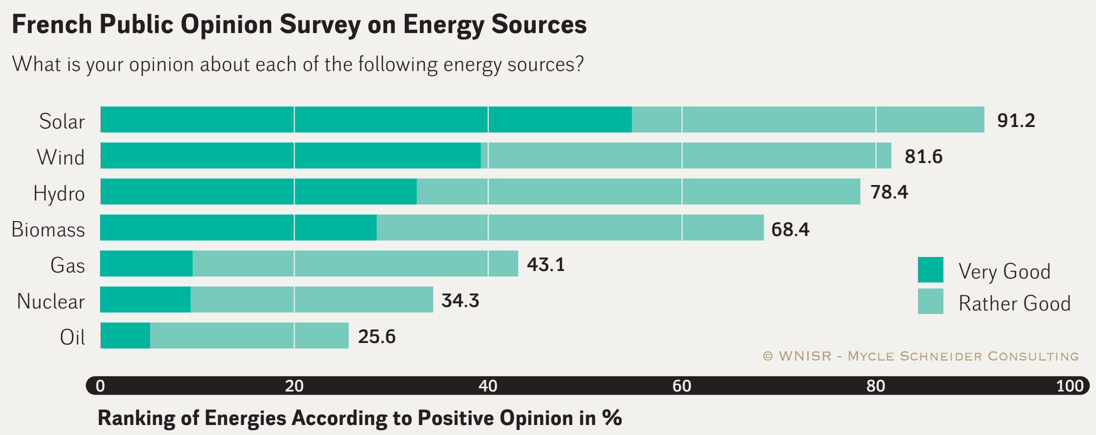
196 - IRSN, "Avis IRSN N°2021-00049", 31 March 2021.

Increasing Role for Renewables Welcome

The national grid company, RTE, stated: "The decline in nuclear production compared to 2019 was thus compensated partially by an increase in wind and solar production". While hydro contributed half of the renewable energy generation in 2020, wind power provided 33 percent, solar 11 percent, and biomass 6 percent.[197]

According to the 2020-edition of IRSN's "Opinion Barometer", nine in ten consulted citizens hold a "rather good" or "very good" opinion of solar energy and eight in ten do the same concerning wind turbines. Concerning nuclear energy, only one third express a "rather good" or "very good" opinion, but 16 percent do have a "very bad" opinion about nuclear power representing the strongest absolute rejection of any suggested energy option. (See Figure 28.)[198]

Figure 28 · Opinion Survey on Energy Sources in France (in 2020)



Sources: IRSN Barometer, 2020

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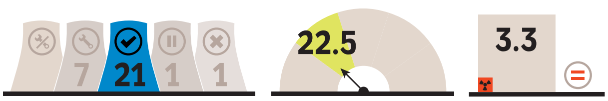

India has 21 operational nuclear power reactors, with a total net generating capacity of 6.5 GW. One unit falls under the LTO category, Madras-1, which was shut down on 30 January 2018 to carry out work on the end-shield and had not come back up as of mid-2021. The Rajasthan-1 reactor, which has not generated power since 2004, is considered permanently closed.[199] The latest of the operational reactors is the third unit of the Kakrapar power plant. The 630-MW

197 - RTE, "Bilan Électrique 2020", January 2021, op. cit.

198 - IRSN, "Baromètre 2020 – La perception des risques et de la sécurité par les français", 2020.

199 - *Deccan Herald*, "End of the road for RAPS 1", 6 September 2014, see http://www.deccanherald.com/content/429550/end-road-raps-1.html, accessed 16 June 2016

Pressurized Heavy Water Reactor (PHWR) went critical on 22 July 2020 and was connected to the grid on 10 January 2021.[200]

In addition to these operating reactors, seven more reactors, with a combined capacity of 5.2 GW, are under construction. These include one VVER-1000s at Kudankulam-5 (first pour of concrete in June 2021)[201], two more VVER-1000s at Kudankulam (under construction since June and October 2017), three PHWRs—including one at Kakrapar (since November 2010) and two at Rajasthan (since July and September 2011)—and a Prototype Fast Breeder Reactor (PFBR) that has been under construction since October 2004.

According to the IAEA's PRIS database, nuclear power contributed 40.4 TWh net of electricity in 2020, marginally less than 40.7 TWh in 2019. This represents a share of 3.1 percent of total power generation, compared to 3.2 percent in 2019. India's Central Electricity Authority (CEA) records 43.9 TWh from nuclear power for the period from April 2020 to March 2021, lower than the corresponding figure of 46.4 TWh from April 2019 to March 2020.[202]

Strong Push for Renewables

In comparison, renewable energy sources, excluding large hydropower plants, together generated 147.3 TWh during the period from April 2020 to March 2021, up from 138.3 TWh generated from April 2019 to March 2020.[203] Of the generation in 2020–2021, wind and solar energy contributed 60.1 TWh and 60.4 TWh, in comparison to 64.6 TWh and 50.1 TWh respectively in the previous year. As was the case in the year before, both wind and solar power have overtaken nuclear power in electricity generation. Together solar and wind energy generated nearly three times as much electricity as nuclear energy during the 2020-21 fiscal year.

BP's 2021 statistical review reports 44.6 TWh gross of nuclear electricity and 151.2 TWh for non-hydro renewables for the year 2020, including solar and wind energy with 58.7 TWh and 60.4 TWh respectively. This compares to 45.2 TWh from nuclear power and 139.2 TWh from non-hydro renewables for the year 2019.[204]

The divergence between the contributions from renewable energy sector and nuclear energy is expected to increase drastically in the coming years and decades. The International Energy Agency (IEA) foresees explosive growth in solar energy followed by a somewhat more modest increase in wind energy, but relatively minuscule levels of growth of nuclear power.[205] Some studies involving modelling the grid in India even suggest that wind and solar energy "could meet 80% of anticipated 2040 power demand supplanting the country's current reliance on

200 - WNISR, "Grid Connection for India's Largest Reactor at Kakrapar", World Nuclear Industry Status Report, 15 January 2021, see https://www.worldnuclearreport.org/Grid-Connection-for-India-s-Largest-Reactor-at-Kakrapar.html, accessed 2 June 2021.

201 - Construction status of Kudankulam-6 remains uncertain.

202 - CEA, "Annual Generation Programme: 2020-21", Central Electric Authority, 2021, see https://cea.nic.in/wp-content/uploads/annual_generation/2019/gen_target-2020.pdf, accessed 2 June 2021.

203 - CEA, "Monthly Renewable Energy (RE) Generation Report March 2021", May 2021, see https://cea.nic.in/wp-content/uploads/resd/2021/03/Monthly%20RE%20generaton%2021.pdf, accessed 3 June 2021.

204 - BP, "Statistical Review of World Energy 2021", July 2021, see https://www.bp.com/en/global/corporate/energy-economics/statistical-review-of-world-energy.html, accessed 12 July 2021.

205 - IEA, "India Energy Outlook 2021 – Analysis", International Energy Agency, 2021, see https://www.iea.org/reports/india-energy-outlook-2021, accessed 5 June 2021.

coal".[206] There seems to be a strong economic logic to renewables being expanded rapidly in India.

However, in 2020, there was relatively sluggish growth in installed capacity due to the COVID-19 pandemic. According to the International Renewable Energy Agency (IRENA), installed solar capacity increased by about 11 percent, from 35.1 GW in 2019 to 39.2 GW. Though still a significant increase in capacity, it is smaller than in earlier years. For comparison, installed solar capacity was only 0.6 GW in 2011. The growth in wind capacity was even more modest, and installed capacity went from 37.5 GW in 2019 to 38.6 GW in 2020 (up from 16.1 GW in 2011).[207]

Nuclear Construction Experiencing Delays

In contrast, the nuclear sector's performance over the past year has been a continuation of earlier trends, most importantly construction delays and cost overruns. Of the seven reactor projects under construction, at least four, and possibly six, are delayed. The uncertainty is with regard to units 3 and 4 of Kudankulam; although there has been no official announcement, in July 2021, *Nuclear Intelligence Weekly* (*NIW*) reported that "Units 3 and 4 were targeted for commissioning in March and November 2023, but will now be completed in September 2024 and March 2025".[208] The other units are officially delayed. The PHWR that started operating in Kakrapar was to be commissioned in 2015. The two PHWRs under construction at Rajasthan were to be commissioned in late 2016. As of March 2021, the anticipated dates of commissioning are February 2022 for Kakrapar-4, and March 2023 for Rajasthan-7 and -8.[209] In a petition to the Central Electricity Regulatory Commission, the Nuclear Power Corporation of India Limited (NPCIL) has stated that it expects Rajasthan-7 to be connected to the grid by 30 June 2022.[210]

Finally, the PFBR continues to maintain its status as the most delayed project. From the initial expectation that it will be commissioned in September 2010, the latest "anticipated" date for commissioning the PFBR is October 2022.[211] The shift from September 2010 to October 2022 was in steps, by a few months or a year at a time.[212] What has also been changing with time is the official explanations for the delays. An initial factor that the nuclear establishment blamed

206 - Tianguang Lu, Peter Sherman et al., "India's potential for integrating solar and on- and offshore wind power into its energy system", *Nature Communications*, 21 September 2020.

207 - IRENA, "Renewable Capacity Statistics 2021", International Renewable Energy Agency, March 2021, see https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2021/Apr/IRENA_RE_Capacity_Statistics_2021.pdf, accessed 4 May 2021.

208 - Rakesh Sharma "Kudankulam-5 Construction Start Marks New Milestone", *NIW*, 2 July 2021.

209 - MoSPI, "Project Implementation Status Report of Central Sector Projects Costing Rs. 150 crore & above (January-March, 2021)", Ministry of Statistics and Programme Implementation, 2021, see http://www.cspm.gov.in/english/QrtrlyReport.htm, accessed 5 June 2021.

210 - Central Electricity Regulatory Commission, "Petition No. 108/MP/2021–In the matter of Petition seeking permission to continue drawal of start-up power from the Grid as per Deviation Settlement Mechanism (DSM) till first synchronization of RAPP-7 or 30.6.2022, whichever is earlier–And in the matter of Nuclear Power Corporation of India Limited (NPCIL) Vs. Northern Regional Load Dispatch Centre", 5 June 2021, see https://cercind.gov.in/2021/orders/108-MP-2021.pdf, accessed 13 July 2021.

211 - MoSPI, "Project Implementation Status Report of Central Sector Projects Costing Rs. 150 Crore & above (January-March, 2021)", op. cit., p.26.

212 - For a partial listing of the various announcements over the years, see M. V. Ramana and Nidhi Sharma, "Problems with the Prototype Fast Breeder Reactor", *The India Forum*, 26 February 2021, see https://www.theindiaforum.in/article/problems-prototype-fast-breeder-reactor, accessed 6 March 2021.

was the December 2004 tsunami.[213] The next cause to be blamed was the Fukushima accident, followed by pointing to "increased regulatory requirements" and the need for "abundant caution".[214] In September 2019, the chairperson of Bhavini, the organization constructing the PFBR, talked about a variety of equipment failures at Bhavini's annual general meeting.[215] More recently, a former nuclear official revealed that the pumps used to circulate the molten sodium have experienced problems.[216]

One set of reasons for the delay that is not explicitly acknowledged relates to the Mixed Oxide (MOX) fuel elements necessary to manufacture the core of the PFBR.[217] There is evidence suggesting problems with either the production of adequate amounts of plutonium,[218] or the ability to use that plutonium to fabricate MOX fuel.[219]

Rising Costs

As it has become progressively delayed, the projected cost of the PFBR has also risen, from the initially anticipated Rs.34.9 billion to, first, Rs.56.8 billion, to currently Rs.68.4 billion.[220] (As of June 2021, the conversion rate to US$ is around Rs.73 per U.S. dollar. However, the PFBR costs are in mixed-year Rupees and so directly converting it into other currencies using one conversion rate is misleading.) Other projects have become more expensive too. Kakrapar-3 and -4 are now projected to cost Rs.165.8 billion, up from Rs. 114.6 billion, while Rajasthan-7 and -8 are now projected to cost Rs.170.8 billion, up from Rs.123.2 billion.[221]

Likely due to the construction cost escalation and delays, NPCIL has sought an increase in tariff for power from Kakrapar-3 and -4 extension, from Rs.3.34/kWh to Rs 5.31/kWh and the state of Gujarat, which is contractually obliged to purchase the output of about one third of the capacity of the two units, reportedly requested the central government to intervene and lower the tariff. The higher rate was particularly problematic for Gujarat because nuclear reactors have what is called "must run" status.[222]

213 - Lok Sabha, "Unstarred question no. 5326: Fast Breeder Reactors", Department of Atomic Energy, Question answered by Shri Prithviraj Chavan, Minister of State for Science & Technology and Earth Sciences (Independent Charge, PMO, Personnel, Public Grievances and Pensions and Parliamentary Affairs, Government of India, 28 April 2010, see https://dae.gov.in/writereaddata/lsus280410.pdf#page=1, accessed 5 June 2021.

214 - Lok Sabha, "Starred question No. 453: Prototype Fast Breeder Reactor", Ministry of Atomic Energy, Question Answered by Jitendra Singh, Minister of State for Personnel, Public Grievances & Pensions and Prime Minister's Office, Government of India, 5 April 2017, see http://164.100.47.194/loksabha/Questions/QResult15.aspx?qref=51719&lsno=16, accessed 1 June 2021.

215 - R. Ramachandran, "India's First Prototype Fast Breeder Reactor Has a New Deadline. Should We Trust It?", *The Wire*, 20 August 2020, see https://science.thewire.in/the-sciences/prototype-fast-breeder-reactor-dae-bhavini-npcil-liquid-sodium-coolant-purchase-orders/, accessed 5 June 2021.

216 - R. D. Kale, "India's fast reactor programme – A review and critical assessment", *Progress in Nuclear Energy*, 1 April 2020.

217 - M. V. Ramana, "Further delay in commissioning India's Prototype Fast Breeder Reactor", *IPFM Blog*, 31 July 2016, see http://fissilematerials.org/blog/2016/07/further_delay_in_commissi.html, accessed 4 March 2020.

218 - Rajya Sabha, "Unstarred Question No. 468: Availability of Plutonium for the FBR", Department of Atomic Energy, Answered by Shri V. Narayanasamy, Minister of State for Personnel, Public Grievances & Pensions and Prime Minister's Office, Government of India, 8 August 2013, see https://dae.gov.in/node/writereaddata/parl/mansoon2013/rsus468.pdf, accessed 5 June 2021.

219 - Sekhar Basu, "Founder's Day Address", BARC, Speech, 29 October 2015, see http://www.barc.gov.in/presentations/fddir15.pdf, accessed 5 June 2021.

220 - MoSPI, "Project Implementation Status Report of Central Sector Projects Costing Rs. 150 Crore & above (January-March, 2021)", op. cit.

221 - Ibidem.

222 - Maulik Pathak, "Kakrapar: Gujarat seeks lower tariff", *The Times of India*, 24 October 2019, see https://timesofindia.indiatimes.com/city/ahmedabad/kakrapar-state-seeks-lower-tariff/articleshow/71729707.cms, accessed 5 June 2021.

Construction starts have also been slow. The government has long "accorded administrative approval and financial sanction for" constructing ten 700-MW PHWRs at various sites around the country.[223] But construction is yet to begin on any of these.

In July 2020, the Chairman of India's Atomic Energy Commission announced that NPCIL planned to start construction of two new projects, Gorakhpur Haryana Anu Vidyut Pariyojana (GHAVP, 2x700 MW) in Haryana and Kudankulam Nuclear Power Project (KNPP) Units 5 and 6 (2x1,000 MW) at Kudankulam in Tamil Nadu "in the course of the year".[224] So far, first concrete has been poured only for Kudankulam-5 (and hypothetically -6). A similar promise was repeated in May 2021 by the Chairman & Managing Director of the Nuclear Power Corporation of India who said that the "first pour of concrete" for the Gorakhpur plant in the northern state of Haryana "is also planned this year".[225] In September 2020, the government did state in parliament that "work has commenced" on the GHAVP and Kudankulam-5 and -6 projects.[226] This presumably meant activities prior to first pour of concrete. Despite construction not starting so far, the government has announced in parliament that "GHAVP 1&2 is expected to commence operation in 2026/2027" with two more units at the same site coming online in 2027 and 2028.[227]

Reactor Imports Make Slow Progress

Ever since the U.S.-India nuclear deal was negotiated between 2005 and 2008, there have been plans to import reactors from the U.S. and France. Despite the clearly uneconomical nature of such projects, they are still being considered, both by NPCIL and by nuclear reactor vendors. In April 2021, EDF submitted a "binding techno-commercial offer to supply engineering studies and equipment for the construction of six (6) EPR [European Pressurized Reactor] reactors at the Jaitapur site" in India.[228] According to this offer, EDF's subsidiary Framatome would provide nuclear steam supply systems, and GE Steam Power would supply the conventional islands, but NPCIL would be responsible for the construction and the commissioning of these

223 - Lok Sabha, "Unstarred question No. 1819: New Atomic Power Plants", Department of Atomic Energy, Answered by Jitendra Singh, Minister of State for Personnel, Public Grievances & Pensions and Prime Minister's Office, Government of India, 21 September 2020, see http://164.100.24.220/loksabhaquestions/annex/174/AU1819.pdf, accessed 5 June 2021.

224 - V. Jagannathan, "NPCIL to build four more atomic power units in 2020, says AEC chief", *Business Standard India*, 29 July 2020, see https://www.business-standard.com/article/companies/npcil-to-build-four-more-atomic-power-units-in-2020-says-aec-chief-120072900992_1.html, accessed 3 June 2021.

225 - V. Jagannathan, "Nuclear Power Corp to spend Rs 18,000 cr on capital expenditure in FY22", *Business Standard India*, 17 May 2021, see https://www.business-standard.com/article/companies/nuclear-power-corp-to-spend-rs-18-000-cr-on-capital-expenditure-in-fy22-121051700186_1.html, accessed 4 June 2021.

226 - Singh et al., "Unstarred Question No. 1819: New Atomic Power Plants – Answered on 21.09.2020", op. cit.

227 - Lok Sabha, "Unstarred question No. 367: Nuclear Power Plants ", Department of Atomic Energy, Answered by Jitendra Singh, Minister of State for Personnel, Public Grievances & Pensions and Prime Minister's Office, Government of India, February 2021, see https://dae.gov.in/writereaddata/lsusq%20367.pdf, accessed 5 June 2021.

228 - EDF, "EDF submits to the Indian nuclear operator NPCIL the French binding techno-commercial offer to build six EPRs at the Jaitapur site", Press Release, 23 April 2021, see https://www.edf.fr/en/the-edf-group/dedicated-sections/journalists/all-press-releases/edf-submits-to-the-indian-nuclear-operator-npcil-the-french-binding-techno-commercial-offer-to-build-six-eprs-at-the-jaitapur-site, accessed 5 June 2021.

reactors. No cost figures were mentioned but EDF explicitly announced that it is "neither an investor in the project nor in charge of the construction".[229]

The performance of the last major imported reactors operating in India, Kudankulam-1 and -2, has been poor. During the 2020-2021 financial year, NPCIL records capacity factors of 64 percent and 72 percent respectively.[230] According to the IAEA's PRIS database, Kudankulam-1 and Kudankulam-2 had load factors of 60.7 percent and 71.9 percent in 2020, and cumulative load factors of 53.4 percent and 52.3 percent respectively. The official tariff for electricity from Kudankulam-1 and -2 is the highest among all nuclear plants.[231]

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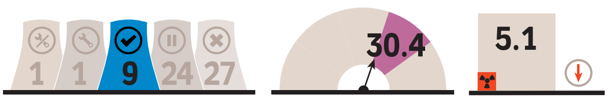


Overview

The past year has seen a decline in electricity generation from nuclear power in large part due to forced extended outages linked to the regulatory deadline for completing anti-terrorism emergency safety facilities. For six weeks from mid-November to late December 2020 only one reactor was operating in Japan.[232] However, by early 2021, four reactors were operating and as of 1 July 2021, eight reactors were operating. On 23 June 2021, the Mihama-3 Pressurized Water Reactor (PWR) restarted for the first time in a decade becoming the first commercial reactor in Japan to operate beyond 40 years after first grid connection.[233]

As of 1 July 2021, a total of ten PWRs had restarted in Japan since the application of new safety guidelines under the Nuclear Regulation Authority (NRA).

Progress by the Tokyo Electric Power Company (TEPCO) towards restart of Advanced Boiling Water Reactors (ABWRs) at its one remaining nuclear plant, at Kashiwazaki-Kariwa in Niigata, suffered a significant setback in April 2021. The NRA ordered a halt to scheduled refueling-operations for Unit 7 until corrective measures were taken in response to security breaches at the site.[234] Restarts of Unit 6 and Unit 7 are also conditional on prefectural approval which is not expected before summer 2022 at the earliest. The order was the first of its kind issued to a commercially operated nuclear facility in Japan and led TEPCO President Tomoaki Kobayakawa to state: "We have grave concerns about whether we can continue to operate the nuclear power generation business."[235]

229 - Ibidem.

230 - NPCIL, "Kudankulam atomic power project", Nuclear Power Corporation of India Limited, May 2021, see https://www.npcil.nic.in/content/320_1_OperatingPerformance.aspx, accessed 5 June 2021.

231 - Lok Sabha, "Unstarred Question No. 367: Nuclear Power Plants", op. cit.

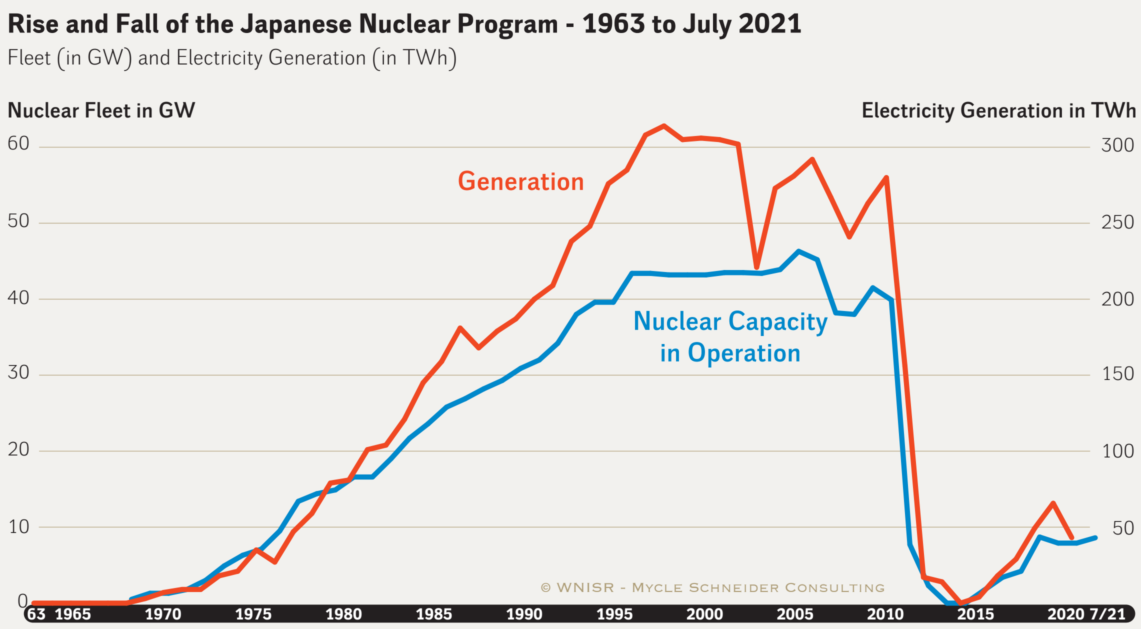
232 - *NEI*, "Only one power reactor remains in operation in Japan", 10 November 2020, see https://www.neimagazine.com/news/newsonly-one-power-reactor-remains-in-operation-in-japan-8354484, accessed 15 May 2021.

233 - JAIF, "Mihama-3 Restarts after Decade-long Hiatus", 28 June 2021, see https://www.jaif.or.jp/en/mihama-3-restarts-after-decade-long-hiatus/, accessed 17 August 2021.

234 - Tsuyoshi Kawamura, "Nuclear agency bans TEPCO from transferring fuel at Niigata plant", *The Asahi Shimbun*, 15 April 2021, see http://www.asahi.com/ajw/articles/14331159, accessed 2 May 2021.

235 - *The Mainichi Shimbun*, "TEPCO banned from restarting nuclear plant over safety flaws", 14 April 2021, see https://mainichi.jp/english/articles/20210414/p2g/00m/0na/050000c, accessed 20 May 2021.

Figure 29 · Rise and Fall of the Japanese Nuclear Program



Sources: WNISR with IAEA-PRIS, 2021

Note: This figure considers Ikata-3 in LTO since 2019. The reactor was shut down in December 2019 for maintenance and refueling.

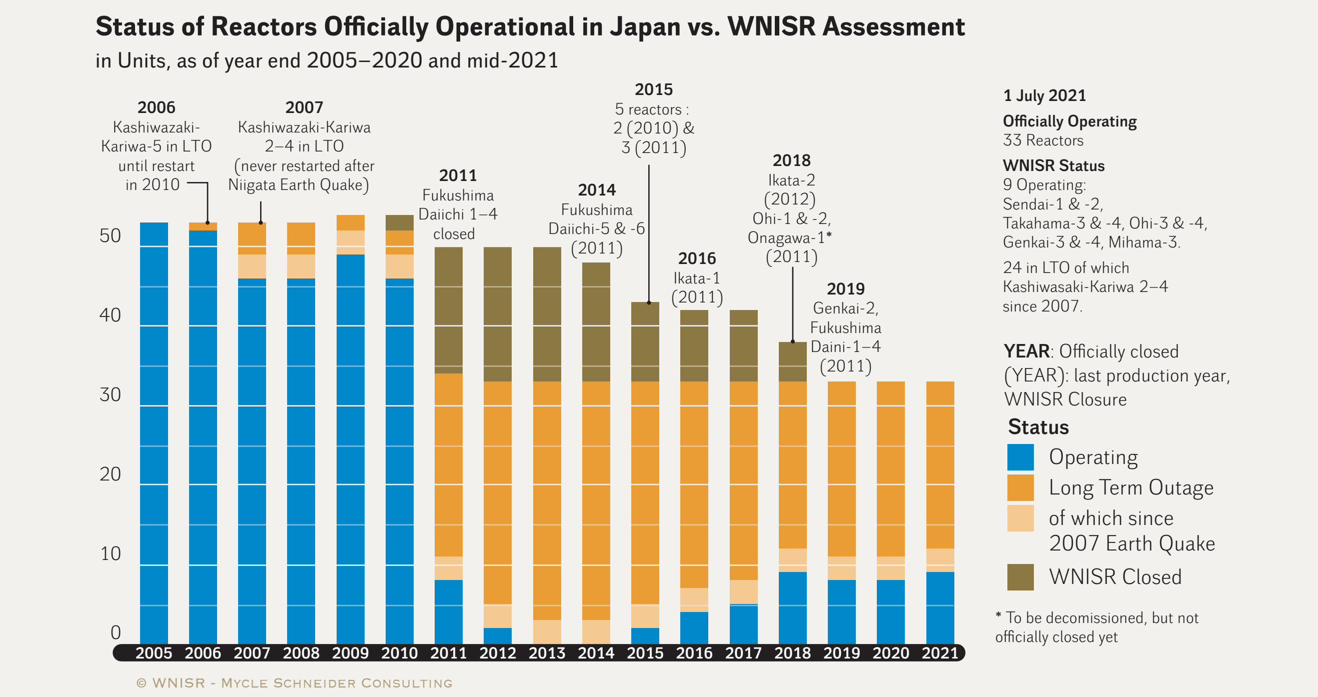
The restart of Mihama-3 is significant as it is the first reactor granted a 20-year license extension by the NRA to resume operations. The reactor is owned by Kansai Electric Power Company (KEPCO), which had been at the center of a bribery and corruption scandal in 2019-2020 (see WNISR2020). Kansai Electric is also planning to restart Takahama-1 and -2, during the second half of 2021 and into 2022. Both reactors have also been granted license extensions by the NRA.

Citizen initiated lawsuits against nuclear plants have continued to destabilize reactor operations in Japan. On 4 December 2020, for the first time a district court ruled that the NRA was not applying its regulations correctly and that the operating license for Ohi-3 and -4 should be withdrawn.[236]

No additional reactors have been declared for permanent closure during the past year, thus the total remains unchanged at 21 reactors (including the ten at Fukushima Daiichi & Daini). With one additional restart, Mihama-3, and one of the previously restarted reactors, Ikata-3, meeting the LTO criteria again, as of 1 July 2021, 24 reactors remain in LTO. WNISR has considered for years that the four reactors at Fukushima Daini will never restart. (See Figure 30 and Annex 2 for a detailed listing of the Japanese Reactor Program).

236 - *Nikkei Asia*, "Japan court nullifies approval of Oi nuclear reactor safety steps", 4 December 2020, see https://asia.nikkei.com/Business/Energy/Japan-court-nullifies-approval-of-Oi-nuclear-reactor-safety-steps, accessed 3 May 2021.

Figure 30 · Status of the Japanese Reactor Fleet



Sources: Various, compiled by WNISR, 2021

In 2020, nuclear power in Japan produced 43 TWh contributing 5.1 percent to the Japan's electricity generation.[237] This compares with 65.7 TWh and a 7.5 percent share in 2019, the largest share of nuclear generated electricity since 2011 (when it fell to 18 percent), compared with 29 percent in 2010 and the historic high of 36 percent in 1998. (See Figure 29.)

As a matter of comparison, according to IEA data, solar PV generation in 2020 was 78.7 TWh or 7.9 percent of electricity production, up 10 percent over the previous year and outpacing nuclear power.[238]

As in past years, from a Japanese utility perspective, there have been both positive and negative developments for the future of nuclear power in Japan, including the potential role it could play in decarbonization and emission reductions. During the past year, the new government of Prime Minister Yoshihide Suga announced more ambitious emissions reduction goals for 2030 and a commitment to net zero carbon emissions by 2050.[239] The Ministry of Economy, Trade and Industry's (METI) Green Growth vision for 2050, without setting firm targets, envisages renewable energy as providing 50–60 percent of electricity by 2050, and that nuclear

237 - These numbers are from IAEA-PRIS. Numbers vary significantly according to sources. The IEA, for example, indicates a total national net electricity production of 991 TWh for 2020 with nuclear plants providing 41.9 TWh or 4.2%, cf. IEA, "Monthly Electricity Statistics", July 2021, see https://www.iea.org/data-and-statistics/data-product/monthly-electricity-statistics, accessed 20 July 2021.

238 - IEA, "Monthly Electricity Statistics", July 2021, see https://www.iea.org/data-and-statistics/data-product/monthly-electricity-statistics, accessed 20 July 2021.

239 - Naoki Kikuchi, "Suga raises the bar on cutting emissions to net zero by 2050", *The Asahi Shimbun*, 26 October 2020, see http://www.asahi.com/ajw/articles/13872287, accessed 26 April 2021.

together with fossil fuel and Carbon Capture, Utilization and Storage (CCUS), would be 30–40 percent.[240]

The process of reviewing the latest *Strategic Energy Plan*, which is due to be completed in summer 2021, also provided a platform for advocates of continued and even expanded nuclear power generation in Japan. The current plan, with a 20–22 percent target for nuclear electricity generation by 2030, is likely to remain unchanged this year. However, *Kyodo News* reported in June 2021 that the government "dropped the key phrase" that it *"will continue to seek to make the most of nuclear power"* following protests from Environment Minister Shinjiro Koizumi and Administrative Reform Minister Taro Kono.[241]

As WNISR reported in 2019 and 2020, the industry has been working to counter unfavorable electricity market conditions. Significantly, this included the launch in April 2020 of a Capacity Market for the year 2024–2025. Calculations by WNISR suggest that seven of the nine reactors that had restarted as of 2020, secured contracts under the capacity market which should yield ¥67.2 billion (US$613 million) in additional income for three utilities (Kansai Electric, Kyushu Electric and Shikoku Electric) in 2024–2025.

As in previous years, a consistent majority of Japanese citizens, when polled, continue to oppose the sustained reliance on nuclear power, support its early phase-out, and remain opposed to the restart of reactors.[242]

Kansai Electric Dominates Nuclear Operations

KEPCO's past year can be considered largely positive in terms of moving towards additional reactor restarts. On the current trajectory the utility within the next 12 months could be operating seven nuclear reactors. This is despite the major scandal that engulfed KEPCO in 2019 and early 2020, and a historic Osaka District Court ruling against its Ohi reactors (see Judicial Decisions on Damages and Criminal Liability for the Fukushima Nuclear Accidents).

As detailed in WNISR2020, a decades-long bribery and corruption scandal in Fukui Prefecture in western Japan extended from local contractors, a former Takahama mayor, local prefectural officials, a chapter of the ruling Liberal Democratic Party (LDP) and executives of KEPCO, including the President (see also Nuclear Power and Criminal Energy).[243] Long considered the nuclear peninsula of Japan, Fukui Prefecture hosts 11 KEPCO reactors, four of which are slated for decommissioning.

As reported in WNISR2020, restarts for KEPCO's Pressurized Water Reactors (PWRs) Takahama-1 and -2, and Mihama-3, which passed NRA review for respective upgrading plans

240 - METI, "'Green Growth Strategy Through Achieving Carbon Neutrality in 2050' Formulated", Press Release, 25 December 2020, Revised in March 2021, see https://www.meti.go.jp/english/press/2020/1225_001.html, accessed 3 May 2021.

241 - *Kyodo News*, "Japan softens commitment to nuclear power in draft growth strategy", 3 June 2021, see https://english.kyodonews.net/news/2021/06/f98a18adaaf9-japan-softens-commitment-to-nuclear-power-in-draft-growth-strategy.html, accessed 3 June 2021.

242 - Robin Harding, "Fukushima nuclear disaster haunts Japan's climate change debate", *Financial Times*, 11 March 2021, see https://www.ft.com/content/36822cab-031d-4486-baa0-1a5e1696f989; and Charles Digges, "10 years after Fukushima, the nuclear industry still has trouble gaining the public's trust", Bellona, 12 March 2021, see https://bellona.org/news/nuclear-issues/2021-03-10-years-after-fukushima-the-nuclear-industry-still-lacks-the-publics-trust, both accessed 21 July 2021.

243 - *The Japan Times*, "LDP chapter led by ex-defense chief Inada got donations from firm with ties to man at heart of Kepco scandal", 5 October 2019, see https://www.japantimes.co.jp/news/2019/10/05/national/ldp-chapter-headed-tomomi-inada-got-donations-security-company-linked-former-takahama-deputy-mayor-eiji-moriyama/, accessed 10 May 2021.

in 2016, were delayed going into 2020 and there were further delays during the past year. In March 2020, KEPCO announced that completion of safety retrofits would take another four months longer than planned.[244] These three reactors, which are 47, 46 and 45 years old respectively, were granted lifetime operation approval to 60 years by the NRA in 2016.[245] Respective restart schedules have all been revised several times over recent years. While KEPCO had indicated restart targets of September–October 2020 for the Takahama and Mihama units, WNISR2020 noted that these were not attainable.

In the end, the first to restart was Mihama-3, on 23 June 2021, and was connected to the grid on 29 June 2021.

While there are no legal requirements that utilities receive local, prefectural assembly and Governor approval prior to reactor operations, without approval it is not possible. Local approval for restart of Mihama-3 was granted by the Mayor of Mihama town on 15 February 2021; this followed local assembly approval.[246] In granting approval, Mayor Hideki Toshima stated that conditions to approve the restart, "have all been met, including understanding from the townspeople and consent from the municipal assembly, as well as promising feedback over regional development by the central government and Kansai Electric", adding, "Both supporters and skeptics of the reactor restart are concerned about its safety. I will make sure to pay attention to the process."[247] Tatsuji Sugimoto, the Governor of Fukui, granted approval for the Mihama-3 restart on 28 April 2021.[248] However, the NRA requires that the emergency safety center onsite be completed by 25 October 2021. KEPCO will not complete construction by this time but instead chose to restart the reactor anyway in June 2021 and will operate the reactor during the summer months and then shut it down again prior to the NRA deadline in October 2021. Nuclear fuel loading was completed on 22 May 2021. The reactor was connected to the grid on 29 June 2021[249], and full operation was achieved on 4 July 2021.[250] KEPCO announced on 2 August 2021 that after shutdown of Mihama-3 in October 2021, following completion of safety retrofits, the reactor will be restarted on 30 October 2022.[251]

244 - *Jiji Press*, "Kansai Electric Puts Off Restart of N-Reactors in Fukui Pref.", as published on *nippon.com*, 31 March 2020, see https://www.nippon.com/en/news/ yjj2020033100928/kansai-electric-puts-off-restart-of-n-reactors-in-fukui-pref.html, accessed 29 May 2021.

245 - Noriyuki Ishii, "NRA Approves Extensions of Operating Periods to 60 Years for Takahama-1 and -2, the First for Aging Reactors", JAIF, 22 June 2016, see https://www.jaif.or.jp/en/nra-approves-extensions-of-operating-periods-to-60-years-for-takahama-1-and-2-the-first-for-aging-reactors/; and Noriyuki Ishii, "NRA Approves Extension of Operating Lifetime for Mihama-3 through 2036", JAIF, 17 November 2019, see https://www.jaif.or.jp/en/nra-approves-extension-of-operating-lifetime-for-mihama-3-through-2036/; both accessed 28 May 2021.

246 - *The Mainichi Shimbun*, "Japan town mayor OKs restarting nuclear reactor over 40 years old", 16 February 2021, see https://mainichi.jp/english/articles/20210216/p2a/00m/0na/008000c, accessed 10 May 2021.

247 - Ibidem.

248 - *WNN*, "Fukui governor approves restart of three reactors", 28 April 2021, see https://world-nuclear-news.org/Articles/Fukui-governor-gives-go-ahead-for-restart-of-three, accessed 13 June 2021.

249 - Kenta Nagai, "Mihama-3 Restarted After Decade-long Hiatus: First Restart in Japan of a Reactor Operating Beyond 40 Years", JAIF, 2 July 2021, see https://www.jaif.or.jp/en/mihama-3-restarted-after-decade-long-hiatus-first-restart-in-japan-of-a-reactor-operating-beyond-40-years/.

250 - JAIF, "Fuel Loading Completed at Mihama-3", 28 May 2021, see https://www.jaif.or.jp/en/fuel-loading-completed-at-mihama-3-npp/, accessed 30 May 2021; and *Jiji Press*, "Mihama No. 3 Reactor Returns to Full Operations", 5 July 2021, as published on *nippon.com*, see https://www.nippon.com/en/news/yjj2021070400261/, accessed 4 August 2021.

251 - KEPCO, "美浜発電所３号機、高浜発電所１、２号機および大飯発電所３、４号機の・特定重大事故等対処施設の運用開始時期と運転計画等について" ["About the operation start time and operation plan of the facility for dealing with specific serious accidents"], 2 August 2021 (in Japanese), see https://www.kepco.co.jp/corporate/pr/2021/pdf/20210802_3j.pdf, accessed 17 August 2021.

For Takahama-1 and -2 restart will only take place after completion of emergency safety control-center construction. The NRA deadline for installation of these was 9 June 2021, which KEPCO was unable to meet. In February 2021, restart approval was granted by Mayor Yutaka Nose of the prefectural town of Takahama; the Municipal Assembly has also approved of the move.[252] As with Mihama-3, Governor Sugimoto granted approval for restart of Takahama-1 and -2 on 28 April 2021. Fuel loading for Unit 1 began on 14 May 2021.

One factor that had been reported as an additional obstacle to prefectural approval was the issue of spent fuel storage. In the end, the political and economic weight of KEPCO asserted itself. The governor of Fukui had requested that KEPCO present its plans for securing a storage facility for spent fuel outside Fukui Prefecture, a condition of granting approval for restart of the Mihama and Takahama reactors. In February 2021, KEPCO President, Takashi Morimoto, had told the Fukui Governor that the utility would pursue all possibilities, including joint use (as the spent fuel intermediate storage facility) of the recyclable spent fuel storage center in Mutsu City, in Aomori Prefecture.[253] He also said that KEPCO would not operate the reactor for more than 40 years without the determination of an external spent fuel site.[254]

Morimoto had earlier told Sugimoto that the company would present a candidate site in 2020 for the spent fuel facility but acknowledged and apologized at the end of the year that it "cannot state a specific place as of this time."[255] After further meetings with Japanese ministers, Sugimoto indicated that he was no longer applying the condition of spent fuel storage prior to reactor approval. However, the prefectural assembly in February refused to consider the restart of Takahama and Mihama, with members accusing the Governor of backing down on his earlier position. On 6 April 2021, Sugimoto met with the head of the Fukui prefectural assembly and explained that central government had proposed new grants to local governments hosting aging nuclear plants of up to ¥2.5 billion (US$23 million) per nuclear plant.[256] On 23 April 2021 the assembly gave its consent to restart. Governor Sugimoto granted approval with an undertaking from KEPCO that they will identify a candidate spent fuel storage site by the end of FY2023 (31 March 2024); if not, KEPCO President Morimoto said, "we will work until we reach a determination, with the unwavering resolve that we will not operate Mihama-3 or Takahama-1 or -2."[257] There are very limited prospects that a site outside Fukui Prefecture will be secured for spent fuel for KEPCO within this timeframe, but this does not mean the reactors will really be shut down as a consequence. But it may have

252 - *The Mainichi Shimbun*, "Japan town mayor OKs restarting nuclear reactor over 40 years old", 16 February 2021, op. cit.

253 - The Mutsu facility has yet to receive spent fuel (currently scheduled for March 2022) but was built with the intention to store 5000 tons of spent fuel only from TEPCO and Japan Atomic Power Company (JAPC). The Recyclable-Fuel Storage Co. at Mutsu is wholly owned by TEPCO and JAPC. In December 2020, the Federation of Electric Power Companies indicated that they were considering opening up the Mutsu facility to other utilities, but there have been no detailed plans and the mayor of Mutsu has expressed his opposition.
See *Jiji Press*, "Aomori spent nuclear fuel site may be opened up to other utilities", *The Japan Times*, 11 December 2020, see https://www.japantimes.co.jp/news/2020/12/11/national/shared-nuclear-fuel-facility-aomori/; and *nippon.com*, "Mutsu Mayor Opposes N-Fuel Facility Joint Use Plan", 18 December 2020, see https://www.nippon.com/en/news/yjj2020121800914/, both accessed May 2021.

254 - Kaoru Ohno, "Site for Spent Fuel Intermediate Storage Facility Outside Fukui Prefecture to Be Determined by End of 2023", JAIF, 17 February 2021, see https://www.jaif.or.jp/en/site-for-spent-fuel-intermediate-storage-facility-outside-fukui-prefecture-to-be-determined-by-end-of-2023/, accessed 28 May 2021.

255 - Ibidem.

256 - *The Asahi Shimbun*, "Fukui governor ignored condition for restart of aging nuke plants", 29 April 2021, see http://www.asahi.com/ajw/articles/14340146, accessed 29 May 2021.

257 - Op. cit. JAIF, 17 February 2021.

been a factor in the 2 August 2021 announcement of KEPCO to not plan to restart Takahama-1 and -2 until June and July 2023, nearly three years later than KEPCO's original schedule.[258]

On the basis of the current schedule, the eventual operation of Takahama-1–4, Ohi-3 and -4 and Mihama-3, would mean that KEPCO by 2023 will account for seven of twelve reactors operating in Japan—assuming no further delays to Kashiwazaki-Kariwa restart.

Under the license extensions granted by the NRA, Takahama-1 and -2 reactors will be permitted to operate until November 2034 and November 2035 respectively; while Mihama-3 could operate until December 2036. Under NRA regulations, the license extension is supposed to be granted under special circumstances, implying not for all reactors, and cannot be extended further. Whether this changes over the coming years remains to be seen.

Nuclear Regulatory Safety Standards Challenged

The past year has witnessed significant rulings from law courts across Japan that underscore the continuing uncertainties for future reactor operation, as well as highlighting some of the underlying safety issues that remain unresolved (see Judicial Decisions on Damages and Criminal Liability for the Fukushima Nuclear Accident).

While KEPCO is making progress to having the single largest number of reactors operating in Japan, prospects for those operations were dealt a potentially significant blow in December 2020. The Ohi-3 and -4 reactors were the subject of a historic legal ruling on 4 December 2020[259] when the Osaka District Court ruled that the NRA approval for operating the two reactors was illegal. This is the first time a Japanese court has withdrawn government approval granted to a utility to operate a nuclear plant under the post Fukushima safety guidelines adopted in 2013. KEPCO, which was an intervenor for the government in the lawsuit, described the ruling as "extremely regrettable and totally unacceptable."[260] An appeal against the judgement was filed on 17 December 2020 and consequently the reactors are permitted to continue to operate pending the result of the appeal.[261] The first hearing of the appeal case opened in the Osaka District Court on 8 June 2021.[262]

The court ruling was the first against the NRA over how it applies the new safety regulations in the screening process for reactor restarts, and specifically the seismic standards which were adopted post Fukushima and outline in a Guide for the Evaluation of Standard Seismic Motion.

258 - KEPCO, "美浜発電所３号機、高浜発電所1、２号機および大飯発電所３、４号機の ・ 特定重大事故等対処施設の運用開始時期と運転計画等について", 2 August 2021, op. cit.

259 - *Kyodo News*, "Japan court nixes approval of post-Fukushima nuclear safety steps", 4 December 2020, see https://english.kyodonews.net/news/2020/12/8c717cf8568d-urgent-japan-court-nullifies-approval-of-oi-nuclear-reactor-safety-steps.html, accessed 29 May 2021.

260 - Ibidem.

261 - *Jiji Press*, "Japanese government launches appeal over Oi nuclear plant restart", as published by *The Japan Times*, 18 December 2020, see https://www.japantimes.co.jp/news/2020/12/18/national/oi-nuclear-plant-restart-appeal/; and KEPCO, "KEPCO's handling of the Osaka district court's ruling that revoked regulatory approval for the Ohi No.3 and 4", 17 December 2020, see https://www.kepco.co.jp/english/corporate/ir/brief/pdf/2020_dec17_1.pdf; both accessed 29 May 2021. Note that due to extended outages for the completion of emergency control centers, both Ohi-3 and -4 were not operational at the time of 4 December 2020 court ruling.

262 - Mihama No Kai, "第1回控訴審　6月8日（火）（大阪高裁）大飯原発3・4号設置変更許可の取り消しを求める裁判" ["1st Appeal Trial June 8 (Tuesday) (Osaka High Court) Trial seeking revocation of permission to change the installation of Ohi Nuclear Power Plant Nos. 3 and 4"], JCA-NET, 7 June 2021 (in Japanese), see http://www.jca.apc.org/mihama/ooisaiban/annai20210608.htm, accessed 7 June 2021.

However, rather than apply the ruling and reassess the approval for all reactors in Japan, the NRA has sought to dismiss the implications of the judgement. On 3 March 2021, Toyoshi Fuketa, chair of the regulatory body, stated that the guide was only a reference and neither the utility nor the NRA should be bound by it. In addition, a proposal was put forward to change the specific reference to variation to seek to bypass the Osaka court ruling. The move by the NRA was strongly condemned by over 100 NGOs across Japan.[263]

While prospects for restart improved for KEPCO during 2020–2021, Moody's kept its credit-ratings outlook negative[264] following its downgrading in March 2020.[265] This reflected Moody's

> concerns over Kansai Electric's oversight, control and governance matters, which increases risk to the ongoing operation of its nuclear reactors. The bribery scandal could lead to higher negative public sentiment on nuclear plants in Japan, impeding Kansai Electric's nuclear business and risking the competitiveness it has as a provider of low-cost nuclear power in the deregulated retail market.[266]

Kashiwazaki Kariwa Safety/Security Scandal and Restart Setback

We have grave concerns about whether we can continue to operate the nuclear power generation business.

Tomoaki Kobayakawa, TEPCO President, April 2021.[267]

Prospects for the restart of Tokyo Electric Power Company (TEPCO)'s Advanced Boiling Water Reactors (ABWRs) Kashiwazaki Kariwa-6 and -7 in Niigata Prefecture suffered a significant blow in early 2021, when NRA commissioners ordered a halt to planned refueling operations for Unit 7 until corrective measures were taken in response to security breaches at the site. The NRA rated the situation at the plant at the most serious level on its four-tier assessment scale, saying that the security flaws could have led the plant to a grave situation in terms of nuclear material protection.[268]

The origin of the NRA Commissioners decision was that on 20 September 2020 a TEPCO employee at the nuclear plant used a colleague's identity card to enter the Kashiwazaki-Kariwa central control room. The guard on duty covered up the incident. Once it realized what had happened, TEPCO failed to notify the Niigata prefectural government and the Kashiwazaki

263 - CNIC, "抗議・要請書 — 原子力規制委員会 更田委員長の「審査ガイド」パブコメ無用発言に抗議する" ["Nuclear Regulatory Commission Chairman Fuketa's 'Examination Guide' Protests Public Comments"], 9 March 2021 (in Japanese), see http://www.jca.apc.org/mihama/ooisaiban/objection_to_huketa20210309.pdf, accessed 28 May 2021.

264 - Moody's Investor Services, "[MJKK]関西電力の国内普通社債に A3 の格付を付与" ["Kansai Electric Power's domestic straight corporate bonds are given an A3 rating"], 9 April 2021 (in Japanese), see https://www.moodys.com/researchdocumentcontentpage.aspx?docid=PR_443746, accessed 16 May 2021.

265 - Moody's Investor Services, "Moody's affirms Kansai Electric's A3 ratings but changes outlook to negative", 24 March 2020, see https://www.moodys.com/research/Moodys-affirms-Kansai-Electrics-A3-ratings-but-changes-outlook-to--PR_420254, accessed 28 May 2021.

266 - Moody's, "Kansai Electric Power Company, Incorporated – Moody's assigns (P)A3 to Kansai Electric's domestic shelf registration", as published by *Yahoo! Finance*, 11 August 2020, see https://finance.yahoo.com/news/kansai-electric-power-company-incorporated-060919393.html? , accessed 4 August 2021.

267 - *The Mainichi*, "TEPCO banned from restarting nuclear plant over safety flaws", 14 April 2021, see https://mainichi.jp/english/articles/20210414/p2g/00m/0na/050000c, accessed 20 May 2021.

268 - *The Asahi Shimbun*, "NRA to delay TEPCO's reactor restart plan over 'shoddy' repairs", 17 March 2021, see http://www.asahi.com/ajw/articles/14276457, accessed 7 June 2021.

city government. The on-site NRA staff also failed to notify the NRA commissioners until January 2021. In the subsequent follow-up investigation in February 2021, security equipment and systems intended to detect illegal entry were found to be non-operational.[269] Subsequent investigations found that the plant was vulnerable to unauthorized entry at 15 locations since March 2020 because of defective intruder detection systems and backups.[270] The station may not have been able to detect intrusions at ten points of entry for over 30 days. On 16 March 2021, the NRA classified the event as "safety significance assessment, red"[271], then on 23 March as an inspection handling category 4 event.[272] On 14 April 2021, TEPCO received an order that banned Kashiwazaki-Kariwa from transporting specified nuclear fuel materials until the inspection handling category was changed to Category 1.[273]

There was also partial loss of function to nuclear material protection equipment. "Systematic monitoring functionality failed, and the effectiveness of the physical protection system could not be adequately confirmed for a long period of time. In terms of nuclear safeguarding, it could have resulted in a grave situation," the regulatory body said.[274] NRA chair Fuketa stated that "using common sense it should be clear that this process cannot be completed within one year"; while malfunctioning counterterrorism equipment had been corrected, the more important issue is whether the utility has a "nuclear safety culture from bottom to top."[275] Both disclosures led to questions of the overall security preparedness of Japanese nuclear facilities.[276]

The scandal that subsequently engulfed TEPCO stands in contrast to the progress it made towards restart in late 2020. A series of submissions and approvals were made in October–November 2020.[277]

269 - *Niigata Nippo*, "ずさん過ぎる管理体制露呈—柏崎刈羽原発不正入室問題" ["Exposing a management system that is too sloppy—Kashiwazaki-Kariwa Nuclear Power Plant's Unauthorized Entry Problem"], 9 February 2021 (in Japanese), see https://www.niigata-nippo.co.jp/news/national/20210209597764.html, accessed 30 May 2021.

270 - *Kyodo/Jiji Press*, "Tepco banned from restarting its largest nuclear plant over safety flaws", as published in *The Japan Times*, 14 April 2021, see https://www.japantimes.co.jp/news/2021/04/14/national/tepco-nuclear-plant-restart-ban/, accessed 7 June 2021.

271 - Significance of events in terms of safety is classified into "red", "yellow", "white", "green" depending on the degree by which the safety of nuclear power facilities was degraded. Red is defined as "large impact on safety functions or performance" and white is "impact on safety functions or performance, and decrease in safety margins, but improvements can be made with regulatory involvement", see Tokyo Electric Power Company Holdings, Inc., "FY2020 Financial Results (April 1, 2020 – March 31, 2021", Released 28 April 2021, TEPCO, see https://www.tepco.co.jp/en/hd/about/ir/library/presentations/pdf/210428_1-e.pdf, accessed 7 June 2021.

272 - Ibidem. Handling categories for additional inspections are separated into Category 1 to Category 5 depending on the inspection indication significance assessment and safety performance index classification. Category 2 is defined as "monitored activities satisfy objectives, but the operator's safety activities have slightly degraded" and Category 4 is defined as "monitored activities satisfy objectives, but the operator's safety activities have significantly degraded, or have been in a degraded state for a long period of time."

273 - Ibidem.

274 - *The Japan Times*, "Japanese nuclear plant vulnerable to unauthorized entry for one year", 17 March 2021, see https://www.japantimes.co.jp%2Fnews%2F2021%2F03%2F17%2Fnational%2Fnuclear-plant-vulnerable%2F&usg=AOvVaw1dXxWmuCe6MYX5Br14QvEy, accessed 4 August 2021.

275 - Dennis Engbarth, "NRA Slams the Door on Kashiwazaki Kariwa Restarts", *NIW*, 26 March 2021, see https://www.energyintel.com/pages/eig_article.aspx?DocID=1101578, accessed 7 June 2021.

276 - Osamu Tsukimori, "Tepco lapse a wake-up call for Japan's nuclear security protocols, expert says", *The Japan Times*, 15 April 2021, see https://www.japantimes.co.jp/news/2021/04/15/national/nra-niigata-tepco-nuclear-security/, accessed 7 June 2021.

277 - On 14 October 2020, the NRA approved TEPCO's application for the design and construction plan for Unit 7; On 30 October 2020, the NRA approved TEPCO's application for authorization of safety regulation revision; on 6 November 2020, the application for pre-service confirmation for Unit 7 was submitted to the NRA – see TEPCO, "FY2020 3rd Quarter Financial Results (April 1 – December 31, 2020) – Overview of FY2020 3rd Quarter Financial Results", Released 10 February 2021, see https://www.tepco.co.jp/en/hd/about/ir/library/presentations/pdf/210210_1-e.pdf, accessed 7 June 2021.

In October 2020, the NRA commissioners approved a report from TEPCO on the modernization and strengthening of safety measures at Kashiwazaki Kariwa-7.[278] This approval came one month after the NRA secretariat knew of the security failures at the site, but according to the NRA, the commissioners were not informed until January 2021.

Even as late as mid-January 2021, the prospects towards local approval for restart seemed to be on track. TEPCO informed the local mayors in Kashiwazaki and Kariwa villages that safety measures would be completed at Unit 7 on 13 January 2021.[279] Mayor Sakurai of Kashiwazaki said at a meeting with TEPCO that, "the first half of this year will be an important time for TEPCO, Kashiwazaki City, and Japan," and expressed his hope that discussions on the restart issue would begin. Kariwa Mayor Shinada told TEPCO that, "I am convinced that it is the year when Unit 7 will move. I want you to proceed with your work firmly."[280]

By late January and into February 2021, TEPCO officials were apologizing across Niigata as well as to the House Budget Committee in the national Diet.[281] In a meeting with LDP officials in Niigata on 30 January 2021, the TEPCO official was told by the LDP Secretary General that, "There are doubts about the ability of the parties (to operate the nuclear power plant) and even the eligibility as a company. It will be a problem if you do not think about how to deal with it."[282]

TEPCO announced in February 2021 that it was disciplining its officials, including President Kobayakawa, noting that it, "considers this incident to be of the utmost seriousness and the decision has been made to take the following disciplinary action against the following individuals in order to further clarify managerial responsibility and thoroughly implement recurrence prevention measures."[283]

It was reported that TEPCO had been aiming to restart Unit 7 as early as June 2021, following securing of local consent. As a result of the security violation disclosures, the LDP Secretary General in Niigata described the TEPCO schedule as "a charade", adding "there is no restart within the year. It will return to the original and start from scratch."[284]

278 - *NEI*, "Japan's NRA approves restart plans for Kashiwazaki-Kariva 7", 19 October 2020, see https://www.neimagazine.com/news/newsjapans-nra-approves-restart-plans-for-kashiwazaki-kariva-7-8191173, accessed 30 May 2021;

279 - *Niigata Nippo*, "柏崎原発7号機工事 13日にも終了東電、下旬から5会場で説明会", 13 January 2021 (in Japanese), see https://www.niigata-nippo.co.jp/news/national/20210113592779.html, accessed 29 May 2021 (machine-translated). In the end, TEPCO did not complete all measures by this date; see TEPCO, "Correction regarding Completed Safety Measure Renovations at Kashiwazaki-Kariwa Nuclear Power Station Unit 7 implemented to Comply with the New Regulatory Requirements", Press Release, 27 January 2021, see https://www.tepco.co.jp/en/hd/newsroom/press/archives/2021/20210127_01.html, accessed 7 June 2021.

280 - *Niigata Nippo*, "柏崎原発7号機工事 13日にも終了東電、下旬から5会場で説明会", 13 January 2021, op. cit.

281 - *Niigata Nippo*, "東電社長 衆院予算委で謝罪" ["President of TEPCO apologizes to the House of Representatives' Budget Committee"], 10 February 2021 (in Japanese), see https://www.niigata-nippo.co.jp/news/politics/20210210598119.html, accessed 29 May 2021.

282 - *Niigata Nippo*, "新潟本社代表が自民県連幹部に謝罪" ["Niigata head office representative apologizes to LDP executives"], 30 January 2021 (in Japanese), see https://www.niigata-nippo.co.jp/news/politics/20210130596056.html, (machine-translated), accessed 29 May 2021.

283 - TEPCO, "Disciplinary Action", Press Release, 15 February 2021, see https://www.tepco.co.jp/en/hd/newsroom/press/archives/2021/20210215_02.html, accessed 7 June 2021.

284 - *Niigata Nippo*, "新潟本社代表が自民県連幹部に謝罪", 30 January 2021, op. cit.

The NRA concluded in April that TEPCO had, "failed to inspect, maintain [nuclear material protection equipment]," and "failed to perform regular assessments and improvements".[285] On 22 April 2021, TEPCO submitted to the NRA a notice of change to the construction plan pertaining to the reactor installation permission for facilities subject to design standards and severe accident handling equipment at Kashiwazaki Kariwa Nuclear Power Station Unit 7.[286] TEPCO's plans for facilities subject to design standards and severe accident handling equipment is now "undetermined" since they "do not know when we will be able to move forward with our original plan as we received the order from NRA on April 14, 2021."[287]

In June 2021, TEPCO announced the creation of an Independent Review Committee on Nuclear Material Protection.[288] The Committee is tasked with the assessment of the validity of cause analysis and fact-finding investigations performed by TEPCO; analyze organizational factors and assess corporate culture including its safety culture and nuclear security culture, and identify signs of degradation pertaining to the incidents being investigated; and propose remedial measures based upon the corporate culture assessment. The results of a root cause analysis of the physical protection incident and responses to the incident are to be reported to the NRA by 23 September 2021,[289] after which the NRA will review TEPCO compliance measures.

The disclosures of TEPCO's security and safety failures at the Kashiwazaki Kariwa plant took place in the run-up to the 10th anniversary of the start of the Fukushima Daiichi accidents. As a result of the 2011 disaster, any exposure of safety and security failures by TEPCO is particularly sensitive. The disclosures have therefore destabilized TEPCO's timetable for restarting reactor units at the Niigata plant but have also damaged the reputation of the NRA. These issues are particularly sensitive for the people of Niigata who have experienced the 2007 Niigata Chuetsu-oki quake at Kashiwazaki Kariwa and multiple TEPCO scandals over the decades.[290] Units 2–4 were never restarted since the 2007 quake.

In 2017, TEPCO's announced aim was to restart Kashiwazaki Kariwa-6 and -7 within fiscal year 2019, or 2020, or 2021.[291] WNISR2018 concluded that the earliest the reactors could restart

285 - TEPCO, "TEPCO's Reply to the Notification of Order Issued by NRA in Accordance with Article 43.3.23 Paragraph 2 of the Act on the Regulation of Nuclear Source Material, Nuclear Fuel Material and Reactors", Press Release, 7 April 2021, see https://www.tepco.co.jp/en/hd/newsroom/press/archives/2021/20210407_01.html, accessed 7 June 2021.

286 - TEPCO, "Submission of Notice of Change to Construction Plan pertaining to the Reactor Installation Permission for the Kashiwazaki-Kariwa Nuclear Power Station", Press Release, 22 April 2021, see https://www.tepco.co.jp/en/hd/newsroom/press/archives/2021/20210422_02.html, accessed 7 June 2021.

287 - The order from the NRA is in accordance with Article 43.3.23 Paragraph 2 of the Act on the Regulation of Nuclear Source Material, Nuclear Fuel Material and Reactors and states, "TEPCO may not move specified nuclear fuel material at the Kashiwazaki-Kariwa Nuclear Power Station until the NRA notifies TEPCO that the nuclear regulatory inspection handling category stipulated for the Kashiwazaki-Kariwa Nuclear Power Station has been changed to Category 1." See TEPCO, "TEPCO, "Submission of Notice of Change to Construction Plan pertaining to the Reactor Installation Permission for the Kashiwazaki-Kariwa Nuclear Power Station", 22 April 2021, op. cit.

288 - TEPCO, "Establishment of an Independent Review Committee on Nuclear Material Protection", Press Release, 2 June 2021, see https://www.tepco.co.jp/en/hd/newsroom/press/archives/2021/20210602_01.html, accessed 7 June 2021.

289 - TEPCO, "Status of Initiatives Pertaining to Nuclear Material Protection at the Kashiwazaki-Kariwa Nuclear Power Station", Attachment 2, 10 June 2021, see https://www.tepco.co.jp/en/hd/newsroom/press/archives/2021/pdf/210610e0102.pdf, accessed 4 August 2021.

290 - KK Scientists, "We demand that the Kashiwazaki-Kariwa Nuclear Power Plant be closed", Group of Concerned Scientists and Engineers Calling for the Closure of the Kashiwazaki-Kariwa Nuclear Power Plant, *Nuke Info Tokyo*, March-April 2008, No. 123, see http://www.cnic.jp/english/newsletter/pdffiles/nit123.pdf, accessed 27 April 2019.

291 - Shaun Burnie, "TEPCO's Atomic Delusion", Greenpeace Japan, 25 June 2018, see https://www.greenpeace.org/static/planet4-japan-stateless/2019/08/3d2e8976-atomic_delusion.pdf, accessed 7 June 2021.

would be 2021, but only if TEPCO were to overcome significant obstacles. Even without the latest scandal, it remains doubtful that restart could have taken place in June 2021. The result of the scandal has set further back TEPCO's plans with no restart scheduled for 2021. However, the financial pressure on TEPCO is such that restart remains a priority for the company and all the resultant political and economic lobbying that will be deployed to secure approval within Niigata. TEPCO confirmed that it is aiming for a 2022 restart "at the earliest", with the publication of its Fourth Comprehensive Special Business Plan on 21 July 2021.[292] However, there remain major obstacles to even achieving this objective.

Underlying safety issues remain central to public and political opposition within Niigata Prefecture to any restart. The Kashiwazaki Kariwa site has a history of major seismic activity, with repeated underestimates and non-disclosures of the seismic risks by TEPCO and resultant coverups. At the time of the licensing of Units 6 and 7 in 1991, TEPCO presented evidence to the regulator that the nearby fault lines were not active. This was then proven to be incorrect, with TEPCO's own data showing that they were aware of active faults as early as 1980. None of this was made public until after the 2007 Niigata Chuetsu-oki quake.[293]

NGO's and seismologists remain deeply concerned about the multiple seismic fault lines in the area of the Kashiwazaki Kariwa site, including through the site.[294] There are large-scale submarine active faults offshore with four main ones, three of which run along either edge of the Sado Basin, a depression between Sado Island and mainland Kashiwazaki.[295] Seismologists have long warned about the threat from major earthquakes leading to a severe nuclear accident at Kashiwazaki Kariwa.[296] Independent seismologists and citizens' groups continue to oppose restart of the reactors, including based on evidence that TEPCO has relied on flawed seismic assessments.[297]

Meanwhile, legal challenges seeking permanent closure are ongoing. A citizen initiative was launched in March 2021 which has the potential to further delay, and even prevent, restart at Kashiwazaki Kariwa.[298] The initiative aims to extend the consent rights for restart to communities beyond the city of Kashiwazaki and the village of Kariwa. Based on the agreement in Ibaraki Prefecture for Tokai-2 (Tokai Daini), the aim would be to require TEPCO to secure approval from all seven municipalities within the 30-km evacuation-preparation area (UPZ). If successful, the initiative will be a potentially major obstacle to restart the Kashiwazaki Kariwa

292 - TEPCO Holdings, "第四次総合特別事業計画", 21 July 2021 (in Japanese), see https://www.tepco.co.jp/press/release/2021/pdf3/210721j0301.pdf, accessed 17 August 2021.

293 - Katsuhiko Ishibashi and Mitsuhisa Watanabe, "Earthquakes and Ground Condition – Just how safe is the Kashiwazaki-Kariwa Nuclear Power Plant?", KK Scientists, Originally Published in Japanese, 24 February 2008, Translation published in CNIC, *Nuke Info Tokyo*, Special Edition, No. 123, March/April 2008, op. cit.

294 - Kashiwazaki Kariwa Nuclear Power Fault Study Group, "柏崎刈羽原子力発電所敷地ならびにその周辺の" ["Kashiwazaki Kariwa Nuclear Power Station site and its surroundings— Request for a rigorous scientific review on stratigraphy of Middle and Upper Pleistocene"], 22 May 2017 (in Japanese), as published in Masaaki Tateishi, "柏崎刈羽原子力発電所敷地内の断層について（1）", *FC2*, 3 June 2017, see http://masatate.blog.fc2.com/blog-entry-55.html, accessed 27 April 2019.

295 - KK Scientists, "We demand that the Kashiwazaki-Kariwa Nuclear Power Plant be closed", *Nuke Info Tokyo*, 9 March 2008, op. cit.

296 - Ishibashi Katsuhiko, "Why Worry? Japan's Nuclear Plants at Grave Risk From Quake Damage", *The Asia-Pacific Journal*, 1 August 2007, Vol. 5, Issue 8, see http://apjjf.org/-Ishibashi-Katsuhiko/2495/article.html, accessed 27 April 2019.

297 - Tateishi Masaaki, "柏崎刈羽原発、寺尾断層露頭の東電解釈への疑義", 30 January 2019 (in Japanese), see http://masatate.blog.fc2.com/blog-entry-64.html, both accessed 27 April 2019.

298 - *Niigata Nippo*, "新安全協定案 初の住民説明会 – 長岡市 柏崎刈羽原発30キロ圏議員研究会", 29 March 2021 (in Japanese), see https://www.niigata-nippo.co.jp/news/politics/20210329607002.html, accessed 7 June 2021.

reactors, given that the communities do not directly receive financial incentives from either TEPCO or the central government for hosting the nuclear power plants.

Following the discovery of security failures at Kashiwazaki Kariwa, breaches in security provisions were also found at TEPCO's closed Fukushima Daini power plant, and Shikoku Electric's Ikata plant. These were announced by the NRA on 19 May 2021, where it reported that the security failures were at the least serious level in the nuclear watchdog's four-point scale assessment about protection of nuclear substances.[299]

Prospects for Other Additional Reactor Operations

All currently operating reactors in Japan are Pressurized Water Reactors (PWRs)—the destroyed Fukushima Daiichi units were Boiling Water Reactors (BWRs). As of 1 July 2021, 15 reactors remain under NRA safety review (out of a total of 25 that have applied since July 2013 of which ten were restarted); with one of those restarted reactors back in LTO since December 2019, adding to the 23 reactors remaining in LTO, there is a total of 24 reactors in LTO as of 1 July 2021. Not all of these will restart, with many questions and disagreements over seismic issues, and many plants far back in the review and screening queue. There are officially two reactors under construction (Shimane-3 and Ohma). WNISR has pulled Ohma off the list, as no active construction could be substantiated.

In addition to the June restart of Mihama-3 and Ohi-3 on 3 July 2021,[300] the only reactor scheduled for resumption of operations during the remainder of 2021 is Ikata-3. The reactor, owned by the Shikoku Electric Power Company, is scheduled to resume operations in late October 2021. The reactor has been off-line since December 2019, when it was shut down for maintenance. However, it was prevented from restarting following a 17 January 2020 injunction ruling by the Hiroshima High Court in favor of residents within a 50-kilometer radius of the plant.[301] On 18 March 2021 the Hiroshima High Court overturned on appeal its earlier 2020 ruling, opening the way for restart following completion of periodic inspections.[302] (See Chapter on Judicial Decisions on Damages and Criminal Liability for the Fukushima Nuclear Accidents).

299 - *The Mainichi*, "Failures in counterterrorism measures uncovered at 2 nuke plants including Fukushima No. 2", 20 May 2021, see https://mainichi.jp/english/articles/20210520/p2a/00m/0na/005000c, accessed 29 May 2021.

300 - KEPCO, "大飯発電所３号機の原子炉起動予定および調整運転の開始予定について" ["About the reactor start schedule and adjustment operation start schedule of Oi Power Station Unit 3"], 2 July 2021 (in Japanese), see https://www.kepco.co.jp/corporate/pr/2021/pdf/20210702_1j.pdf, accessed 18 August 2021.

301 - *The Asahi Shimbun*, "Residents win appeal to halt Ikata reactor over safety fears", 17 January 2020; and Shikoku Electric Power Co., "広島高等裁判所での抗告審における伊方発電所３号機運転差止仮処分の決定について", 17 January 2020 (in Japanese), see https://www.yonden.co.jp/press/2019/__icsFiles/afieldfile/2020/01/17/pr006_1.pdf, accessed 28 May 2021.

302 - *NEI*, "As one Japanese court approves operation of Ikata 3 another bars restart of Tokai 2", 22 March 2021, see https://www.neimagazine.com/news/newsas-one-japanese-court-approves-operation-of-ikata-3-another-bars-restart-of-tokai-2-8616738, accessed 28 May 2021.

Tokai-2 (Tokai Daini)

Prospects for an early restart of the 1100-MW BWR Tokai-2, owned by Japan Atomic Power Company (JAPC), remain unlikely. Court judgements in 2021 have only added to the uncertainties. The reactor, located in Ibaraki Prefecture and connected to the grid in 1978, is the closest to the Tokyo metropolitan area. It was shut down on 11 March 2011. JAPC announced on 28 January 2020 that engineering and construction works at the plant, including a 1.7 km long coastal levee, were taking longer than anticipated.[303] On 22 February 2019, JAPC announced its intention to proceed with the restart of Tokai-2.[304] The target date is January 2023. This followed a 7 November 2018 unanimous decision by NRA commissioners to approve an additional 20 years of operation.[305]

On 28 October 2019, the board of Tokyo Electric Power Company (TEPCO) approved the financing of ¥220 billion (US$2 billion) for Tokai-2.[306] The decision is particularly controversial as TEPCO is effectively a state-owned utility and technically bankrupt following 3/11. JAPC is unique in Japan as it is a utility owned by all other nuclear utilities, with TEPCO owning the lion share. Failure to secure financing for Tokai-2 would have taken JAPC one step closer to bankruptcy, with serious implications for other utilities. This represents one major reason why TEPCO and the other utilities have agreed to finance the reactor backfitting. The utility has only one other reactor, Tsuruga-2 in Fukui Prefecture. JAPC has been in dispute with the NRA for the past years over the designation of an active seismic fault at the site,[307] and there are currently no prospects for the reactor operating.

As previously reported in WNISR, local approval is more complicated for Tokai-2 than other sites in Japan as the power plant is covered by an agreement between the utility and municipalities. There is strong public opposition within Ibaraki Prefecture to the potential restart of Tokai-2.[308] JAPC must obtain restart consent for Tokai-2 from six municipalities—Tokai village and the cities of Hitachi, Hitachinaka, Hitachiota, Mito and Naka—as well as the prefectural government of Ibaraki before it can restart the unit. About 940,000 people live in 14 municipalities within a 30-kilometer radius of the Tokai plant and the facility is closer to the Tokyo area than any other nuclear plant.

In March 2021, the Mito District Court in Ibaraki Prefecture issued an order halting operation of Tokai-2 due to an "inadequate regional evacuation plan",[309] (see Judicial Decisions on Damages and Criminal Liability for the Fukushima Nuclear Accidents).

303 - JAPC, "東海第二発電所の原子炉設置許可に係る – 工事計画の変更について" ["Tokai-2 Nuclear Power Plant license—About change of construction plan"], Japan Atomic Power Company, Press Release, 28 January 2020 (in Japanese), see http://www.japc.co.jp/news/press/2019/pdf/200128.pdf, accessed 29 May 2021.

304 - JAPC, "東海発電所・東海第二発電所 原子力事業者防災業務計画の修正について", Press Release, 22 February 2019 (in Japanese), see http://www.japc.co.jp/news/press/2018/pdf/310222_1.pdf, accessed 28 May 2021.

305 - JAIF, "NRA Allows Tokai-2 to Be Operated for Sixty Years, a First for a BWR", 16 November 2018, see https://www.jaif.or.jp/en/nra-allows-tokai-2-to-be-operated-for-sixty-years-a-first-for-a-bwr/, accessed 28 May 2021.

306 - *The Asahi Shimbun*, "TEPCO to pour 220 billion yen into Tokai No. 2 nuclear plant", 29 October 2019, see http://www.asahi.com/ajw/articles/AJ201910290042.html, accessed 28 May 2021.

307 - *WNN*, "Tsuruga 2 sits on active fault, NRA concludes", 26 March 2015, see https://www.world-nuclear-news.org/RS-Tsuruga-2-sits-on-active-fault-NRA-concludes-2603155.html, accessed 5 August 2021.

308 - *The Asahi Shimbun*, "EDITORIAL: TEPCO needs to make its case for bailing out aging nuclear plant", 31 October 2019, see http://www.asahi.com/ajw/articles/AJ201910310032.html, accessed 28 May 2021.

309 - Kenta Nagai, "Preparations Continue Toward Restarting Tokai-2 NPP", JAIF, 1 June 2021, see https://www.jaif.or.jp/en/preparations-continue-toward-restarting-tokai-2-npp/, accessed 5 August 2021.

On 19 March 2021, the ruling was appealed by JAPC to the Tokyo High Court on the grounds that its regional evacuation plan was still under consideration, and that it was therefore premature and irrational for the court to make a substantive judgment on such a plan.[310] As of 1 July 2021 the first hearing of the appeal had not been held.

Flaws in the existing evacuation plans compiled by Ibaraki Prefecture were highlighted in May 2021.[311] This included confirmation that the maximum limit of people which were estimated to be able to be evacuated within the prefecture was 443,000. Ibaraki Prefecture requested that the remaining 517,000 of the then population of 960,000 people be received as evacuees by the nearby five prefectures.

On 20 May 2021, JAPC President Mamoru Muramatsu said that the company would "do its best to issue a regional evacuation plan" but without giving a date.[312]

The utility in February 2020 indicated an envisaged restart date of December 2022 in its application to the NRA for pre-operational inspections. This had been widely criticized in the local community given that no approval had been granted and negotiations have not even formally commenced. In January 2020, the completion of construction works at the site was delayed to November and December 2022, with restart scheduled for the first half of 2023.[313] With likely additional cost escalations, the uncertainties in the latest construction schedule,[314] and the complexities of overcoming opposition within Ibaraki and securing municipality approval, there remains major doubt about a 2023 restart for Tokai-2, by which time it will have been in LTO for 12 years.

Onagawa-2

Tohoku Electric Power Company made important progress towards the restart of Onagawa-2 during the past year. Approval was granted in November 2020 by host community Ishinomaki city and Onagawa town, followed by approval by Miyagi prefectural governor, Yoshihiro Murai.[315]

On 26 February 2020, the NRA commissioners had granted permission to Tohoku Electric to make changes to the Onagawa-2 reactor (i.e. basic design approval).[316] The reactor, situated on

310 - JAPC, "東海第二発電所の運転差止等訴訟控訴審に係る•控訴理由書の提出について"["Tokai No. 2 Power Station Operation Injunction Proceedings Appeal Trial – About submission of reason for appeal"], Press Release, 7 May 2021 (in Japanese), see http://www.japc.co.jp/news/press/2021/pdf/210507.pdf, accessed 28 May 2021.

311 - *The Mainichi*, "Evacuation plan for east Japan nuclear plant was focused on inaccurate, simplified data", 11 May 2021, see https://mainichi.jp/english/articles/20210511/p2a/00m/0na/017000c, accessed 12 May 2021.

312 - JAIF, "Preparations Continue Toward Restarting Tokai-2 NPP", 1 June 2021, see https://www.jaif.or.jp/en/preparations-continue-toward-restarting-tokai-2-npp/, accessed 7 June 2021.

313 - JAPC, "２０２０年度 東海発電所・東海第二発電所の年間主要事業計画について", 30 April 2020 (in Japanese), see http://www.japc.co.jp/news/press/2020/pdf/200430.pdf, accessed 29 May 2021.

314 - For overview of construction work in progress see JAPC, "東海・東海第二発電所の近況について（２０２１年５月）", 12 May 2021 (in Japanese), see http://www.japc.co.jp/tokai/news/2021/pdf/tokai2105.pdf, accessed 28 May 2021.

315 - *NHK*, "女川原発2号機 再稼働への ・ 地元同意を表明 宮城県知事" ["Governor of Miyagi Prefecture announces local consent to restart Onagawa Nuclear Power Plant Unit 2"], 11 November 2020, (in Japanese), see https://www.nhk.or.jp/politics/articles/statement/48117.html; and Motoko Hasegawa, "Japan's Onagawa nuclear restart approved", *Argus*, 12 November 2020, see https://www.argusmedia.com/en/news/2159129-japans-onagawa-nuclear-restart-approved, both accessed 29 May 2021.

316 - JAIF, "NRA Approves Changes to Reactor Installation for Onagawa-2 under New Regulatory Standards", 27 February 2020, see https://www.jaif.or.jp/en/nra-approves-changes-to-reactor-installation-for-onagawa-2-under-new-regulatory-standards/, accessed 29 May 2021.

the Ishinomaki Peninsula on the Pacific coast of Miyagi Prefecture, was the 16th in Japan and the fourth BWR to win approval under the NRA's new safety standards. This major step in the approval of the safety of the reactor was reported as meaning that Onagawa-2 will be the first BWR to restart operations under the new guidelines, with completion of works planned by the owner scheduled for 2021. However, two months after securing NRA regulatory approval for its Onagawa-2 BWR, the President of Tohoku Electric announced on 30 April 2020 a two-year delay in completion of construction work at the reactor site.[317] Work is now planned to be finished by March 2023.[318]

With NRA approval, it was reported in February 2020 that Onagawa-2 would likely be the first BWR to resume operations in Japan.[319] As of November 2019, Tohoku Electric had committed ¥340 billion (about US$$_{2019}$3.1 billion) in safety retrofits at the site.[320]

Onagawa-2 still has several stages of approval by the NRA to pass before restart. There are three stages: Application for Permission to Install a Reactor (Basic design); Application for Approval of Construction Plan (Detailed design based on basic design); and Application for Approval of Operational Safety Program (Matters regarding operations, including operational safety), followed by pre inspection approval. Onagawa has passed only the first of these (Basic Design) and still has to pass the remaining stages before restart. As with all NRA review-processes, it is an enormous logistical exercise. For example, in November 2020, Tokoku Electric submitted its third tranche of documents to the NRA which are required for review under 'Approval of Construction Plan'. The documents, which were on the subjects of seismic resistance and Reactor Pressure Vessel (RPV) integrity, totaled 17,000 pages.

Doubts persist over the actual condition of the Onagawa reactors, including Unit 2. The Onagawa site is the closest nuclear plant to the epicenter of the 3/11 earthquake. Unit 2 was subcritical in startup mode on 3/11, while Units 1 and 3 were in full operation. In January 2017, the utility disclosed to the NRA that the reactor building had sustained 1,130 cracks in the walls and "lost an estimated 70 percent of structural rigidity" in the 3/11 earthquake.[321] The disclosures led Tohoku to push back restart schedule from 2018 to 2019 and then beyond 2020. The disclosures to the NRA followed an architectural investigation which identified that structural rigidity, the ability to withstand earthquakes and other stresses from outside without being distorted, was concentrated in the upper third of the reactor building with the third floor only retaining 30 percent of its integrity compared with July 1995 when the reactor began operation. It also confirmed a 25-percent loss of structural rigidity in the two above-ground floors and three basement levels.[322]

317 - Tohoku Electric, "4月定例社長記者会見概要" ["Overview of April Presidential Press Conference"], 30 April 2020 (in Japanese), see https://www.tohoku-epco.co.jp/news/press/1214692_2560.html, accessed 29 May 2021.

318 - *WNN*, "Onagawa 2 upgrade faces further delay", 4 May 2020, see https://world-nuclear-news.org/Articles/Further-delay-in-completion-of-Onagawa-2-safety-up, accessed 5 August 2021.

319 - Shota Ushio and Yuzo Yamaguchi, "Onagawa-2 to likely be first BWR to restart since Fukushima I accident", *S&P Global*, 26 February 2020, see https://www.spglobal.com/platts/en/market-insights/latest-news/electric-power/022620-onagawa-2-to-likely-be-first-bwr-to-restart-since-fukushima-i-accident, accessed 29 May 2021.

320 - *The Mainichi*, "Editorial: Reactor restart OK a reminder Japan must abandon nuclear power", 28 November 2019, see https://mainichi.jp/english/articles/20191128/p2a/00m/0na/007000c, accessed 29 May 2021.

321 - *The Asahi Shimbun*, "1,130 cracks, 70% rigidity lost at Onagawa reactor building", 18 January 2017.

322 - Ibidem.

Significantly, the disclosure contrasts starkly with the assessment and conclusions of a high-profile International Atomic Energy Agency (IAEA) mission to the plant in 2012.[323] The IAEA mission included a "Structures Team" assigned to observe and collect information on the performance of the structural elements of buildings. They reported that, as far as cracks in Unit 2 are concerned, they were "less than 0.3mm, although at some locations there were cracks of approximately 0.8mm. These minor cracks do not affect the overall integrity of the structure." The IAEA concluded: "The lack of any serious damage to all classes of seismically designed facilities attests to the robustness of these facilities under severe seismic ground shaking", and that, "the structural elements of the NPS [Nuclear Power Station] were remarkably undamaged given the magnitude and duration of ground motion experienced during this great earthquake."[324]

The NRA draft assessment of Onagawa-2 in November 2019 garnered 979 public submissions where, "many local citizens expressed concerns over the threat posed to the plant by earthquakes and tsunami, but the NRA dismissed their comments."[325] Public opposition to the operation of Onagawa, includes the major issue of emergency planning including evacuation. The location of the power plant on the Ishinomaki Peninsula with narrow roads and vulnerability to seismic and tsunami damage has led citizens to claim that there is no effective evacuation plan in place. On 28 May 2021, seventeen residents of Ishinomaki City and from within 30 km of the Onagawa nuclear plant filed a lawsuit against Tohoku Electric at the Sendai District Court, claiming that the evacuation plan formulated by the prefecture and city is not effective in the event of an accident.[326] According to the complaint, full evacuation would not be possible as planned due to traffic congestion and the difficulty in securing appropriate means of evacuation. This would lead to radiation exposure.[327]

Onagawa-3

As of 1 July 2021, the utility had not applied for NRA review of Onagawa-3 which began operation in May 2001. Tokoku Electric's President stated in October 2018 that they were in preparation for submitting a safety review application to the NRA for the reactor, without specifying a date.[328] In November 2020, President of Tohoku Electric Kojiro Higuchi said in reference to applying to the NRA for Unit 3, that, "We are not at the stage where we can make a

323 - IAEA Department Of Nuclear Safety And Security, "Mission To Onagawa Nuclear Power Station To Examine The Performance Of Systems, Structures And Components Following The Great East Japanese Earthquake And Tsunami", Mission Report to the Government of Japan, 30 July–11 August 2012, Onagawa and Tokyo (Japan), IAEA Department Of Nuclear Energy, see https://www.iaea.org/sites/default/files/iaeamissiononagawa.pdf, accessed 26 April 2019.

324 - Ibidem.

325 - *The Asahi Shimbun*, "Onagawa reactor passes screening under new NRA safety standards", 26 February 2020, see http://www.asahi.com/ajw/articles/13166013, accessed 21 May 2020.

326 - *NHK*, "女川原発2号機「避難計画 実効性ない」運転しないよう住民提訴", *Nippon Hōsō Kyōkai*, 28 May 2021 (in Japanese), see https://www3.nhk.or.jp/news/html/20210528/k10013057081000.html, accessed 29 May 2021.

327 - *Kahoku Shimpo*, "女川２号機再稼働 石巻市民、差し止め求め提訴へ 「避難計画に問題" ["Onagawa Unit 2 restarted: Ishinomaki citizens filed an injunction request 'problem with evacuation plan'"], 26 May 2021 (in Japanese), see https://kahoku.news/articles/20210526khn000016.html, accessed 29 May 2021.

328 - Yuzo Yamaguchi, "Tohoku Electric preparing to apply to NRA for Onagawa-3 safety review", *NW*, 1 November 2018.

concrete statement."[329] There are suspicions that damage sustained at Unit 3 is more significant than reported.

Shimane-2

Chugoku Electric Power Company, which owns the Shimane-2 reactor, is moving toward some form of conclusion in its safety review by the NRA, according to reports in May 2021.[330] The utility has recently submitted amendments to the NRA that raised the maximum expected design-base earthquake for the reactor from 600 gal[331] to 820 gal and the maximum tsunami height from 9.5 meters above sea level to 11.6 meters above sea level. In June 2021, the NRA approved a draft report finding the reactor to meet the new regulatory standards. The assessment will now go to public comment review.[332] Local consent and Shimane prefectural approval are still required for Shimane-2 restart, which is envisaged in spring 2022.

Reactor Closures

No additional reactors were formally declared for decommissioning in the year to 1 July 2021. The 11 commercial Japanese reactors now confirmed to be decommissioned (not including the Monju Fast Breeder Reactor (FBR) or the ten Fukushima reactors) had a total generating capacity of 6.4 GW, representing 14.7 percent of Japan's operating nuclear capacity as of March 2011.[333] Together with the ten Fukushima units, the total rises to 21 reactors and 15.2 GW or just under 35 percent of nuclear capacity prior to 3/11 that has now been permanently removed from operations (see Figure 30 and Table 3).

On 26 August 2019, at a meeting between Masahiro Sakurai, the mayor of Kashiwazaki City and TEPCO's President Tomoaki Kobayakawa, it was announced that the company would consider taking steps within five years of restart of Units 6 and 7 that could result in the decommissioning of one or more reactors at the site.[334] (See TEPCO's Kashiwazaki Kariwa).

As of mid-2021, the Japanese nuclear fleet consisting of 33 units including 24 in LTO had reached a mean age of 30.4 years, with 15 units over 31 years (see Figure 31).

329 - *Nikkei*, "東北電力社長「早期の再稼働へ全力」、女川原発地元同意で" ["Tohoku Electric Power President 'We will do our best to restart early', with local consent"], 18 November 2020 (in Japanese), see https://www.nikkei.com/article/DGXMZO66383140Y0A111C2L01000/, accessed 29 May 2021.

330 - *The Yomiuri Shumbun*, "＜島根原発２号機＞再稼働へ安全審査 大詰め" ["<Shimane Nuclear Power Station Unit 2> Safety examination for restart"], 27 May 2021 (in Japanese), see https://www.yomiuri.co.jp/local/shimane/news/20210526-OYTNT50039/, accessed 29 May 2021.

331 - A gal is a unit of acceleration and is expressed in centimeter per second squared (cm/s2).

332 - *Jiji Press*, "Shimane Nuclear Reactor Clears Regulatory Screenings for Restart", 23 June 2021.

333 - Based on a total installed capacity of 43.6 GW (not including the 246 MW Monju FBR and Kashiwazaki Kariwa 2–4) which were in LTO in March 2011.

334 - *The Asahi Shimbun*, "EDITORIAL: Put state in charge of TEPCO's plan for reactor restarts", 10 September 2019, see http://www.asahi.com/ajw/articles/AJ201909100038.html, accessed 28 May 2021.

Table 3 - Official Reactor Closures Post-3/11 in Japan (as of 1 July 2021)

Operator	Reactor	Capacity MW	Startup Year	Closure Announcement[a] dd/mm/yy	Official Closure Date[b] dd/mm/yy	Last Production	Age[c]
TEPCO	Fukushima Daiichi-1 (BWR)	439	1970	-	19/04/12	2011	40
	Fukushima Daiichi-2 (BWR)	760	1973	-	19/04/12	2011	37
	Fukushima Daiichi-3 (BWR)	760	1974	-	19/04/12	2011	36
	Fukushima Daiichi-4 (BWR)	760	1978	-	19/04/12	2011	33
	Fukushima Daiichi-5 (BWR)	760	1977	19/12/13	31/01/14	2011	34
	Fukushima Daiichi-6 (BWR)	1 067	1979	19/12/13	31/01/14	2011	32
	Fukushima Daini-1 (BWR)	1 067	1981	31/07/19	30/09/19	2011	30
	Fukushima Daini-2 (BWR)	1 067	1983	31/07/19	30/09/19	2011	28
	Fukushima Daini-3 (BWR)	1 067	1984	31/07/19	30/09/19	2011	26
	Fukushima Daini-4 (BWR)	1 067	1986	31/07/19	30/09/19	2011	24
KEPCO	Mihama-1 (PWR)	320	1970	17/03/15	27/04/15	2010	40
	Mihama-2 (PWR)	470	1972	17/03/15	27/04/15	2011	40
	Ohi-1 (PWR)	1 120	1977	22/12/17	01/03/18	2011	34
	Ohi-2 (PWR)	1 120	1978	22/12/17	01/03/18	2011	33
KYUSHU	Genkai-1 (PWR)	529	1975	18/03/15	27/04/15	2011	37
	Genkai-2 (PWR)	529	1980	13/02/19	13/02/13	2011	31
SHIKOKU	Ikata-1 (PWR)	538	1977	25/03/16	10/05/16	2011	35
	Ikata- 2 (PWR)	538	1981	27/03/18[d]	27/03/18	2012	30
JAEA	Monju (FBR)	246	1995	12/2016[e]	05/12/17	LTS[f] since 1995	-
JAPC	Tsuruga -1 (BWR)	340	1969	17/03/15	27/04/15	2011	41
CHUGOKU	Shimane-1 (PWR)	439	1974	18/03/15	30/04/15	2010	37
TOHOKU	Onagawa-1 (BWR)	498	1983	25/10/18	21/12/18[g]	2011	27
TOTAL: 22 Reactors /15.5 Gwe							

Sources: JAIF, Japan Nuclear Safety Institute, compiled by WNISR, 2021

Notes

BWR: Boiling Water Reactor; **PWR**: Pressurized Water Reactor; **FBR**: Fast Breeder Reactor; **LTS**: Long-Term Shutdown.

JAPC: Japan Atomic Power Company; **JAEA**: Japan Atomic Energy Commission

(a) – Unless otherwise specified, all announcement dates from Japan Nuclear Safety Institute, "Licensing status for the Japanese nuclear facilities", 23 June 2021, see http://www.genanshin.jp/english/facility/map/, accessed 5 August 2021.

(b) – Unless otherwise specified, all closure dates from individual reactors' page via JAIF, "NPPs in Japan", Japan Atomic Industrial Forum, see http://www.jaif.or.jp/en/npps-in-japan/, as of July 2021.

(c) – Note that WNISR considers the age from first grid connection to last production day.

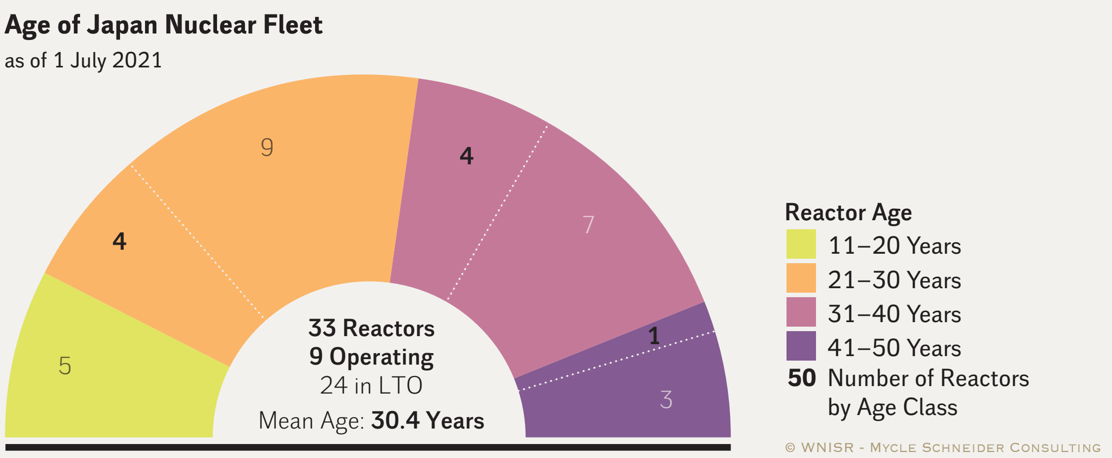
(d) – *WNN*, "Shikoku decides to retire Ikata 2", 27 April 2018, see http://www.world-nuclear-news.org/C-Shikoku-decides-to-retire-Ikata-2-2703184.html, accessed 22 July 2018.

(e) – *The Mainichi*, "Japan decides to scrap trouble-plagued Monju prototype reactor", 21 December 2016.

(f) – The Monju reactor was officially in Long-Term Shutdown or LTS (IAEA-Category Long Term Shutdown) since December 1995. Officially closed in 2017.

(g) – The decision to close the reactor was announced in October 2018.

Figure 31 · Age Distribution of the Japanese Nuclear Fleet



Sources: WNISR with IAEA-PRIS, 2021

Energy Policy Key to Nuclear Future

Japan's latest Strategic Energy Plan (SEP), also called the Basic Energy Plan, has been under negotiation during the past year and is to be finalized and published in summer 2021.

The revision of the SEP takes place under the Advisory Committee for Natural Resources and Energy, under the Agency for Natural Resources and Energy (ANRE), which itself is within the Ministry of Economy Trade and Industry (METI). The draft SEP, presented on 21 July 2021 at METI's strategic policy committee at its advisory committee for natural resources and energy, proposed:

- a significant increase in the proposed share of renewable energy from the current target of 22–24 percent of electricity generation to between 36–38 percent;
- fossil fuel generation, in particular coal, to be reduced from 56 percent to 41 percent;
- nuclear generation is to remain unchanged at 20–22 percent, a target that would require in the range of 30 reactors to be in operation by 2030.[335]

The draft SEP is scheduled to be approved by the Cabinet before Japan submits its Nationally Determined Contributions (NDCs) ahead of the 26th UN Climate Change Conference of the Parties (COP26).

The Japanese government is currently a coalition made up of the largest party, the Liberal Democratic Party (LDP) and its smaller partner, the New Komeito Party. Reports in 2021 suggested that the LDP was moving towards active support for new construction and replacement of existing nuclear power plants, which would be a change to the present SEP. As of 1 July 2021, it was unclear whether New Komeito's position which was for eventual

335 - METI, "エネルギー基本計画（素案）の概要" ["Outline of basic energy plan (draft)"], 21 July 2021 (in Japanese), see https://www.enecho.meti.go.jp/committee/council/basic_policy_subcommittee/2021/046/046_004.pdf; and *Kyodo News*, "Japan to raise FY 2030 renewables to meet carbon neutrality goal", 21 July 2021, see https://nordot.app/790535466852958208?c=445918389795193953, both accessed 18 August 2021.

zero nuclear power and a society not dependent on nuclear power would prevent language change to the SEP. New Komeito does not support new construction and is in favor of limiting operational licenses to 40 years.

The LDP, which has rarely been out of power since the mid-1950s, has been the principal political driver of nuclear power policy in Japan. Support for nuclear remains strong inside the party but with notable exceptions, including in Ministerial positions. Different LDP parliamentary associations have advocated slightly varying policies towards nuclear power. For example, "Headquarters for Achievement of Carbon Neutrality by 2050", under direct supervision of Prime Minister Suga, recommends that nuclear energy will be valued, while renewable energies will be introduced to the maximum extent possible.[336]

On 25 May 2021, a draft Strategic Energy Plan was proposed at a joint conference of the LDP's Economy, Trade and Industry Division and its Research Commission on Comprehensive Energy Strategy. Research Commission Chair Fukushiro Nukaga, a former Finance Minister, stressed that nuclear energy must be utilized in order to realize carbon neutrality. The draft called for renewable energy to be deployed to the maximum possible extent, and also a "correction" of the forty-year license limit. These would be compatible with the "3E+S" which provides the framework for current Japanese energy policy – namely: energy security, economic efficiency and environmental protection, along with safety.[337]

The removal of the 40-year license limit for reactor operation, as is being suggested for the next Strategic Plan, would be an important signal to Japan's electric utilities of central government policy commitment and support for a significant share of nuclear power in Japan's future electricity. In 2011, NISA, Japan's then regulator, granted life extension beyond 40 years to Fukushima Daiichi-1 only two months before the 11 March accident. Post-Fukushima revised guidelines applied by the NRA sought to avoid this by limiting operation of nuclear reactors to 40 years, which if strictly applied would lead to the reduction and eventual decommissioning of reactors. However, the guidelines did allow, and only under exceptional circumstances, for reactors to be eligible for one license extension of up to 20 years. The restart of Mihama-3, and planned restart of Takahama-1 & -2, all of which applied and were granted by the NRA 20-year license extensions to operate beyond 40 years, highlights the likely future reality in Japan. With sufficient financial incentive, utilities are almost certainly going to seek to extend the operations of their existing fleet. (See Capacity Market below).

The justification for allowing license extension within the revised guidelines was in response to possible future electricity shortages.[338] In 2021, this remains a concern and prospect of narrow electricity supply margins, and even blackout, has been an important factor in the context of this year's drafting of the Strategic Energy Plan. With very tight margins in the past winter, due to a combination of surge in electricity prices, multiple units offline, and extended cold

336 - Kenta Nagai, "Opinions Differ Within Japan's Governing Coalition Concerning Nuclear Power", JAIF, 8 June 2021, see https://www.jaif.or.jp/en/opinions-differ-within-japans-governing-coalition-concerning-nuclear-power/, accessed 8 June 2021.

337 - Kenta Nagai, "Support Grows Within LDP for Nuclear Power", JAIF, 4 June 2021, see https://www.jaif.or.jp/en/support-grows-within-ldp-for-nuclear-power/, accessed 28 May 2021.

338 - *The Asahi Shimbun*, "EDITORIAL: Limiting Life of Nuclear Plants to 40 Years Should Be Continued", 26 November 2020, see http://www.asahi.com/ajw/articles/13964250, accessed 5 June 2021.

weather,[339] the lobby for maintaining nuclear capacity received a boost during recent months. In May 2021, Japan's power coordinator, the Organization for the Cross-regional Coordination of Transmission Operators (OCCTO), issued its outlook for summer and winter 2021 noting energy supply risks during peak demand seasons. Planned decommissioning of fossil fuel plants is outpacing the installation of new renewable capacity. *Platts* reported Masashi Morimoto, director of METI's Office for Electricity Supply Policy, as warning that, "In the next five to 10 years, we expect thermal power will continue to have an extremely severe outlook…Of course increasing renewable energy and adding storage battery and other tools will be important, but securing the immediate stable supply is becoming a critical issue."[340] Five reactor units are scheduled to go offline for inspection and maintenance in the year to 31 March 2022. The prospects and risks, real or otherwise, of a shortfall in energy supply to Japanese society will remain a central theme in the coming years and will inevitably provide leverage for utilities and policy makers to maintain nuclear capacity.

Former cabinet minister Daishiro Yamagiwa stated 25 May 2021 that construction of new and replacement reactors would remain part of the LDP's proposal, as they would be "necessary to achieve carbon neutrality".[341] The LDP's Parliamentary Association for Promotion of Replacement Advanced Reactors also called on the government to include the construction of new nuclear reactors in the Strategic Plan. However, as mentioned above, due to opposition from two LDP-Ministers, language advocating the maximum utilization of nuclear energy was removed from the draft SEP.[342]

Capacity Market

The capacity market is a mechanism whereby utilities can secure financing for their existing power plants. The case for capacity markets is premised on the basis that in a liberalized electricity market, generators are not incentivized to maintain surplus generation. For Japan's large nuclear utilities, faced with growing competition from renewable energy, the creation of the capacity market is one of multiple electricity market reforms that have been introduced that will provide further incentive to restart reactors, and when the time comes, apply for a 20-year license extension.[343] There are more than 600 power retailing companies in Japan who purchase 85 percent of their electricity on the wholesale market. The capacity market fee is paid to the successful utilities by the retailers via the Organization for Cross-regional Coordination of Transmission Operators (OCCTO).

339 - Aaron Sheldrick, "Japan power prices hit record above 200 yen/kWh as cold grips, supplies tighten", *Reuters*, 21 January 2021, see https://www.reuters.com/article/japan-electricity-prices-idUKL4N2JN01J, accessed 3 June 2021.

340 - Takeo Kumagai, "Analysis: Japan's power supply facing risks as it moves to decarbonize energy mix", *S&P Global*, 21 May 2021, see https://www.spglobal.com/platts/en/market-insights/latest-news/coal/052121-japans-power-supply-facing-risks-as-it-moves-to-decarbonize-energy-mix, accessed 3 June 2021.

341 - JAIF, "Support Grows Within LDP for Nuclear Power", 4 June 2021, op. cit.

342 - *Kyodo News*, "政府、原発の「最大限活用」削除", ["Government removes 'maximum use' of nuclear power plants"], 3 June 2021 (in Japanese), see https://nordot.app/772993140909129728?c=113147194022725109, accessed 6 June 2021.

343 - Matsukubo Hajime, "The Capacity Market: An overview and issues", CNIC, 5 June 2019, see https://cnic.jp/english/?p=4435, accessed 12 May 2021.

The first auction was held in 2020 and covered the year starting April 2024. The price was set at ¥14,137 (US$131) per kilowatt for surplus generation capacity, the highest in the world.[344] Nearly 168 GW of capacity was accepted in the auction, meaning that utilities will receive ¥1.6 trillion (US$14.6 billion) in subsidies for the year April 2024 – March 2025. METI did not provide details as to which utilities and which generation facilities will get subsidies for the 2024 capacity, but they did report that of the total capacity of bidders, 42 percent were gas-fired facilities, 25 percent were coal-fired facilities, and only 4.2 percent were nuclear reactors. While the nuclear percentage is low compared to the total within the market, it represents a high share of the total operating nuclear fleet available for consideration in 2020.

A total of 7.1 GW of nuclear capacity was secured by Japanese utilities for the 2024–2025 capacity market, out of the total of 8.7 GW that was available as of 1 July 2020. While it is impossible to say which reactors have secured contracts, most likely seven of the nine reactors that had restarted as of July 2020 had secured contracts under the capacity market. A likely breakdown is three reactors each for Kyushu Electric and Kansai Electric plus Shikoku Electric's single reactor at Ikata. This share of the capacity market will yield ¥67.2 billion (US$613 million) for the three utilities in 2024/25. With the restart of additional reactors in the coming years, it is nearly certain that the nuclear share of the capacity market will increase with resulting significant financial benefits accruing.[345]

The capacity market inevitably will have a negative impact on new and renewable energy companies, which are not entitled to apply to the capacity market if they are subject to financing via the Feed-In Tariff. This led Environment Minister Shinjiro Koizumi in 2020 to request the reform of the system, "so that it will promote expansion of clean energy."[346]

METI confirmed changes to the capacity-market system in April 2021 to be applied in time for the next auction in September/October 2021 and covering the period April 2025–March 2026.[347] The reforms include a lower fee for older coal power plants which is aimed at reducing total coal generation capacity.

Prospects for Nuclear Power

Ten years after 3/11, Japan's nuclear utilities have failed to overcome the multiple obstacles to restarting a major part of their nuclear fleet. The public and political opposition to nuclear power was highlighted on the 10th anniversary of the Fukushima Daiichi accident, when five former Prime Ministers of Japan— Hosokawa Morihiro, Murayama Tomiichi, Koizumi Jun'ichiro, Hatoyama Yukio and Kan Naoto—publicly called for the end of nuclear power.[348] No other

344 - Aya Takada, "Japan's Koizumi Eyes Reform in a $15 Billion Power Market", *Bloomberg*, 6 October 2020, see https://www.bloomberg.com/news/articles/2020-10-06/japan-s-koizumi-eyes-reform-in-15-billion-power-capacity-market; and Motoko Hasegawa, "Japan mulls 177GW for first power capacity auction", *Argus*, 29 May 2020, see https://www.argusmedia.com/en/news/2109642-japan-mulls-177gw-for-first-power-capacity-auction, both accessed May 2021.

345 - Ibidem.

346 - Ibidem.

347 - Motoko Hasegawa, "Japan revises power capacity auction rules", *Argus*, 28 April 2021, see https://www.argusmedia.com/en/news/2209730-japan-revises-power-capacity-auction-rules, accessed 12 May 2021.

348 - CNIC, "Five Former Prime Ministers Appeal for No Nukes", 3 April 2021, see https://cnic.jp/english/?p=5394, accessed 28 May 2021.

country in the world with a large nuclear industry has garnered such opposition—and yet the ruling party of government, the LDP, remains wedded to nuclear power.

The number of reactors operating in Japan has barely changed during the past few years. However, by the end of FY 2023, it is expected that there will be 12, possibly 14 reactors operating in Japan, three of which are reactors resuming operation after being in LTO between ten to twelve years If these reactors operate for a full year, total electricity generation could be in the order of 82–99 TWh, based on the maximum output from these reactors in the immediate years prior to March 2011. In reference to the annual electricity generation in 2020, this would be 9–10 percent of total production, which is around half of the current government target of 20–22 percent by 2030. The path to achieving this larger share is less clear.

Any assessment of the likely order of restarts must take into account multiple factors: where they are in the NRA review process, which includes the status of seismic assessments; progress towards completion of construction of post Fukushima safety measures; and the local and prefectural politics in terms of opposition to restart, including status of lawsuits. All these uncertainties mean there a several scenarios possible over the coming years.

If TEPCO can overcome the opposition in Niigata, the next reactors to restart could be Kashiwazaki Kariwa-7 followed by Unit 6 in 2022–2023. Thereafter, there is a possibility of restart of Shimane-2, Onagawa-2 and even Tokai-2 by 2023–2024. Delays on these are also a distinct possibility, if not a certainty. Approval for the operation of the new Shimane-3 ABWR looks possible with a start of operations by 2025. This would bring the total number of reactors operating in Japan to 18 by mid-decade. Based on the same estimates, total electricity generation with one full year of operation could be as much as 127 TWh by 2026/27, equal to 14 percent of Japan's electricity. On balance, this is one plausible scenario, if rather favorable to the utilities.

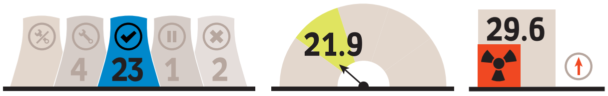
This WNISR analysis is more favorable to the outlook for nuclear than for example Fitch Solutions which in February 2020 noted, that as a result of public opposition and technical challenges, "We expect these factors will continue to challenge Japan's push for nuclear restarts, prompting our more bearish outlook on nuclear power generation which we now expect will reach approximately 85.4TWh by 2029, accounting for 8.4% of the total power mix."[349]

There are other reactors under NRA review, including two units at Chubu Electric's Hamaoka site; Hokkaido Electric's three-unit Tomari plant; and Tohoku Electric's Higashidori. There is even a limited prospect of completion of construction of J-Power's Ohma ABWR and TEPCO's Higashidori ABWR. If all of these were to overcome the major obstacles to their operation, which is unlikely, then additional electricity generation by 2030 could in theory reach 59 TWh, for a total of 186 TWh, which would represent 20 percent of Japan's electricity demand (on basis of the 2020 numbers). This would meet the current SEP share for nuclear generated electricity produced by operating 26 nuclear reactors at an output based on their historical maximum.

349 - Danielle Isaac, "Japan to miss nuclear targets amidst industry headwinds", *Asian Power*, 24 February 2020, see https://asian-power.com/regulation/news/japan-miss-nuclear-targets-amidst-industry-headwinds, accessed 18 May 2020.

The barriers to achieving this scale of nuclear generation by 2030, even with all the financial incentives, market distortion, and central government support, look insurmountable. Therefore, there is no prospect that the SEP lays out the nuclear future for Japan during the next critical decade. Without a more ambitious expansion of renewable energy during the coming years, the shortfall in electricity supply due to the failure to meet nuclear targets, could be filled by fossil fuel. The 2021-SEP thus takes on even greater significance, if Japan is to begin to have any prospects of rapidly reducing its emissions by 45 percent by 2030, securing the necessary energy transition and to meet its 2050 goals of decarbonization and zero emissions.

SOUTH KOREA FOCUS



On the Korean Peninsula, South Korea (Republic of Korea) operates 23 reactors, plus one reactor in Long-Term Outage (LTO), and has four reactors under construction. One of two reactors which had been in LTO, Hanbit-3, resumed operation in November 2020. Both reactors had been shut for more than two and three years respectively, due to voids in concrete containment walls and corrosion on containment liner plates.

In December 2020, the Government of President Moon Jae-in announced its 9th Basic Plan for Long-term Electricity Supply and Demand which aims to significantly increase renewable energy, while reducing installed nuclear capacity and coal-fired plants in the period up to 2034. However, the possibility that current Korean energy policy will be overturned looms with the Presidential election scheduled for 2022.

South Korea's nuclear fleet, owned by Korea Hydro & Nuclear Power Company (KHNP), is located at the Hanbit, Hanul, Kori and Wolsong sites. Nuclear power provided 152.6 TWh in 2020, almost 10 percent more than the 138.8 TWh in 2019.

Construction

All four reactors under construction in South Korea are APR-1400 design. Construction of Shin-Hanul-1 and -2 has been nearly completed, but startup dates have been pushed back. Fuel loading for Unit 1 began on 14 July 2021 while Unit 2 is planned to be fueled one year later, on 1 July 2022.[350] There is no date for grid connection, but KHNP has scheduled commercial operation for Unit 1 on 31 March 2022, and exactly one year later for Unit 2.

KHNP had also planned to construct two additional reactors at the site, Shin-Hanul-3 and -4. But they were ordered by the Moon government in 2017 to suspend their plans. The government's 2017-Basic Plan for Long-term Electricity Supply and Demand cancelled Shin-Hanul-3 and -4, as well as four other reactors Cheonji-1 and -2 (in Yeongdeok) and either Cheonji-3 and -4 or Daejin-1 and -2 (in Samcheok). While there is no immediate prospect of construction actually beginning under the current administration, in February 2021, the Ministry of Trade, Industry and Energy (MOTIE) extended the construction license permits for Shin-Hanul-3 and -4, which

350 - KHNP, "Nuclear Power Construction - Shin-Hanul #1,2", Korea Hydro & Nuclear Power Co., Updated 30 April 2021, see https://cms.khnp.co.kr/eng/content/547/main.do?mnCd=EN03020303, accessed 4 June 2021.

were due to expire, until end of 2023.[351] The suspension of construction could be terminated if the opposition party wins the upcoming 2022-Presidential elections.

The two other reactors, Shin Kori-5 and Shin Kori-6, have been under construction since April 2017 and September 2018 and were planned to be completed in March 2023 and June 2024 respectively.[352] However, in March 2021, KHNP applied for an extension of the construction license, with a completion schedule for Shin Kori-5 now extended one additional year until 31 March 2024, and for Shin Kori-6, nine months later to 31 March 2025.[353]

Typhoon Shutdowns

As a result of two typhoon systems hitting Korea in September 2020, a total of 5.3 GW of nuclear capacity was shut down. Six KHNP reactors suffered loss of off-site power caused by Typhoon Maysak on 3 September 2020 and Typhoon Haishen on 7 September 2020. Kori-3 and -4, and Shin Kori-1 and -2 had been operating on 3 September 2020 when they were tripped and emergency diesel generators began operation. Kori-1 and -2 had been offline undergoing refueling and maintenance at the time. On 7 September 2021, Wolsong-1 and -2 were tripped while the supply of off-site power was sustained and the reactors started to operate at 60 percent of reactor power, and then were shut down.

The Nuclear Safety and Security Commission (NSSC) and the Ministry of Trade, Industry and Energy (MOTIE) investigation into the event concluded that wind-carried salt had deposited on the transformer instruments, which measure electrical quantities generated from the reactors, which led to fire sparks or flashovers. It led to the opening of the breaker in the switchyard, which was the beginning of the event. KHNP said the typhoon was stronger than expected. However, Han Byeong-seop, director of the Korean Institute for Nuclear Safety (KINS) said that even if salinity was the cause, the real problem might be "poor-quality parts and slapdash construction," *The Hankyoreh* newspaper reported.[354] Countermeasures to be applied include replacing insulators with salt-resistant materials and minimizing parts exposed to the outside environment, including main transformers, standby transformers, and instrument transformers of the reactors by sealing the facilities.

As a consequence of the typhoons, combined with reactors offline due to refueling and maintenance during the off-peak autumn season, a total of 12 reactors with a combined capacity of 10.9 GW were offline in September 2020, or 47 percent of South Korea's overall

351 - *NucNet*, "Ministry Extends Construction Licence For Delayed Shin-Hanul Units", 23 February 2021, see https://www.nucnet.org/news/ministry-extends-construction-licence-for-delayed-shin-hanul-units-2-2-2021, accessed 9 June 2021.

352 - *S&P Global*, "S Korea's 9 nuclear plants restarting Sep-Oct to pressure LNG demand", 2 September 2020, see https://www.spglobal.com/platts/en/market-insights/latest-news/natural-gas/090220-s-koreas-9-nuclear-plants-restarting-sep-oct-to-pressure-lng-demand, accessed 9 June 2021.

353 - *Chosun Biz*, "'탈원전 기조 유지' 문승욱…후쿠시마 사고로 원전 불안감 커져"["Maintaining the post-nuclear power cycle… increased insecurity at the nuclear power plant due to the Fukushima accident - Seung-wook Moon"], 4 May 2021 (in Korean), see https://biz.chosun.com/policy/policy_sub/2021/05/04/ET6KS2F65JFEDEUGPER4U2M7CU/, accessed 9 June 2021.

354 - *The Hankyoreh*, "Six reactors shut down due to salinity during recent typhoons", 11 September 2020, see https://english.hani.co.kr/arti/english_edition/e_national/961833.html, accessed 28 July 2021.

capacity of 23 GW across 24 nuclear reactors, KHNP reported on 28 September 2020.[355] (See also Nuclear Power and Climate Change Resilience).

Permanent Closure

The NSSC formally passed the bill for the permanent closure of Wolsong-1 on 24 December 2019. The decision has met protests from the main opposition Liberal Democratic Party (LDP) and the labor union of KHNP, which have launched legal action against NSSC and its members. The controversy over the closure has escalated during the past year (see below).

Table 4 – Status of Nuclear Reactor Fleet in South Korea (with scheduled closure dates)

Reactor	Type	MW	Grid connection	Expected Closure
Kori-2	PWR	640	1983	2023
Kori-3	PWR	1 011	1985	2024
Kori-4	PWR	1 012	1985	2025
Hanbit-1	PWR	995	1986	2025
Hanbit-2	PWR	988	1986	2026
Wolsong-2	PHWR	606	1997	2026
Wolsong-3	PHWR	630	1998	2027
Hanul-1	PWR	966	1988	2027
Hanul-2	PWR	967	1989	2028
Wolsong-4	PHWR	609	1999	2029
Hanbit-3	PWR	986	1994	
Hanbit-4	PWR	970	1995	
Hanbit-5	PWR	992	2001	
Hanbit-6	PWR	993	2002	
Hanul-3	PWR	997	1998	
Hanul-4	PWR	999	1998	
Hanul-5	PWR	998	2003	
Hanul-6	PWR	997	2005	
Shin-Kori-1	PWR	996	2010	
Shin-Kori-2	PWR	996	2012	
Shin-Kori-3	PWR	1 416	2016	
Shin-Kori-4	PWR	1 418	2019	
Shin-Wolsong-1	PWR	997	2012	
Shin-Wolsong-2	PWR	993	2015	

Sources: MOTIE, 2017

Following the closure of Wolsong-1, seven additional reactors are planned to be closed just prior to reaching their 40-year operating lifetime with a total 6.6 GW of capacity. The reactors are Kori-2 to be closed in 2023, Kori-3 in 2024, Kori-4 and Hanbit-1 in 2025, and Hanbit-2 in 2026, Hanul-1 in 2027 and Hanul-2 in 2028. Three reactors are scheduled to be closed as they

355 - Atsuko Kawasaki and Charles Lee, "Feature: South Korea bucks trend by turning to LSFO after typhoon-led nuclear shutdowns", *S&P Global*, 28 September 2020, see https://www.spglobal.com/platts/en/market-insights/latest-news/electric-power/092820-feature-south-korea-bucks-trend-by-turning-to-lsfo-after-typhoon-led-nuclear-shutdowns, accessed 8 July 2012.

reach their 30-year lifetime: Wolsong-2 in 2026, Wolsong-3 in 2027 and Wolsong-4 in 2029 (see Table 4).[356]

Containment Liner Plate Corrosion

In recent years, there have been extended outages of South Korea's nuclear reactors. The principal reason has been that out of the 24 reactors South Korea operated (prior to startup of Shin-Kori-4 and closure of Wolsong-1 in 2019) 21 were found to have corrosion in the Containment Liner Plates (CLP) or voids in the concrete structure.[357] Reactor containment-buildings in South Korea are insulated with a CLP of six millimeters in diameter, and then concrete 1.2 meters in diameter thick. As the U.S. Nuclear Regulatory Commission (U.S. NRC) noted in 1997: "Any corrosion (metal thinning) could change the failure threshold of the liner plate under a challenging environmental or accident condition. Thinning has the effect of changing the geometry of the liner plate, creating different transitions and strain concentration conditions. This may reduce the design margin of safety against postulated accident and environmental loads."[358]

Under nuclear regulation, evidence of structural deterioration that could affect the structural integrity or leak-tightness of metal and concrete containments must be corrected before the containment can be returned to service. Corrosion of a liner plate can occur at a number of places where the metal is exposed to moisture, or where moisture can condense (behind insulation) or accumulate. The corrosion repair has consisted of removal of the damaged liner section and embedded foreign material (e.g. wood), grouting the resulting void, and replacing the liner plate section.[359] Root cause analysis of the causes of CLP corrosion reported by Korea Institute of Nuclear Safety (KINS) were predominately due to exposure to moisture (environment), as well as the presence of foreign debris.[360] KHNP is required to submit its structural integrity assessment of the concrete voids found in the containment building of the reactors to the NSSC, which will then require a technical review by KINS, a technical support organization, and independent verification by the Korea Concrete Institute.[361] For details on KHNP reactors impacted by CLP see WNISR2019 and WNISR2020.

One of the reactors impacted with CLP remaining in LTO is Hanbit-4 though it is scheduled to resume operation in August 2021, while Hanbit-3, also with CLP problems, returned to operation at the end of 2020. On 7 July 2019, Korean broadcaster *MBC* reported that KHNP had confirmed 94 holes between the steel plate and concrete inside the reactor building of

356 - MOTIE, "The 8th Basic Plan for Long-term Electricity Supply and Demand (2017-2031)", Ministry of Trade, Industry and Energy, 2017, see https://www.kpx.or.kr/www/downloadBbsFile.do?atchmnflNo=30051, accessed 9 June 2021.

357 - Charles Lee, "South Korea completing safety checks on all reactor containment structures", *Nucleonics Week*, 9 May 2019.

358 - Office of Nuclear Reactor Regulation, "Information Notice No. 97-10: Liner Plate Corrosion in Concrete Containments", U.S.NRC, 13 March 1997, see https://www.nrc.gov/reading-rm/doc-collections/gen-comm/info-notices/1997/in97010.html, accessed 29 June 2021.

359 - Jason P. Petti, Dan Naus et al., "Nuclear Containment Steel Liner Corrosion Workshop: Final Summary and Recommendation Report", Sandia National Laboratories, operated for the U.S. Department of Energy, Report SAND2010-8718, July 2011, see https://www.nrc.gov/docs/ML1121/ML112150012.pdf, accessed 29 June 2021.

360 - Yonglak Paek, Sangyun Kim, Euisik Yoon and Hun Cha, "Introduction of Containment Liner Plate (CLP) Corrosion", Korea Institute of Nuclear Safety, Transactions of the "Korean Nuclear Society Spring Meeting", 17–18 May 2018, see https://www.kns.org/files/pre_paper/39/18S-189%EB%B0%B1%EC%9A%A9%EB%9D%BD.pdf, accessed 29 June 2021.

361 - NSSC, "Regarding Concrete Voids of Containment Buildings of Hanbit Unit 3 and 4, the NSSC Will Verify Structural Integrity Objectively and Transparently", 12 March 2020.

Hanbit-3 and 96 holes in Hanbit-4. KHNP, according to MBC, explained that the holes found are up to 90 cm in size, but there would be "no problem with the structural stability of the containment."[362]

Hanbit-3 entered LTO status in July 2020. However, on 12 November 2020 and following repairs to the CLP damage, the NSSC approved criticality of Hanbit-3, which had been shut down on 11 May 2018.[363] There were further delays to the restart plans for Hanbit-4, following shutdown in 2017 and originally scheduled for October 2020.[364] As of 1 July 2021, Hanbit-4 remains in LTO status but is due to restart operations on 17 August 2021.[365]

Wolsong Debacle and Uncertainty Over Energy Policy

Highlighting the political and economic pressure against the Moon administration over its energy policy is the on-going controversy over the closure of Wolsung-1. The Pressurized Heavy Water Reactor (PHWR) was closed on 24 December 2019. The closure of the Wolsong-1 reactor has been used by those opposed to President Moon's energy policy and is now set to continue in the runup to the 2022 Presidential election. The leading opposition candidate for President, Yoon Seok-youl, is the former Prosecutor General who ordered the investigation into the Wolsong case, and later resigned.[366]

The Wolsong-1 reactor was a CANDU-6 PHWR design, which was connected to the grid on 31 December 1982, and had originally been licensed for 30 years until 2012, but KHNP secured a license extension of 10 years to November 2022. KHNP spent 700 billion won (U$616 million) during the period 2009–2011 on a first-of-its-kind complete retubing. All 380 zirconium calandria-tubes, which contain the reactor fuel channels and which allow heavy water coolant to circulate, were removed and replaced.[367] KHNP stated that the work should enable the 679-MWe reactor to operate for a further 25 years.[368] The reactor closed in November 2012, when its operating license expired, and restarted June 2015, after the NSSC voted in favor of lifetime extension.[369] President Moon was elected in 2017 on a manifesto that included early

362 - *MBC News*, "한빛 3·4호기 격납건물서 구멍 190곳 발견" ["190 hatch holes in the containment building of Hanvit 3. 4"], 7 July 2019 (in Korean), see https://n.news.naver.com/article/214/0000961974, accessed 2019.

363 - NSSC, "NSSC Approved Criticality of Hanbit Unit 3 During Periodic Inspection and to Conduct Power Ascension and Other Remaining Tests", 12 November 2020.

364 - *S&P Global*, "S Korea's 9 nuclear plants restarting Sep-Oct to pressure LNG demand", 2 September 2020, see https://www.spglobal.com/platts/en/market-insights/latest-news/natural-gas/090220-s-koreas-9-nuclear-plants-restarting-sep-oct-to-pressure-lng-demand, accessed 29 June 2020.

365 - *Argus*, "Nuclear disruption to support South Korea coal burn", 22 March 2021, see https://www.argusmedia.com/en/news/2198274-nuclear-disruption-to-support-south-korea-coal-burn, accessed 29 June 2021.

366 - Ser Myo-ja"Yoon incinerates Moon's anti-nuclear energy policy", *The Korea JoongAng Daily*, 6 July 2021, see https://koreajoongangdaily.joins.com/2021/07/06/national/politics/Yoon-Seokyoul-nuclear-phaseout-Wolsong1/20210706183300295.html, accessed 6 July 2021.

367 - AECL, "AECL achieves milestone in Korean CANDU Refurbishment Project", Atomic Energy of Canada Limited, 1 December 2010, see https://www.newswire.ca/news-releases/aecl-achieves-milestone-in-korean-candu-refurbishment-project-546964022.html, accessed 5 June 2021.

368 - *WNN*, "Korean Candu restarts after refurbishment", 29 July 2011, see https://www.world-nuclear-news.org/C_Korean_Candu_restarts_after_refurbishment_2907114.html, accessed 5 June 2021.

369 - NSSC, "The Commissioners Decided to Approve Continued Operation of Wolsong Unit 1 in the 35th Meeting", Press Release, 27 February 2015, see http://www.nssc.go.kr/nssc/english/release/list.jsp?mode=view&article_no=17977&pager.offset=10&board_no=501, accessed 10 July 2017.

closure of Wolsong-1. In June 2018, the commercial operation of Wolsong-1 was "terminated",[370] and the NSSC on 24 December 2019 formally passed the bill for its closure.[371]

The opposition to the closure decision (and Moon's overall nuclear and energy policy) was given a boost in October 2020 when the Korean Board of Audit and Inspection (BAI), concluded that, "The economic effectiveness of continuing operation of the reactor was unreasonably devalued," as result of a "faulty assessment that unfairly underestimated the economic advantage of keeping it operating".[372] The investigation was launched at the request of the Korean National Assembly in September 2019. The BAI avoided ruling on the validity of the state-run corporation's decision. The BAI found that an accounting firm had submitted a report that undervalued the economic advantage of continuing the operation of the reactor to KHNP in June 2018.

The Ministry of Trade, Industry and Energy (MOTIE), as part of the Moon administration's energy policy, had already decided to close the reactor prior to the report being completed. Paek Woon-kyu, President Moon Jae-in's first MOTIE minister decided on 4 April 2018 that the reactor would be closed earlier than the scheduled closure in 2022. KHNP, according to BAI, was prevented from considering any other options and this influenced the company's economic efficiency assessment.

The BAI report did make clear that the audit looked only at the economic factors, not wider safety issues, stating that, "Safety and region-based elements were excluded from the scope of the audit," and that,

> The decision to close the reactor was a result of a range of factors such as safety and regional acceptance, in addition to economic viability. As the inspection was not about determining the validity of the policy decision, it is not appropriate to view the results of this inspection as a comprehensive assessment on the closure of Wolsong-1 reactor. [373]

The BAI did conclude that Minister Paek deserved to be punished for having violated the State Public Officials Act, but no reprimand was recommended at that time because he had retired from the government in September 2018. The BAI recommended the government issue a strong warning to the president of KHNP and punish public servants who obstructed its audit.

Defending the decision to close the reactor, Rep. Youn Kun-young of the ruling Democratic Party warned that, "Shutting down the Wolsong-1 reactor was Moon's presidential campaign pledge, and it was a policy endorsed by the people through the election. Auditing or investigating the policy to shut down the reactor is a direct challenge to democracy".[374]

370 - KHNP, "Nuclear Power Operation - Plant Status", 31 December 2018, see http://cms.khnp.co.kr/eng/content/529/main.do?mnCd=EN03020101, accessed 29 June 2021.

371 - NSSC, "The 112th Meeting of the Commission Was Held", 24 December 2019.

372 - Ser Myo-ja, "BAI slams Wolsong I nuclear plant shutdown process", *The Korea JoongAng Daily*, 20 October 2020, see https://koreajoongangdaily.joins.com/2020/10/20/national/politics/Board-of-Audit-and-Inspection-BAI-Wolsong/20201020191600377.html, accessed 5 June 2021.

373 - *Asia Today*, "BAI: Wolsong-1 reactor's economic viability unreasonably undervalued", 21 October 2020, see http://en.asiatoday.co.kr/view.php?key=20201020002137344, accessed 8 July 2021.

374 - *The Korea JoongAng Daily*, "BAI head refutes ruling party, stands by Wolsong probe", 23 February 2021, see https://koreajoongangdaily.joins.com/2021/02/23/national/politics/BAI-Choe-Jaehyeong-Wolsong/20210223172300387.html, accessed 29 June 2021.

The main opposition People Power Party (PPP) demanded a criminal investigation into the government's decision to close the reactor and public servants' attempts to hinder the audit. In December 2020, Daejeon District Prosecutors Office sought arrest warrants for three officials from MOTIE suspected of deleting documents related to the closure of Wolsong-1 charging them with disturbing the state auditors' examination and alleging that they had destroyed 444 materials and files about the decision.

On 1 July 2021, the Prosecutors' Office charged former Minister of Trade, Industry and Energy Paik Un-gyu and former presidential secretary for industrial policy Chae Hee-bong with abuse of power and obstructing the business of KHNP. Chung Jae-hoon, president of the KHNP, was indicted on charges of breach of trust and obstruction of business.[375]

Moon Administration's Energy Policy Under Threat

Despite the mounting pressure on the administration of President Moon from the main opposition party, industry and much of the media, the government confirmed a more ambitious renewables energy policy, the "9th Long-Term Basic Blueprint for Power Supply over 2020–2034", which was announced on 20 December 2020.

Details of the plan, as reported in WNISR2020, were confirmed in the final version. The Government plan is to reduce dependence on nuclear and fossil fuel from the 46.3 percent in 2020 to 24.8 percent by 2034. Renewable energy is to be expanded from 20 GW in 2020 to 77.8 GW, supplying 40 precent of the country's electricity by 2034, compared with the current 15.1 percent.[376]

The number of reactor units would peak at 26 in 2024, and by 2034 there would be 17 reactors operating with a total of 19.4 GW installed nuclear capacity generating 10.4 percent of South Korea's electricity.[377] This compares with 24 reactors (including the one in LTO) in 2020 and 23.3 GW and 19.2 percent of the nation's electricity. A total of 5.6 GW of new nuclear capacity—Shin-Hanul-1 and -2, and Shin-Kori-5 and -6 are now scheduled to begin commercial operation between 2022–2024.

The uncertainty going forward was highlighted by the announcement of the lead opposition Presidential candidate, Yoon Seok-youl, who stated on 29 June 2021 that, "The nuclear phase-out policy was a poorly and hastily crafted one, and it must be revised…the Wolsong nuclear reactor probe is directly related to my resignation (as prosecutor in March 2021)…As soon as I ordered the Daejeon District Prosecutors' Office to conduct raids to investigate the suspicion that the reactor was shut down earlier than scheduled due to an assessment that deliberately underestimated the economic advantages of keeping it going, a disciplinary process against me started. There were also enormous pressures on how we handled the case."[378]

375 - *The Korea JoongAng Daily*, "Former energy minister charged with abuse of power", 1 July 2021, see https://koreajoongangdaily.joins.com/2021/07/01/national/socialAffairs/Paik-Ungyu-Chae-Heebong-Wolsong1/20210701154800369.html, accessed 6 July 2021.

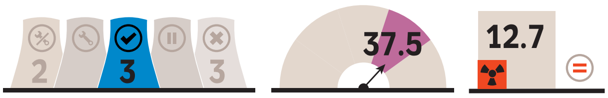
376 - *The Korea Herald*, "Korea sets 42% renewable energy target by 2034", 16 December 2020, see https://ieefa.org/korea-sets-42-renewable-energy-target-by-2034/, accessed 29 June 2021.

377 - Kyeongho Lee, "South Korea's 9th Basic Plan for electricity – a step closer to carbon neutrality?", Woods Mackenzie, 8 March 2021, see https://www.woodmac.com/our-expertise/focus/Power--Renewables/south-koreas-9th-basic-plan-for-electricity--a-step-closer-to-carbon-neutrality/, accessed 29 June 2021.

378 - The Korea JoongGang Daily, "Yoon incinerates Moon's anti-nuclear energy policy", 6 July 2021, op. cit.

It appears clear that the future of South Korean energy policy for the coming years, including the planned closure of 10 reactors, will be determined by the outcome of the 2022 Presidential elections.

TAIWAN FOCUS



Taiwan has three operating reactors at Kuosheng (Guosheng) and Maanshan, all owned by the Taiwan Power Company (Taipower), the state-owned utility monopoly. This is one less reactor than previously due to closure of the Kuosheng Unit 1 (Guosheng) BWR on 1 July 2021.[379] The Kuosheng Unit 1 closure is the third Taiwanese reactor to be closed under President Tsai Ing-wen government's nuclear phase out plan and another milestone in the island's energy transition including the end of nuclear generation by 2025.

In 2020, nuclear generation was almost stable at 30.3 TWh, compared to 31.1 TWh in 2019, equal to 12.7 percent of Taiwan's electricity compared to 13.4 percent in 2019. Nuclear generation reached its maximum share of 41 percent in 1988.

As a consequence of the January 2020 re-election of President Tsai Ing-wen of the Democratic Progressive Party (DPP) the nuclear phase out and energy transition enacted in the first term, remains official policy.[380] The rival Chinese Nationalist Party (KMT) continues to strongly oppose President Tsai's energy policy, calling for a life extension of existing reactors and the construction of new plants.[381]

Reactor Closures

As reported in WNISR2020, Taipower announced the closure of Chinshan Unit 1 on 5 December 2018, while Chinshan-2, which remained shut down from June 2017, was officially closed on 15 July 2019, when its 40-year operating license expired.

On 1 July 2021, Taipower announced that due to lack of spent fuel storage capacity, Kuosheng Unit 1 had been permanently shut down, which was six months earlier than planned.[382] The closure of Kuosheng Unit 1 was originally scheduled for 27 December 2021 when its operating license expired. Nuclear fuel was loaded into the reactor during the refueling and maintenance outage in 2020, but in February 2021 Taipower reduced the reactor power level to 80 percent to allow it to extend operations until June.[383]

379 - Taipower, "核 1號機燃料池滿今提前停機" ["The fuel pool of Nuclear No. 2 Unit 1 was shut down ahead of schedule today"], 1 July 2021 (in Chinese), see https://www.taipower.com.tw/tc/news_info.aspx?id=4741&chk=75ddf691-44f7-406a-922c-ebf676c2fbd8&mid=17, accessed 5 July 2021.

380 - Yang Chun-hui, Shih Hsiao-kuang and Lin Liang-sheng, "2020 Elections: Tsai wins by a landslide", *Taipei Times*, 12 January 2020, see https://www.taipeitimes.com/News/front/archives/2020/01/12/2003729107, accessed 7 July 2021.

381 - Pan Han-shen, "Han, nuclear fans lie about wind", *Taipei Times*, 5 January 2020, see https://www.taipeitimes.com/News/editorials/archives/2020/01/05/2003728728, accessed 7 July 2021; and *Nucleonics Week*, "Taiwan election returns anti-nuclear president to office", 6 February 2020.

382 - Taipower, "核 1號機燃料池滿今提前停機", 1 July 2021, op. cit.

383 - *WNN*, "Early shutdown for Taiwanese reactor", 1 July 2021, see https://www.world-nuclear-news.org/Articles/Early-shutdown-for-Taiwanese-reactor, accessed 7 July 2021.

The reactor, which is located on the northern coast of Taiwan, approximately 22 km northeast of Taipei City, was a 985MW BWR/6 unit with Mark III containment supplied by General Electric, and was connected to the grid on 21 May 1981. In its last full year of operation in 2020, it generated 7.4 TWh of electricity.[384] Local opposition in Taiwan prevented the construction of additional spent fuel dry storage capacity and is one principal reason for the early closure of Kuosheng Unit 1. Taipower undertook the installation of high density spent fuel storage racks (HDFSRs) in the early 1990's at Kuosheng and installed even higher density in 2005.[385]

The Kuosheng Unit 2 is planned for closure on 15 March 2023. Maanshan's PWR Unit 1 and Unit 2 are scheduled for closure on 26 July 2024 and 17 May 2025, respectively.

Referendum on Lungmen

As a result of the COVID-19 pandemic a decision was taken to postpone the planned referendum that was scheduled on 28 August 2021 to 18 December 2021. The referendum is intended to attempt to overturn the current nuclear phase out policy, and will ask voters to approve restarting the Lungmen Nuclear Power Plant 4 project.[386] In reality there is no prospect for a restart of the Lungmen reactors.

According to the Atomic Energy Commission (AEC), as of the end of March 2014, Lungmen-1 was 97.7 percent complete,[387] while Lungmen-2 was 91 percent complete. The plant was, as of 2014, estimated to have cost US$9–9.9 billion.[388] After multiple delays, rising costs, and large-scale public and political opposition, including through local referendums, on 28 April 2014, the then Premier Jiang Yi-huah announced that Lungmen-1 will be mothballed after the completion of safety checks, while work on Unit 2 at the site was to stop. The Democratic Progressive Party (DPP) government was elected with a pledge to halt construction of the Lungmen reactors, and with a nuclear phase-out planned for 2025, there is little prospect that they will ever operate. A formal decision on terminating the project would potentially force Taipower to file for bankruptcy as the listing of Lungmen as an investment asset would put the company in the red.[389]

Any resumption of Lungmen construction would require Taiwan's legislature and AEC approval, which, given the current government, is not going to happen. Taipower explained in February 2019 that it would not be able to replace major components installed nearly 20 years ago, including instrumentation and control as well as renegotiation with the main supplier

384 - IAEA-PRIS, "Kuosheng-1 – Reactor Details", Updated 20 August 2021, see https://pris.iaea.org/PRIS/CountryStatistics/ReactorDetails.aspx?current=556, accessed 21 August 2021.

385 - *NEI*, "Keeping Kuosheng operating", 15 March 2018, see https://www.neimagazine.com/features/featurekeeping-kuosheng-operating-6084804/, accessed 7 July 2021.

386 - Matthew Strong, "Taiwan postpones 4 referendums from August to December due to COVID", *Taiwan News*, 2 July 2021, see https://www.taiwannews.com.tw/en/news/4238648, accessed 9 September 2021.

387 - Planning Department, "Status and Challenges of Nuclear Power in Taiwan", AEC, April 2014, see http://www.aec.gov.tw/english/whatsnew/files/20140506-5.pdf, accessed 7 July 2021.

388 - *WNN*, "Political discord places Lungmen on hold", 28 April 2014, see http://www.world-nuclear-news.org/NN-Political-discord-places-Lungmen-on-hold-2804144.html, accessed 7 July 2021.

389 - Lee I-chia, "Nuclear Power Debate: Scrapping plant would ruin Taipower: Duh", *Taipei Times*, 29 April 2014, see http://www.taipeitimes.com/News/taiwan/archives/2014/04/29/2003589160, accessed 7 July 2021.

General Electric (GE).[390] Taipower stated that it could take 6–7 years to complete construction if all of these obstacles were overcome. WNISR took the units off the listing in 2014, where they remain as of 1 July 2021. The International Atomic Energy Agency (IAEA) although listing the reactors as under construction as of June 2019,[391] as of 1 July 2021 they were no longer listed.[392]

Energy policy

Historical public opposition to nuclear power in Taiwan dramatically escalated during and in the months following the start of the Fukushima Daiichi accident and has been a principal driver of the nation's ambitious plans for a renewable energy transition. The "New Energy Policy Vision", announced by the administration in summer 2016, aims at establishing "a low carbon, sustainable, stable, high-quality and economically efficient energy system" through an energy transition and energy industry reform.[393] On 12 January 2017, the Electricity Act Amendment completed and passed its third reading in the legislature, setting in place the mechanisms for Taiwan's energy transition, including nuclear phase-out.[394] The law also gives priority to distributed renewable energy generation, by which its generators will be given preferential rates, and small generators will be exempt from having to prepare operating reserves.

The closure of Kuosheng-1 prior to summer peak electricity demand has led some to question the merits of the government's current energy policy[395]; however, a Taipower official stated that the loss of the reactor will not impact power supply margins as the company had "anticipated the shutdown for several months and Taipower has controlled for this", through the commissioning of a new 500-MW combined cycle gas turbine (CCGT) and 500 MW of new solar PV installations. "We have confidence that we can provide full power supply this summer with no problems".[396]

President Tsai in October 2020 called for Taiwan to become a leading center of green energy in the Asia-Pacific region.[397] Between 2021 and 2025, Taiwan aims to add 5.7 GW of offshore wind power to the grid, and a total of 14.2 GW by 2025. In 2020, the government's position was that an additional 10 GW of offshore wind will be added to the grid between 2026–2035.[398] In

390 - *NEI*, "Taipower rules out operation of Lungmen", 6 February 2019, see https://www.neimagazine.com/news/newstaipower-rules-out-operation-of-lungmen-6970272, accessed 7 July 2021.

391 - IAEA-PRIS, "Taiwan, China", as of 10 June 2019, see https://pris.iaea.org/PRIS/CountryStatistics/CountryDetails.aspx?current=TW, accessed 11 June 2019.

392 - IAEA-PRIS, "Taiwan, China", 1 July 2021, op. cit.

393 - MOEA, "Taiwan's New Energy Policy", 6 April 2017, Ministry of Economic Affairs, see https://www.moea.gov.tw/Mns/ ietc_e/content/Content. aspx?menu_id=21511, accessed 7 July 2021.

394 - Bureau of Energy, "The Three-Stage Reading Process for Electricity Act Amendment Completed Moving Towards the 2025 Target of Nuclear-Free Homeland", Ministry of Economic Affairs, 1 March 2017, see https://eng.wra.gov.tw/7618/7662/7717/30138/, accessed 7 July 2021.

395 - Darrell Proctor, "Taiwan Shuts Another Reactor as Part of Nuclear-Free Goal", *POWER Magazine*, 7 July 2021, see https://www.powermag.com/taiwan-shuts-another-reactor-as-part-of-nuclear-free-goal/, accessed 7 July 2021.

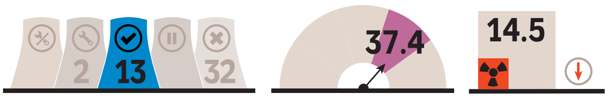
396 - *Nikkei Asia*, "Taiwan nuclear plant closure tests Tsai's energy transition", 5 July 2021, see https://asia.nikkei.com/Business/Energy/Taiwan-nuclear-plant-closure-tests-Tsai-s-energy-transition, accessed 7 July 2021.

397 - Energy Taiwan, "Energy Taiwan Establishing the Trifecta of PV Solar, Wind Power and Smart Energy Storage", 16 October 2020, see https://www.energytaiwan.com.tw/en/news/0D605CE74CB29C4E/info.html?lt=data&cr=7&cid=news; and *Energy Trend*, "2020 Energy Taiwan Commenced as Taiwan Become Hot Spot for Global Green Energy Investment", 15 October 2020, see https://www.energytrend.com/news/20201015-19621.html, both accessed 7 July 2021.

398 - U.S. Department of Commerce, "Taiwan Renewable Energy Market", 5 March 2021, see https://www.trade.gov/market-intelligence/taiwan-renewable-energy-market, accessed 7 July 2021.

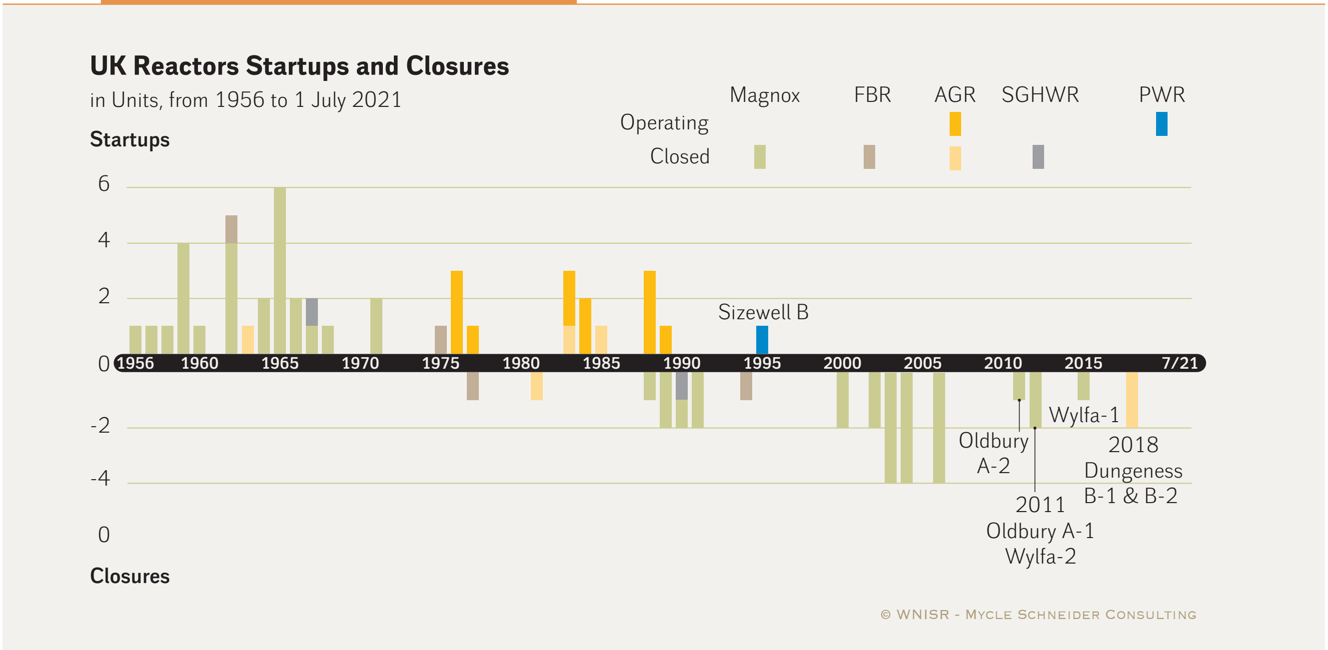
May 2021, this was increased to 15 GW.[399] The reform of the electricity market is continuing with the second stage during 2019–2025 to include grid unbundling, the restructuring of Taipower into a holding company with two entities: a power generation corporation and a transmission and distribution corporation; and the separation of the accounting system for these planned within 2 years and complete separation within six to nine years.[400]

UNITED KINGDOM FOCUS



In 2020, the United Kingdom operated 13 reactors, with two units, Dungeness B-1 and B-2, in the LTO category (one less than in WNISR2020) as they had not operated since September and August 2018 respectively. In June 2021, it was announced that those two reactors would not be restarted. Nuclear plants provided 16 percent of power, down from a maximum of 26.9 percent in 1997. Generation from nuclear was 50.3 TWh in 2020, a decrease of 11 percent compared to 2019. This was due to a series of statutory and unplanned outages at the U.K.'s nuclear plants over the year.[401] The average age of the U.K. fleet now stands at 37.4 years (see Figure 33).

Figure 32 · U.K. Reactor Startups and Closures



Sources: WNISR with EDF-Energy and IAEA-PRIS, 2021

Final consumption of electricity was 284.4 TWh in 2020, a decrease of 4.7 percent compared to 2019. This was largely driven by a reduction in non-domestic electricity consumption due

399 - *Wind Power Monthly*, "Taiwan ups offshore wind goal with plans to auction 15GW", 11 May 2021, see https://www.windpowermonthly.com/article/1715534/taiwan-ups-offshore-wind-goal-plans-auction-15gw, accessed 7 July 2021.

400 - Chung-Han Yang and Chengkai Wang, "The Energy Regulation and Markets Review: Taiwan", *The Law Reviews*, 16 June 2021, see https://thelawreviews.co.uk/title/the-energy-regulation-and-markets-review/taiwan#footnote-055, accessed 7 July 2021.

401 - BEIS, "Energy Trends – UK, October to December 2020 and 2020", Department for Business, Energy and Industrial Strategy, March 2021, see https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/972779/Energy_Trends_March_2021.pdf, accessed 11 April 2021.

to restrictions introduced as a result of the Covid-19 pandemic. Total electricity generated in 2020 was 312.8 TWh, 3.7 percent less than in 2019 (324.8 TWh), but continues a trend that has occurred since 2010.

Generation from renewable sources has been increasing year-on-year and in 2020 exceeded the generation from fossil fuels the first time. Renewable sources generated 134.3 TWh in 2020, an increase of 11 percent over the previous year.

A total of 32 power reactors have been permanently closed, all 26 Magnox reactors, two units at Dounreay, both Fast Breeder Reactors (FBR), a prototype Advanced Gas-cooled Reactor (AGR) at Windscale and a prototype Steam Generating Heavy Water Reactor (SGHWR) at Winfrith. Six of the U.K.'s seven second-generation nuclear stations, each with two AGRs, are operating past the end of their original 25-year design lives. These are now expected to close between 2022 and 2030, while the country's only Pressurized Water Reactor (PWR), at Sizewell B—the last of the U.K. units to start up, in 1995 (see Figure 32)—is scheduled to operate until at least 2035.[402] However, with Heysham A and Hartlepool expected to close by 2024, EDF Energy will be left with just three operating nuclear stations (see Table 5).

Table 5 – Expected Closure Dates of U.K. Nuclear Reactor Fleet – As of 1 July 2021

Reactor	Type/Model	Net Capacity (MW)	Grid Connection	Age	Expected Closure	Status / Comment
Dungeness B-1	AGR	545	03/04/1983	38.2		Closed. Last power generation on 28 September 2018
Dungeness B-2	AGR	545	29/12/1985	35.4		Closed. Last power generation on 27 August 2018
Hartlepool A-1	AGR	590	01/08/1983	37.8	March 2024	
Hartlepool A-2	AGR	595	31/10/1984	36.6		
Heysham A-1	AGR	485	09/07/1983	37.9	2024	
Heysham A-2	AGR	575	11/10/1984	36.6	2024	
Heysham B-1	AGR	620	12/07/1988	32.9	2030	
Heysham B-2	AGR	620	11/11/1988	32.6	2030	
Hinkley Point B-1	AGR	485	30/10/1976	44.6	July 2022	
Hinkley Point B-2	AGR	480	05/02/1976	45.3		
Hunterston B-1	AGR	490	06/02/1976	45.3	January 2022	
Hunterston B-2	AGR	495	31/03/1977	44.2		
Sizewell-B	PWR	1 198	14/02/1995	26.3	2035	
Torness-1	AGR	595	25/05/1988	33.0	2030	
Torness-2	AGR	605	03/02/1989	32.3	2030	

Sources: EDF Energy, 2020–2021

EDF Energy, a wholly owned subsidiary of French state-controlled utility EDF, is the majority owner of the company Lake Acquisitions that owns these reactors. Centrica has a minority share (20 percent) in Lake Acquisitions. However, Centrica was trying to sell its stake since 2013, and the 2019 annual report says, "we re-affirmed our strategic direction back towards

402 - EDF Energy, "Nuclear Lifetime Management", EDF, Updated, see https://www.edfenergy.com/energy/nuclear-lifetime-management, accessed 11 April 2021.

the customer and our desire to exit nuclear".[403] However, in its 2020 annual report they have stated "We have postponed the intended disposal of our nuclear generation assets until there is greater operational certainty". Centrica also reported, an adjusted operating *loss* of £17 million (US$23 million) in 2020, compared to a *profit* of £19 million (US$27 million) in 2019, with lower generation volumes reflecting the extended outages at a number of power stations.[404]

Serious Ageing Issues

Managing reactors as they age is a constant problem for any technology design and the AGRs are no exception. In recent years problems with the core's graphite moderator bricks have raised concerns. Keyway Root Cracks (KWRCs) were found at the Hunterston B reactors. This can lead to the degradation of the keying system, a vital component which houses the fuel, the control rods and the coolant (CO_2). Their cracking or distortion could impact on the insertion of the control rods or the flow of the coolant. There are also issues of erosion of the graphite, and a number of the AGRs are close to the erosion limits that the Office for Nuclear Regulation (ONR) has set. ONR has said these issues are likely to be the lifetime-limiting factor for the AGRs, as it is not possible to replace the graphite bricks.[405]

In March 2018, during a scheduled outage, EDF discovered a higher number of KWRCs in the older of the two reactors at Hunterston than was predicted by its computer models in 2016 when the reactor underwent its statutory 10-year Periodic Safety Review. Since then, there has been a series of announcements indicating that the cracking problem is more extensive and the remedial measures more complicated than envisaged. In July 2019, the ONR's Annual Report stated that Hunterston B were in an "enhanced level of regulatory attention" rather than routine. This was because assessment of the cracks required "substantial additional effort." Part of the reason for the delay is that ONR revealed in a technical report that 58 fragments had broken from the graphite bricks and there was "significant uncertainty", over the risk of these blocking the fuel channels. The ONR would require more robust arguments before agreeing to the restart of the reactors.[406]

Reactor 3 at Hunterston B (Hunterston B-1) was eventually restarted in August 2020, leaving the LTO status, and Reactor 4 (Hunterston B-2) in September. However, EDF Energy has confirmed that both units will be permanently closed before 7 January 2022,[407] while the two reactors at Hinkley Point B, will be permanently closed before 15 July 2022.[408]

403 - Centrica, "Annual Report and Accounts 2019", March 2020, see https://www.centrica.com/investors/annual-report-2019/, accessed 11 April 2021.

404 - Centrica, "Annual Report and Accounts 2020", March 2021, see https://www.centrica.com/media/4860/centrica-ar2020.pdf, accessed 11 April 2021.

405 - ONR, "Operating power stations: Graphite core of AGRs", Office for Nuclear Regulation, 5 March 2021, see http://www.onr.org.uk/civil-nuclear-reactors/graphite-core-ageing.htm, accessed 11 April 2021.

406 - Rob Edwards, "Safety fears as Hunterston's cracked nuclear reactors start to crumble", *The Ferret*, 17 October 2019, see https://theferret.scot/hunterston-graphite-debris-nuclear/, accessed 11 April 2021.

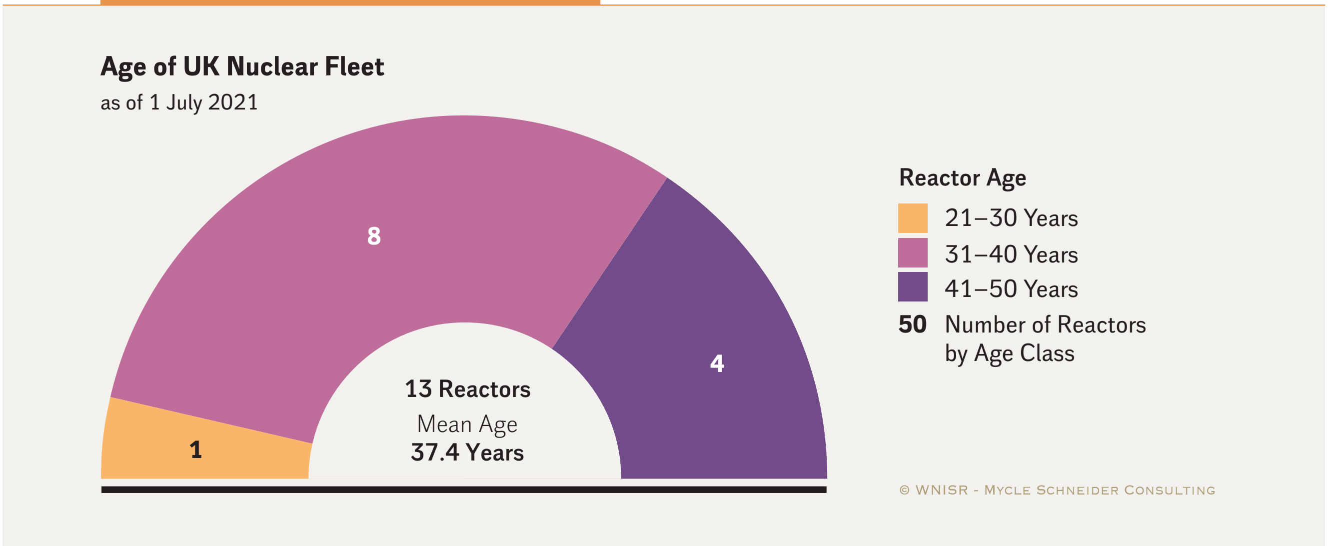
407 - Paul Forrest, "Letter to the Hunterston Site Stakeholder Group - 27 August", Station Direction, Hunterston B, EDF Energy, 27 August 2020, see https://www.edfenergy.com/media-centre/news-releases/letter-hunterston-site-stakeholder-group-27-august, accessed 11 April 2021.

408 - EDF Energy, "UK's most productive nuclear power station to move into decommissioning by July 2022", 19 November 2020, see https://www.edfenergy.com/media-centre/news-releases/uks-most-productive-nuclear-power-station-move-decommissioning-july-2022, accessed 20 November 2020.

Concerns have been raised that lifetime-limiting cracking will be found at the other AGRs and in May 2020, it was revealed that the ONR in its 10-year Periodic Safety Review had estimated that "The predicted timescales for onset of keyway root cracking has changed from 2028 to mid-2022."[409] Consequently, the future of many of the AGRs is being questioned by EDF's shareholders, who see ongoing outages and higher maintenance costs now outweighing the economic benefits of a possible additional couple of years of operation.[410]

Age-related problems, in this case corrosion rather than problems with graphite, have been found at similar reactors at Dungeness-B, with Unit 2 closed for what was supposed to be a 12-week outage in August 2018 and then Unit 1 for "common statutory outage work", in September 2018, with both initially expected to restart in April 2019.[411] However, on 7 June 2021, EDF Energy, to the surprise of many, announced that it would not seek to restart its Dungeness B nuclear power plant. EDF had said that "the station has a number of unique, significant and ongoing technical challenges that continue to make the future both difficult and uncertain". EDF further stated that "the current scheduled decommissioning date is 2028. Given the unique technical challenges noted above, a range of scenarios are being actively explored. These include moving directly into the defueling phase later this year."[412] It was revealed that changes to the condition of the plant's boilers, as well as serious issues on components that cover fuel assemblies were behind the decision to close the units.[413]

Figure 33 · Age Distribution of U.K. Nuclear Fleet



Sources: WNISR, with IAEA-PRIS, 2021

409 - Rob Edwards, "Torness nuclear reactors predicted to start cracking in 2022", *The Ferret*, 6 May 2020, see https://theferret.scot/torness-nuclear-reactors-cracking-2022/, accessed 11 April 2021.

410 - Phil Chaffee, "Restive Investors Challenge EDF on UK's Troubled AGRs", *NIW*, 28 February 2020.

411 - EDF Energy, "Dungeness B - Site Stakeholder Group Report June 2020", June 2020, see https://www.edfenergy.com/media-centre/news-releases/dungeness-b-site-stakeholder-group-report-june-2020, accessed 11 April 2020.

412 - EDF Energy, "Update on Dungeness B power station", 8 April 2021, see https://www.edfenergy.com/media-centre/news-releases/update-dungeness-b-power-station, accessed 11 April 2021.

413 - *NIW*, "Dungeness B Moves Into Early Retirement", 11 June 2021, see https://www.energyintel.com/0000017b-a7dd-de4c-a17b-e7df78500000.

Pathways to Net Zero

In June 2019, the Parliament set in law a commitment to reach net zero carbon emissions by 2050 and as part of this process six select committees jointly agreed to establish a citizens' assembly on climate change and how the Net Zero Target could be met. Special attention was to be given to the findings of the Committee as "it is unique: a body whose composition mirrors that of the U.K. population."

The conclusions of the Committee on nuclear power were:

- Assembly members saw three main disadvantages to nuclear: its cost, safety, and issues around waste storage and decommissioning.
- Support for nuclear power was second lowest to the use of fossil fuels with Carbon Capture and Storage (CCS), with 34 percent of the assembly agreeing or strongly agreeing that it should be part of how the U.K. generates electricity, compared to 78 percent for onshore wind, 95 percent for offshore wind and 81 percent for solar.[414]

The Climate Change Committee, an independent body established to advise the Government on meeting its climate commitments has produced a report on how the U.K. can meet its Net Zero commitments. Three out of five of the Committee's energy scenarios featured just 5 GW of nuclear capacity, equal to completing Hinkley Point C (HPC) and life-extending Sizewell B for the period 2035–2055. The remaining two scenarios featured 10 GW of nuclear capacity. The Committee concluded on nuclear power:[415]

> Renewables are cheaper than alternative forms of power generation in the U.K. and can be deployed at scale to meet increased electricity demand in 2050 - we therefore consider deep decarbonisation of electricity to be a Core measure.
>
> Reducing emissions towards net-zero **will** require continued deployment of renewables and **possibly** nuclear power and other low-carbon sources such as carbon capture and storage and hydrogen, along with avoiding emissions by improving energy efficiency or reducing demand. [Emphasis added.]

The committee is clearly recognizing the economic and deployment advantages of renewables over nuclear power as the country moves toward a zero emissions economy.

In November 2020, the U.K. Government published a Ten-Point Plan for a Green Industrial Revolution, which included a specific point on, "Delivering New and Advanced Nuclear Power".[416] This put forward milestones for the sector, including:

- 2021: Launch of Phase 2 of U.K. Small Modular Reactor (SMR) design development.
- Mid 2020s: HPC comes online.
- Early 2030s: First SMRs and Advanced Modular Reactor (AMR) demonstrator deployed in the U.K.

414 - Climate Assembly UK, "The Path to Net Zero", House of Commons, 2020, see https://www.climateassembly.uk/report/read/final-report-exec-summary.pdf.

415 - Committee on Climate Change, "Net Zero – Technical report", 2 May 2019, see https://www.theccc.org.uk/publication/net-zero-technical-report/, accessed 12 April 2021.

416 - BEIS, "The Ten Point Plan for a Green Industrial Revolution", November 2020, see https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/936567/10_POINT_PLAN_BOOKLET.pdf.

To support the development of the next generation of reactors the Government proposed to provide up to £385 million (US$533 million) in an Advanced Nuclear Fund for the next generation of nuclear technology, aiming, by the early 2030s, to develop an SMR and to build an AMR demonstrator. The Government is clearly backing SMRs and are extremely optimistic about a potential delivery timetable, which is a high-risk strategy given the industry's track record of delivering established designs, never mind first-of-a-kind prototypes.

Then in December 2020, the Government published a long-awaited Energy White Paper. In this they stated that their aim was to "bring at least one largescale nuclear project to the point of Final Investment Decision by the end of this Parliament, subject to clear value for money and all relevant approvals".[417] In an accompanying press statement the Government said it would begin negotiations with EDF on Sizewell C.[418] However, the language was prudent and requires a "value-for-money" hurdle to be passed, which given the current economics of nuclear vs. renewables is likely to be difficult. U.K. minister Gerry Grimstone told the *Financial Times* "If you read the energy white paper before Christmas it's by no means certain that this country is going to be building large nuclear power stations".[419]

Nuclear Newbuild

The development of new nuclear reactors in the U.K. has been slow since the current development cycle was "officially launched" 15 years ago, when then Prime Minister Tony Blair stated that nuclear issues were "back on the agenda with a vengeance".[420] In July 2011, the Government released the National Policy Statement (NPS) for Nuclear Power Generation.[421] The eight "potentially suitable" sites considered in the document for deployment "before the end of 2025" are exclusively current or past nuclear power plant sites in England or Wales, except for one new potential site, Moorside, adjacent to the fuel-chain facilities at Sellafield. Northern Ireland and Scotland are not included. The Scottish Government is opposed to new-build and has reiterated their "continued opposition to new nuclear stations, under current technologies. The economics of these stations are prohibitive, especially given the falling costs of renewable and storage technologies".[422]

417 - BEIS, "Energy White Paper – Powering our Net Zero Future", December 2020, see https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/945899/201216_BEIS_EWP_Command_Paper_Accessible.pdf, accessed 11 April 2021.

418 - BEIS, "Government sets out plans for clean energy system and green jobs boom to build back greener", 14 December 2020, see https://www.gov.uk/government/news/government-sets-out-plans-for-clean-energy-system-and-green-jobs-boom-to-build-back-greener, accessed 14 December 2020.

419 - Jim Pickard and Daniel Thomas, "UK woos sovereign wealth funds over green investments", *Financial Times*, 28 April 2021, see https://www.ft.com/content/f2352470-2bef-4b15-bae8-fb9e002212d0, accessed 5 May 2021.

420 - *BBC*, "Blair backs nuclear power plans", 16 May 2006, see http://news.bbc.co.uk/1/hi/uk_politics/4987196.stm, accessed 11 April 2021.

421 - Department of Energy and Climate Change, "National Policy Statement for Nuclear Power Generation", July 2011.

422 - Scottish Government, "The future of energy in Scotland: Scottish energy strategy", December 2017, see https://www.gov.scot/publications/scottish-energy-strategy-future-energy-scotland-9781788515276/, accessed 11 April 2021.

Hinkley Point C

EDF Energy was given planning permission to build two reactors at Hinkley Point in April 2013. In October 2015, EDF and the U.K. Government[423] announced updates to the October 2013 provisional agreement of commercial terms of the deal for the £16 billion (US$19.5 billion) overnight cost of construction of Hinkley Point C (HPC). The estimated cost of construction has since risen at the following times:

- In 2017, it stood at $£_{2015}$19.6 billion ($US\$_{2015}$25.3 billion), up from the $£_{2015}$18 billion ($US\$_{2015}$23.2 billion)—a figure which included the financial costs. EDF said at the time that the £1.5 billion (US$1.9 billion) increase results mainly "from a better understanding of the design adapted to the requirements of the British regulators, the volume and sequencing of work on site and the gradual implementation of supplier contracts."[424]
- In November 2019, EDF announced a further increase in costs due to "challenging ground conditions", "revised action plan targets" and "extra costs needed to implement the completed functional design", with the new completion cost (in 2015 values) now being estimated between £21.5 billion (US$26.6 billion) and £22.5 billion (US$27.9 billion). Furthermore, it was stated that the risk of delay had increased and that such a delay would increase costs by £0.7 billion (US$0.9 billion) over and above these estimates, so the upper end of the range is now £23.2 billion (US$28.8 billion).[425] EDF stated that "management of the project remains mobilised to begin generating power from Unit 1 at the end of 2025", which is not a clear statement of confidence in the current schedule.[426]
- In January 2021, EDF announced that Unit 1 is expected to generate power in June 2026, compared to end-2025 as announced in 2016. The project completion costs are now estimated in the range of $£_{2015}$ 22–23 billion (US$31–32.5 billion), a rise of £0.5 billion (US$0.7 billion).[427]

The critical points of the HPC deal were a Contract for Difference (CfD), effectively a guaranteed real electricity price for 35 years, which, depending on the number of units ultimately built, would be £89.5–92.5/MWh, in 2012 values ($US\$_{2020}$110–115/MWh), with annual increases linked to the Retail Price Index. In early 2020, EDF broke down the £92.50/MWh ($US\$_{2020}$115) strike price saying that £19.5 ($US\$_{2020}$24.1) would go toward operating and maintenance costs, and only £11 ($US\$_{2020}$13.6) to standard construction costs, excluding financing. The remaining £62 ($US\$_{2020}$76.8) covers risk, with £26 ($US\$_{2020}$32.2) for financing costs "for typical regulated asset without construction risk" and £36 ($US\$_{2020}$44.6) to cover first-of-a-kind construction risk.[428] The validity of and rationale for releasing these figures remain unclear. On the one hand, it could be designed to say that the cost of construction has been inflated in the U.K. due to the

423 - Department of Energy & Climate Change, "Hinkley Point C to power six million UK homes", UK Government, 21 October 2015, see https://www.gov.uk/government/news/hinkley-point-c-to-power-six-million-uk-homes, accessed 11 April 2021.

424 - EDF, "Clarifications on Hinkley Point C project", 3 July 2017, see https://www.edf.fr/en/the-edf-group/dedicated-sections/journalists/all-press-releases/clarifications-on-hinkley-point-c-project, accessed 11 April 2021.

425 - EDF, "Update on Hinkley Point C project", 25 September 2019, see https://www.edfenergy.com/media-centre/news-releases/update-on-hinkley-point-c-project, accessed 11 April 2021.

426 - Ibidem.

427 - EDF, "Hinkley Point C project update", 27 January 2021, see https://www.edf.fr/en/the-edf-group/dedicated-sections/journalists/all-press-releases/hinkley-point-c-project-update-1, accessed 27 January 2021.

428 - Phil Chaffee, "United Kingdom: Industry Pushes for Government Action", *NIW*, 6 March 2020.

particular conditions in the U.K. leading to an extremely high cost of risk. However, on the other hand, it does highlight that building reactors is financially extremely risky.

The cost of this support scheme has rocketed, and the U.K. National Audit Office (NAO) suggested that the additional 'top-up' payments—the difference between the wholesale price, as of the beginning of 2020 at £36/MWh (US$50/MWh) and the agreed fixed price (or Strike Price), required through the CfD—have increased from £6.1 billion ($US\$_{2013}$9.9 billion) in October 2013 to £29.7 billion ($US\$_{2016}$41.2 billion) in March 2016. This was due to falling wholesale electricity prices. This is the discounted[429] estimate, and the undiscounted estimate would be closer to £50 billion ($US\$_{2020}$62 billion) The NAO also stated that "the [Government] Department's deal for HPC has locked consumers into a risky and expensive project with uncertain strategic and economic benefits."[430]

There was an expectation that construction would be primarily funded by debt (borrowing) backed by U.K. sovereign loan guarantees, expected to be about £17 billion (US$26.9 billion). EDF announced in November 2015 its intention to sell non-core assets worth up to €10 billion (US$11.4 billion), including a stake in Lake Acquisitions, to help finance HPC and other capital-intensive projects.[431]

The expected composition of the consortium owning the plant changed from October 2013 to October 2015 with the effective bankruptcy and dismantling of AREVA making their planned contribution of 10 percent impossible. The Chinese stake, through China General Nuclear Power Corporation (CGN), fell to 33.5 percent from 40 percent and the other investors (up to 15 percent) had not materialized, leaving EDF with 66.5 percent rather than 45 percent it had hoped for in 2013. The rising construction cost and its increased share has impacted upon the amount EDF has to pay. Since 2013, the cost of EDF's expected share of the project has gone up by about 150 percent[432] and significantly contributed to its large, €42.3 billion (US$51.6 billion) debt load. The HPC cost overruns were part of Standard & Poor's decision to downgrade EDF's credit rating in June 2020 (see France Focus).

The administration of Prime Minister Theresa May finally approved and signed binding contracts for the HPC project in September 2016, with the Government retaining a 'special share', that would give it a veto right over changes to ownership, including preventing EDF from selling down to less than 50 percent, if national security concerns arose.[433] The U.S. Government continues to have security concerns and in October 2018 Assistant Secretary of State, Christopher Ashley Ford, even warned the U.K. explicitly against partnering with

429 - Discounting reduces the nominal value of costs and estimates the further in the future they occur.

430 - NAO, "Hinkley Point C", 12 June 2017, see https://www.nao.org.uk/wp-content/uploads/2017/06/Hinkley-Point-C.pdf, accessed 7 May 2018.

431 - Michael Stothard, "EDF looks to sell €10bn of assets to boost balance sheet", *Financial Times*, 18 October 2015, see https://www.ft.com/content/fcd6a462-7578-11e5-a95a-27d368e1ddf7, accessed 21 May 2020.

432 - Steve Thomas and Alison Downes, "Financing the Hinkley Point C", Public Services International Research Unit, University of Greenwich, Commissioned by the Theberton & Eastbridge Action Group on Sizewell, January 2020, see https://www.nuclearconsult.com/wp/wp-content/uploads/2020/01/HPC-finance-Steve-Thomas.pdf, accessed 11 April 2021.

433 - Rowena Mason and Simon Goodley, "Hinkley Point C nuclear power station gets government green light", *The Guardian*, 15 September 2016, see http://www.theguardian.com/uk-news/2016/sep/15/hinkley-point-c-nuclear-power-station-gets-go-ahead, accessed 11 April 2021.

CGN, saying that Washington had evidence that the business was engaged in taking civilian technology and converting it to military uses.[434]

A New Funding Model for Nuclear?

Recognizing that the Contract for Difference (CfD) for Hinkley Point C (HPC) was leading to higher power prices than available alternatives, such as offshore wind, whose 2019 tender led to prices of £$_{2012}$39.65/MWh (US$50/MWh), in July 2019, the Government announced a consultation for the introduction of a new funding model to facilitate the construction of new nuclear via a Regulated Asset Base (RAB). In such a case the project developer could charge consumers upfront for the construction, which would be broken down into different phases during the build process. EDF has claimed that all households would have to pay only £6 (US$7.5) per year additionally for them to build the proposed reactors at Sizewell C.[435] In the U.S., this model has led to at least nine tariff increases for consumers for the construction of the two V.C. Summer reactors in South Carolina, started in 2012 and abandoned in 2017 after the expenditure of over US$10 billion. The financing scheme had been abandoned by most of the U.S. states in the 1970s and led to the cancellation of more reactor orders than were eventually carried through.

Charging upfront reduces the overall construction costs as it avoids the need to include interest during the construction phase, thus cutting the amount of compounded debt to be serviced and paid off during the life of the asset, which could be key for nuclear projects as financing represents a significant share of the overall project costs. Furthermore, by breaking the construction into different phases, it is expected that this would increase certainty and therefore further reduce the cost of finance. EDF argues that the aim would be to reduce the weighted average cost of capital (WACC) from the 9.2 percent on HPC to around 5.5-6 percent.[436] However, as a paper by the National Infrastructure Commission concludes:

> it would be inappropriate to compare the price achieved under a CfD model, into which the developer has priced the risks of cost and time overruns, with a price achieved under a RAB model made on the basis that the project will be built on time and on budget.[437]

Furthermore, the consumer protection association, Citizens Advice stated in their response to the consultation that:

> While there are credible reasons to believe that a RAB model would reduce the cost of capital associated with bringing forward new nuclear power stations, these are outweighed by

434 - Jonathan Ford, "UK's reliance on China's nuclear tech poses test for policymakers", *Financial Times*, 14 February 2019, see https://www.ft.com/content/7734e3be-2f6f-11e9-8744-e7016697f225, accessed 21 May 2020.

435 - David Sheppard, "EDF forecasts nuclear plant project would add £6 a year to UK bills", *Financial Times*, 11 June 2019, see https://www.ft.com/content/897d548a-8c34-11e9-a24d-b42f641eca37, accessed 23 May 2020.

436 - Jonathan Ford, "EDF seeks to charge customers upfront for UK nuclear plants", *Financial Times*, 22 November 2018, see https://www.ft.com/content/f9a96304-e980-11e8-885c-e64da4c0f981, accessed 23 May 2020.

437 - National Infrastructure Commission, "Estimating comparable costs of a nuclear regulated asset base versus a contract for difference financing model", October 2019, see https://www.nic.org.uk/wp-content/uploads/NIC_RAB_Paper_October_2019-3rd-Layout-003.pdf, accessed 30 May 2020.

> the risk of highly material increases in the volume of capital that consumers will need to finance.[438]

A key selling point for the Government was a hope that funding would not have to come from the Treasury—and therefore remain off the Government's balance sheet. However, Energy Minister Kwasi Kwarteng reportedly told an event at the Conservative Party conference that the Treasury now believes that government support under a nuclear RAB would be scored as balance sheet debt.[439]

Consequently, it was reported that the Government was, at the end of 2020, considering the option to taking a greater direct stake in nuclear new build and the Prime Minister's spokesman said, "The government is looking at options to invest in Sizewell".[440]

In December the Government published its response to the consultation and concluded that, "following the consultation, Government will continue to explore a range of financing options with developers, including RAB".[441] Which hasn't, at least publicly, clarified the Government's position.

Other U.K. New-Build Projects

Sizewell C

EDF and CGN are also preparing to launch the development of a follow-on to Hinkley Point C (HPC), the Sizewell C project. Chinese investment would be limited to 20 percent, leaving EDF with 80 percent. The 80/20 split covers only the stage up to final investment decision. There is no agreement to invest beyond that stage. Given the apparent problems EDF is having financing HPC, this makes the Sizewell project even more difficult. Despite this, a public engagement process has been ongoing, and EDF was expected to submit a planning application, a so called "development consent order" in February 2020, but concerns by statutory agencies about the readiness of the application followed by the pandemic and the Government's control measures led to it being delayed until May 2020.[442] On 24 June 2020, the Planning Inspectorate accepted the application and consequently the next stage of the planning process could begin.[443] However, in October 2020, EDF announced it intended to make changes to the

438 - Citizens Advice, "Response to BEIS consultation on whether it should move to a Regulated Asset Base (RAB) model to finance new nuclear power stations", Press Release, 11 October 2019, see https://www.citizensadvice.org.uk/cymraeg/amdanom-ni/our-work/policy/policy-research-topics/energy-policy-research-and-consultation-responses/energy-consultation-responses/response-to-beis-consultation-on-whether-it-should-move-to-a-regulated-asset-base-rab-model-to-finance-new-nuclear-power-stations/, accessed 23 May 2021.

439 - Phil Chaffee, "United Kingdom: Policy Void Prompts Developer Scramble", *NIW*, 30 October 2020.

440 - Elizabeth Piper, "UK looking at funding options for EDF's Sizewell C nuclear plant", *Reuters*, 17 September 2020, see https://www.reuters.com/article/us-britain-nuclear-sizewell-idUKKBN26824E, accessed 12 April 2021.

441 - BEIS, "RAB Model for Nuclear – Government Response to the consultation on a RAB model for new nuclear projects", December 2020, see https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/943762/Nuclear_RAB_Consultation_Government_Response-.pdf, accessed 12 April 2021.

442 - EDF Energy, "Sizewell C submits planning application", Press Release, 27 May 2020, see https://www.edfenergy.com/media-centre/news-releases/sizewell-c-dco, accessed 11 April 2021.

443 - The Planning Inspectorate, "Application by NNB Nuclear Generation (SZC) Limited for an Order Granting Development Consent for The Sizewell C Project—Notification of decision to accept an application for Examination for an Order Granting Development Consent", Email to Richard Bull, EDF Energy, 2020, see https://infrastructure.planninginspectorate.gov.uk/wp-content/ipc/uploads/projects/EN010012/EN010012-002268-A05%20Notification%20of%20decision%20to%20accept%20application_.pdf, accessed 26 June 2020.

application, leading to further delay.[444] The final decision on whether to grant a development consent order to build Sizewell-C is planned to be taken by the Government by 14 April 2022.

EDF is hoping that it can sequence the construction of Sizewell C with the completion of HPC, so that workers can move from one project to another. But given the earliest conceivable preliminary construction works start date of Sizewell C in 2022, this seems impossible. EDF is optimistic that it can reduce construction costs, with their current estimate put at £18 billion (US$22 billion).[445] However, they are also hoping that the financing costs of Sizewell-C can be reduced by shifting from the CfD mechanism to the Regulated Asset Base (RAB) model. EDF have suggested that with a better financing model and no "first-of-a-kind costs", they could "peel away" the strike-price by £36/MWh (US$44.5/MWh),[446] as a result of EDF's "base case" for Sizewell C's cost being £20 billion (US$24.8 billion), with 60 percent financed by loans.[447] In its planning documents, EDF confirmed construction costs of £20 billion (US$24.8 billion), despite previously suggesting that costs would be 20 percent lower than HPC thus limited to £18 billion (US$22.3 billion).[448] However, without the development of a new financing model and confidence that the problems that have plagued the construction of all EPRs around the world, it is unlikely, especially in the current economic climate, that Sizewell C will proceed.

In March 2021 EDF's financial report for 2020 said a Final Investment Decision (FID) was likely to be made in mid-2022, but used cautious language on the whole about the project, stating "EDF aims to ensure that risk sharing with the U.K. government in the as-yet un-validated regulatory and financing scheme will make it possible to find third party investors during the FID and avoid consolidating the project (including the economic debt calculation adopted by rating agencies). To date, it is not clear whether the Group will reach this target." It went on to say

> EDF's ability to make a FID on Sizewell C and to participate in the financing of this project beyond the development phase could depend on the operational control of the HPC Point C project, on the existence of an appropriate regulatory and financing framework, and on the sufficient availability of investors and funders interested in the project. To date, none of these conditions are met. Failure to obtain the appropriate financing framework and appropriate regulatory approval could lead the Group not to make an investment decision or to make a decision in less than optimal conditions.[449]

Bradwell

EDF is allowing China General Nuclear Power Corporation (CGN) to use the Bradwell site it had bought as back-up, if either the Hinkley **Point** or Sizewell sites proved not to be viable. CGN plans to build with its own technology, the Hualong One (or HPR-1000) at this site, with EDF

444 - Richard Cornwell, "EDF formally submits proposed changes to Sizewell C plans", *East Anglian Daily Times*, 13 January 2021, see https://www.eadt.co.uk/news/sizewell-c-plans-changes-submitted-6900486, accessed 4 May 2021.

445 - *NEI*, "Plans for Sizewell C submitted to UK Planning Inspectorate", 28 May 2020, see https://www.neimagazine.com/news/newsplans-for-sizewell-c-submitted-to-uk-planning-inspectorate-7943163, accessed 11 April 2021.

446 - Phil Chaffee, "United Kingdom: Industry Pushes for Government Action", *NIW*, 2020, op. cit.

447 - Roger Murray, "Hinkley Point Cost Overrun- Bad News for Sizewell C?", *NIW*, 27 September 2019.

448 - Donato Paolo Mancini and Nathalie Thomas, "Cost of new Sizewell C nuclear plant put at £20bn", *Financial Times*, 26 June 2020, see https://www.ft.com/content/77c209f7-6d18-4609-ac3c-77d1b5b82b34, accessed 26 June 2020.

449 - EDF, "2020 Annual Results - Appendices", March 2021, see https://www.edf.fr/sites/default/files/contrib/groupe-edf/espaces-dedies/espace-finance-en/financial-information/publications/financial-results/2020-annual-results/pdf/annual-results-2020-appendices-20210304.pdf, accessed 4 May 2021.

taking a 33.5 percent stake,[450] up to the point of getting the Generic Design Assessment (GDA), going forward the plant will need a new consortium. In January 2017, the U.K. Government requested that the regulator begin the GDA of the HPR-1000 reactor,[451] and by February 2020 the Office for Nuclear Regulation (ONR) had completed Step 3 of the GDA, with the final Step expected to be completed by the end of 2021, with a closure stage potentially taking another year.[452] The key moment in the GDA, when specific issues are identified, is Step 4. In December 2020, the U.K.'s gas and electricity markets regulator, Ofgem, granted an electricity generating license to the Bradwell Power Generation Company Ltd.[453]

In August 2019, the U.S. blacklisted CGN for allegedly diverting the country's nuclear technology for "military uses". The Federal Register added the state-owned Chinese firm and three subsidiaries to its "Entity List". This makes it virtually impossible for American companies to supply CGN without specific licenses.[454] This and the increasing breakdown in the relationship between China, the U.S. and to some extent Europe, may well impact on the development of Bradwell as will the current economic climate and the likelihood of a global recession. In particular for the U.K., there is ongoing and growing concern over the situation in Hong Kong. Consequently, it has been suggested that as nuclear power plants "are part of the U.K.'s strategic national infrastructure, and China is no longer a friend to be trusted with such levers of power" it is impossible to envisage the government approving the Bradwell station.[455] Furthermore, there is increased attention on the Bradwell project with the cancellation of negotiations about future nuclear projects in the Czech Republic and Romania due to security concerns with China.

Despite this, the project still has inertia and remains within the licensing process. From a Chinese perspective having the Hualong reactor design approved in the U.K. would be valuable as it seeks to sell its technology in other parts of the world. Therefore, it is likely that the process will continue, despite the U.K. Government making it clear that it sees no more than one nuclear project being approved in the lifetime of the current Parliament, ending 2024.

Moorside

In June 2014, NuGen finalized a new ownership structure with Toshiba-Westinghouse (60 percent) and Engie – then GDF Suez – (40 percent), as Iberdrola sold its shares to Toshiba-Westinghouse. The group planned to build three Toshiba-Westinghouse-designed

450 - EDF Energy, "Agreements in place for construction of Hinkley Point C nuclear power station", Press Release, 21 October 2015, see https://www.edfenergy.com/energy/nuclear-new-build-projects/hinkley-point-c/news-views/agreements-in-place, accessed 11 April 2021.

451 - ONR, "Assessing new nuclear reactor designs—Generic Design Assessment Periodic Report: November 2016 – January 2017", March 2017, see http://www.onr.org.uk/new-reactors/reports/gda-quarterly-report-nov16-jan17.pdf, accessed 11 April 2021.

452 - ONR, "Generic Design Assessment (GDA) of new reactors - Timeline", 5 March 2021, see http://www.onr.org.uk/new-reactors/timeline.htm, accessed 11 April 2021.

453 - *NEI*, "UK's Bradwell B granted electricity generating licence", 21 December 2020, see https://www.neimagazine.com/news/newsuks-bradwell-b-granted-electricity-generating-licence-8420726/, accessed 12 April 2021.

454 - Felix Todd, "China nuclear firm blacklisted by US for 'unauthorised' use of tech", *NS Energy*, 15 August 2019, see https://www.nsenergybusiness.com/news/china-nuclear-us-tech/, accessed 5 July 2021.

455 - Nick Butler, "How growing conflict with China could impact UK nuclear power", *Prospect Magazine*, 10 April 2021, see https://www.prospectmagazine.co.uk/world/nuclear-investment-power-uk-china-government-energy, accessed 12 April 2021.

AP1000 reactors at the Moorside site, with units proposed to begin operating in 2024.[456] The AP1000 design completed the GDA process. However, Westinghouse, after its financial collapse, filed for Chapter 11 bankruptcy protection in the U.S. in March 2017. The perilous state of the project also led to Engie selling its remaining 40 percent to Toshiba-Westinghouse for US$138 million, who were contractually obliged to buy at the pre-determined price. In late April 2017, Toshiba started mothballing the project.[457]

Toshiba was initially in with both South Korea's KEPCO, a nationally owned utility and reactor vendor, and CGN of China, as potential buyers of NuGen. However, in November 2018, Toshiba announced that it was winding down NuGen, without finding a buyer. This could have opened up the opportunities for others to buy the Moorside site and build their own reactors—but this has not yet occurred. In the meantime, the Moorside site has reverted to the U.K.'s Nuclear Decommissioning Authority (NDA).

Wylfa and Oldbury

The other company that was involved in the proposed nuclear new-build is Horizon Nuclear Power, which was bought by the Japanese company Hitachi-GE from German utilities E.ON and Rheinisch-Westfälisches Elektrizitätswerk (RWE) for an estimated price of £700 million (US$1.2 billion) in 2012. The company submitted its Advanced Boiling Water Reactor (ABWR) design for technical review and it completed the GDA, whilst at the time making it clear that its continuation in the project would depend on the outcome of the negotiations with the Government.[458]

Hitachi was looking for partners in their project, hoping to reduce their stake to 50 percent and, if no other investors could be found, the company would have to withdraw. An internal review had found that the construction cost was likely to reach US$27.5 billion, considered too big a risk for the company on its own. In January 2019, Hitachi announced that it was suspending the project and that this decision was taken "from the standpoint of economic rationality"; in doing so the company accepted a ¥300 billion (US$$_{2019}$2.75 billion) impairment.[459] Horizon CEO Duncan Hawthorne wrote in a 27 January 2021 letter to the U.K. Planning Inspectorate withdrawing Horizon's application for a Wylfa Newydd development consent order.[460] The site will revert to the NDA.

456 - *NucNet*, "Toshiba Finalises Controlling Stake In UK Nuclear Company NuGen", 30 June 2014, see https://www.nucnet.org/all-the-news/2014/06/30/toshiba-finalises-controlling-stake-in-uk-nuclear-company-nugen, accessed 12 April 2021.

457 - John Collingridge, "Toshiba mothballs Cumbrian nuclear power project", *Sunday Times*, 30 April 2017.

458 - Ambrose Evans-Pritchard, "Hitachi reluctant about UK nuclear reactor plan", *The Telegraph*, 14 April 2013, see https://www.telegraph.co.uk/finance/newsbysector/energy/9993564/Hitachi-reluctant-about-UK-nuclear-reactor-plan.html, accessed 23 May 2020.

459 - Dennis Engbarth, "Hitachi Cites 'Economic Rationality' for Wylfa Decision", *NIW*, 1 January 2019.

460 - Phil Chaffee, "Covid-19's Impact on Hinkley Point C", *NIW*, 27 January 2021.

UNITED STATES FOCUS

Overview

With 93 commercial reactors operating as of 1 July 2021, the U.S. continues to possess by far the largest nuclear fleet in the world. Two reactors were closed in the year since WNISR2020. Duane Arnold-1 in the state of Iowa was closed on 10 August 2020, following significant storm damage, and four months earlier than scheduled.[461] The Indian Point-3 reactor closed on 30 April 2021, bringing to an end nuclear generation at the site, which is located on the Hudson River, 48 km from Manhattan, New York.[462] Unit 2 at the site was disconnected from the grid on 20 April 2020.[463]

Construction continued on the one new nuclear plant in the U.S., the twin AP-1000s at Plant Vogtle Units 3 and 4, in the state of Georgia. As in previous years, evidence has continued to emerge of the enormous scale of the problems with the Vogtle project, owned by Georgia Power. In June 2021, an expert witness to the Georgia Public Service Commission testified that the startup of the new Vogtle reactors would likely be delayed until at least the summer of 2022, and that the plant owners' schedules "are unachievable and cannot be relied upon."[464] This is even later than the most recent prediction from Georgia Power of January 2021, which was five years later than originally planned.

On 23 July 2020, the former executive vice president of SCANA Corporation pleaded guilty in federal court to conspiracy to commit mail and wire fraud in connection with the construction of the V.C Summer nuclear plant project in South Carolina which was halted in 2017.[465] Documents released in 2019 allege that the CEO and other officials conducted, "a years-long cover-up to hide huge losses in then-ongoing construction at the V.C. Summer nuclear plant."[466] This follows the July 2017 decision to terminate construction of the twin V.C. Summer AP-1000 reactor project.[467] According to the U.S. Department of Justice, the SCANA executive, Stephen A. Byrne, was aware as early as June 2016 that the V.C. Summer construction schedule and completion dates were unrealistic and unlikely to be achieved.[468] Consequently, V.C. Summer Unit 2 and 3 would not meet the construction completion deadline entitling them to federal

461 - WNISR, "Storm Damage Prompts Early Closure of Duane Arnold Nuclear Reactor in the U.S.", 26 August 2020, see https://www.worldnuclearreport.org/Storm-Damage-Prompts-Early-Closure-of-Duane-Arnold-Nuclear-Reactor-in-the-U-S.html, accessed 20 July 2021.

462 - WNISR, "End of Nuclear Generation at Indian Point, 50 km from Manhattan, New York", 30 April 2021, see https://www.worldnuclearreport.org/End-of-Nuclear-Generation-at-Indian-Point-50-km-from-Manhattan-New-York.html, accessed 20 July 2021.

463 - WNISR, "Closure of 47-Year-Old Indian Point Reactor Near New York City", 30 April 2020, see https://www.worldnuclearreport.org/Closure-of-47-Year-Old-Indian-Point-Reactor-Near-New-York-City.html, accessed 20 July 2021.

464 - Darrell Proctor, "More Vogtle Delays; Experts Target Mid-2022 Startup at Earliest", *POWER Magazine*, 8 June 2021, see https://www.powermag.com/more-vogtle-delays-experts-target-mid-2022-startup-at-earliest/, accessed 14 August 2021.

465 - ANA, "Former SCANA exec pleads guilty in Summer fraud case", 27 July 2020, see https://www.ans.org/news/article-381/former-scana-exec-pleads-guilty-in-summer-fraud-case/, accessed 20 July 2021.

466 - John Monk, "SCANA conspirators helped Byrne spin lies about nuclear project, document alleges", *The State*, 9 June 2020, see https://www.thestate.com/news/local/crime/article243395241.html, accessed 5 July 2020.

467 - SCANA, "South Carolina Electric & Gas Company To Cease Construction And Will File Plan Of Abandonment Of The New Nuclear Project", *CISION PR Newswire*, 31 July 2017, see https://www.prnewswire.com/news-releases/south-carolina-electric-- gas-company-to-cease-construction-and-will-file-plan-of-abandonment-of-the-new-nuclear-project-300496644.html, accessed 20 July 2021.

468 - Ibidem.

nuclear production tax credits worth potentially hundreds of millions of dollars per year.[469] Byrne's false and misleading statements contributed to SCANA's success in obtaining state rate increases to finance on-going construction. In February 2021, the former CEO of SCANA also pleaded guilty to conspiracy fraud charges involving a cover-up of financial problems with the V.C Summer project.[470]

The guilty pleas follow Federal Bureau of Investigations (FBI) criminal investigations into the failed nuclear project, which cost South Carolina power customers billions of dollars. FBI investigations during the past year have been ongoing, extending beyond SCANA to include amongst others, the Westinghouse corporation, the designer and supplier of the AP-1000 V.C Summer reactors. In May 2021, Westinghouse's most senior executive managing the nuclear construction project was charged with the felony offence of lying to the FBI over his role in the scandal with SCANA.[471]

During the past few years, utilities have both succeeded and failed in their ongoing efforts to secure state financial support for operating nuclear plants, with the balance being in the industry's favor. As of July 2020, 13 reactors in the U.S. were receiving or are eligible for subsidies as a result of state legislation such as Zero Emission Credits (ZEC) or equivalent: Nine Mile Point, FitzPatrick and Ginna in New York; Clinton and Quad Cities in Illinois; Salem and Hope Creek in New Jersey; Millstone in Connecticut; and Davis Besse and Perry in Ohio (now rescinded with termination of HB6).

Attempts to secure further financial support for the U.S. nuclear industry have made significant progress in the past year following the election of President Biden. On 24 June 2021, Democratic Senators presented the Zero-Emission Nuclear Power Production Credit Act of 2021 (S. 2291)[472] which would make existing merchant nuclear power owners/operators eligible for a tax credit of US$15/MWh.[473] Estimates have projected that if applied to eligible nuclear plants across the nation, it could yield US$50 billion in additional revenue for utilities by 2030.[474] The subsidies on offer have emerged with the renewed commitment of the Biden administration to reduce emissions and establish a "100% clean electric grid". As one insider noted to *Reuters* news agency, "There's a deepening understanding within the administration that it needs nuclear to meet its zero-emission goals'.[475] With no prospects of major nuclear plant construction in the

469 - Taxpayers for Common Sense, "Subsidies for Nuclear Reactor Projects Waste Taxpayer Money", 17 August 2017, see https://www.taxpayer.net/energy-natural-resources/subsidies-for-nuclear-reactor-projects-waste-taxpayer-money/, accessed 20 July 2021.

470 - John Monk, "Ex-SCANA CEO Kevin Marsh pleads guilty to conspiracy tied to failed nuclear project", *The State*, 24 February 2021, see https://www.thestate.com/news/local/crime/article249477970.html, accessed 20 July 2021.

471 - John Monk, "Former Westinghouse official to plead guilty in FBI probe of SCANA's nuclear failure", *The State*, 24 May 2021, see https://www.thestate.com/news/politics-government/article251639033.html, accessed 20 July 2021.

472 - U.S. Senate, "A Bill To amend the Internal Revenue Code of 1986 to establish a tax credit for production of electricity using nuclear power", also referenced to as "Zero-Emission Nuclear Power Production Credit Act of 2021", 117th Congress, 1st Session, see https://www.cardin.senate.gov/imo/media/doc/zero%20emissions%20nuclear%20PTC.pdf, accessed 22 July 2021.

473 - Senator Ben Cardin, "Cardin, Manchin, Carper, Whitehouse, Booker Introduce Bill to Extend Production Tax Credit for Zero-Emission Energy Sources to Existing Nuclear Plants", Press Release, 24 June 2021, see https://www.cardin.senate.gov/newsroom/press/release/cardin-manchin-carper-whitehouse-booker-introduce-bill-to-extend-production-tax-credit-for-zero-emission-energy-sources-to-existing-nuclear-plants-, accessed 22 July 2021.

474 - Friends of the Earth, "Cardin backs $50 billion nuke bailout", 26 May 2021, see https://foe.org/news/cardin-backs-50-billion-nuke-bailout/, accessed 22 July 2021.

475 - *Reuters*, "U.S. eyes nuclear reactor tax credit to meet climate goals -sources", 5 May 2021, see https://www.reuters.com/business/sustainable-business/white-house-eyes-subsidies-nuclear-plants-help-meet-climate-targets-sources-2021-05-05/, accessed 22 July 2021.

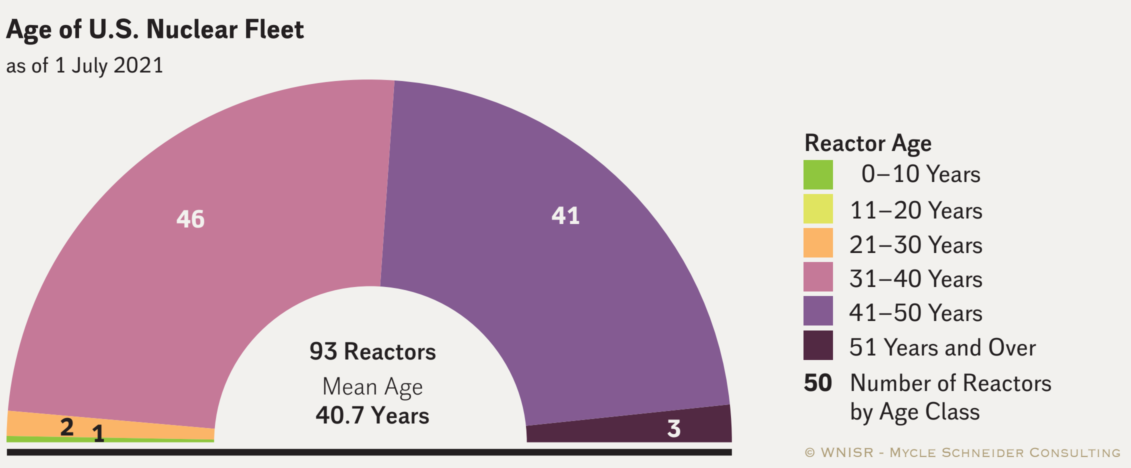
coming years,[476] the legislative efforts have focused on providing subsidies to prevent further reactor closures. Industry lobbying efforts of Congress and the promotion of nuclear energy as necessary for emissions reductions appear to be paying off.[477]

As of 1 July 2021, the final status of nuclear subsidies legislation remains unknown; however, there is every prospect of significant financial gain for nuclear utilities from 2022. Thus, while it is inevitable that the size of the U.S. nuclear fleet will continue to decline, the decline is likely to be slowed down, perhaps substantially, by the proposed direct subsidies.

The U.S. reactor fleet provided 789.9 TWh in 2020, a drop of 2.4 percent over 2019. Nuclear plants provided a stable 19.7 percent of the nation's electricity in 2020, though about 3 percentage points below the highest nuclear share of 22.5 percent, reached in 1995.

With only one new reactor started up in the past 20 years, the U.S. fleet continues to age, with a mid-2021 average of 40.7 years—exceeding 40 years for the first time—amongst the oldest in the world: 44 units have operated for 41 and more years (of which three for more than 51 years) and all but three for 31 and more years (see Figure 34).

Figure 34 · Age Distribution of the U.S. Nuclear Fleet



Sources: WNISR, with IAEA-PRIS, 2021

Extended Reactor Licenses

As of 1 July 2021, 85 of the 93 operating U.S. units had already received 20-year Initial License Renewals, which permits reactor operation during the period 40–60 years. In the past year, the Nuclear Regulatory Commission (NRC) did not issue any additional 20-year license renewals. Four reactors are currently listed as intending to apply for license extension in the

476 - Mark Cooper, "Building a least-cost, low-carbon electricity system with efficiency, wind, solar, & intelligent grid management: why nuclear subsidies are an unnecessary threat to the transformation", Institute for Energy and the Environment, Vermont Law School, July 2021, see https://www.vermontlaw.edu/sites/default/files/2021-07/Building_a_21st_Century_Electricity_System.pdf, accessed 22 July 2022.

477 - See for example the work of the Rhodium Group, "Pathways to Build Back Better: Maximizing Clean Energy Tax Credits", 8 July 2021, see https://rhg.com/research/build-back-better-clean-energy-tax-credits/, accessed 10 August 2021.

period 2022–2024. [478] Under the Atomic Energy Act (AEA) of 1954, as amended, and NRC regulations, the NRC issues initial operating licenses for commercial power reactors for 40 years. NRC regulations permit license renewals that extend the initial 40-year license for up to 20 additional years per renewal. However, in July 2017, the NRC published a final document describing "aging management programs" that allow the NRC to grant nuclear power plants operating licenses for "up to 80 years".[479] As of 1 July 2021, the NRC has granted Subsequent Renewed Operating Licenses to six reactors, which permit operation from 60 to 80 years. A further seven reactors have their applications still under review.

The NRC on 4 December 2019 issued its first ever Subsequent Renewed Operating Licenses for Turkey Point-3 and -4. The license grants Florida Light and Power (FL&P) permission to operate the reactors for a total of 80 years.[480] The reactors are located 32 kilometers (20 miles) south of Miami and their previous 20-year license extensions, which were granted in 2002, had allowed them to operate until 2032 and 2033. FL&P applied for an additional 20 years of operation in May 2018.[481]

On 5 March 2020, the NRC granted Subsequent Renewed Operating Licenses for the Peach Bottom Unit 2 and Unit 3 owned by the Exelon Generation Company, LLC (Exelon).[482] Prior to this decision, Peach Bottom Unit 2 had an operating license until 8 August 2033, while the license for Peach Bottom Unit 3 was to run until 2 July 2034.[483] Exelon applied to the NRC on 10 July 2018 for subsequent license renewal for the reactors.[484] Peach Bottom-2 and -3 were both connected to the grid in 1974 and are General Electric MK1 Boiling Water Reactors (BWRs). With the additional extension of 20 years, the reactors are licensed to operate until 8 August 2053 and 2 July 2054 respectively.

The Subsequent Renewed Operating Licenses for Peach Bottom-2 and-3 were contested by the organization Beyond Nuclear.[485] In evidence, seeking a review by the Atomic Safety Licensing

478 - U.S.NRC, "Future Submittals of Applications", as of 10 August 2021, see https://www.nrc.gov/reactors/operating/licensing/renewal/applications.html, accessed 10 August 2021.

479 - Office of Nuclear Reactor Regulation, "Generic Aging Lessons Learned for Subsequent License Renewal (GALL-SLR) Report", NRC, Final Report, NUREG-2191, Vol. 2, July 2017, see https://www.nrc.gov/docs/ML1718/ML17187A204.pdf, accessed 10 June 2020.

480 - U.S.NRC, "ISSUANCE Of Subsequent Renewed Facility Operating License Nos. DPR-31 And DPR-41 For Turkey Point Nuclear Generating Unit Nos. 3 And 4 (EPID L-2018-RNW-0002)", 4 December 2019, see https://www.nrc.gov/docs/ML1930/ML19305C879.pdf; and *Utility Dive*, "FPL's Turkey Point first US nuclear plant to get license out to 80 years", 4 December 2020, see https://www.utilitydive.com/news/fpls-turkey-point-first-us-nuclear-plant-to-get-license-out-to-80-years/568593/, both accessed 2 July 2020.

481 - U.S.NRC, "Turkey Point Nuclear Plant, Units 3 & 4 – Subsequent License Renewal Application", Updated 11 June 2021, see https://www.nrc.gov/reactors/operating/licensing/renewal/applications/turkey-point-subsequent.html, accessed 14 August 2021.

482 - U.S.NRC, "Peach Bottom Atomic Power Station, Unit 3—Subsequent Renewed Facility Operating License Subsequent Renewed License No. DPR-56", Docket No. 50-278 5 March 2020, see http://static1.1.sqspcdn.com/static/f/356082/28268685/1583938196653/pch_slr_03052020_approval_ML20024G426.pdf?token=thU59yfOgtDRthueNS6NLUzJ8%20NY%3D; also NRC, "Peach Bottom Atomic Power Station, Units 2 & 3 – Subsequent License Renewal Application", see https://www.nrc.gov/reactors/operating/licensing/renewal/applications/peach-bottom-subsequent.html; and Beyond Nuclear, "NRC Greenlights Peach Bottom 80-year license extension despite significant safety questions", 12 March 2020, see http://www.beyondnuclear.org/relicensing/; all accessed 2 July 2020.

483 - Office of Nuclear Reactor Regulation, "Generic Environmental Impact Statement for License Renewal of Nuclear Plants—Supplement 10, Second Renewal—Regarding Subsequent License Renewal for Peach Bottom Atomic Power Station Units 2 and 3–Final Report", NUREG-1437, U.S.NRC, January 2020, see https://www.nrc.gov/docs/ML2002/ML20023A937.pdf, accessed 2 July 2020.

484 - U.S.NRC, "Subsequent License Renewal Application: Peach Bottom Atomic Power Station Units 2 and 3—The Second License Renewal Application", Facility Operating License Nos. DPR-44 and DPR-56, 10 July 2018, see https://www.nrc.gov/docs/ML1819/ML18193A773.pdf, accessed 10 May 2019.

485 - U.S.NRC, "In the Matter of Exelon Generation Company, LLC Peach Bottom Atomic Power Station, Units 2 & 3—Beyond Nuclear, Inc.'s Amended Hearing Request And Petition To Intervene", Before The Atomic Safety And Licensing Board, Docket Nos. 50-277/278 SLR, 1 May 2019, see https://www.nrc.gov/docs/ML1912/ML19121A453.pdf; and Lindsay C. VanAsdalan, "Activists challenge license extension for Peach Bottom nuclear plant", *York Dispatch*, 6 March 2019, see https://eu.yorkdispatch.com/story/news/2019/03/05/activists-challenge-license-extension-peach-bottom-nuclear-plant/3060252002/, both accessed 12 July 2019.

Board (ASLB), expert witness David Lochbaum contends that Exelon in its application to the NRC had failed to provide evidence of adequate aging management programs and on how operating experience will be applied during the 60–80 year period of operation of Peach Bottom-2 and -3. Lochbaum added: "Abundant evidence also speaks to gaps, deficiencies, and uncertainties in present understanding of aging degradation mechanisms." [486] The ASLB on 20 June 2019 denied the request for a review. A new filing to the NRC related to non-compliance with the National Environmental Protection Act (NEPA) and NRC regulations 10 CFR § 51.71 was filed in September 2019.[487] On 12 November 2020, the NRC upheld its decision granting the licenses stating that it was correct to rely on NRC's Generic Environmental Impact Statement (GEIS) for license renewal.[488] Notably, two of the NRC Commissioners dissented from the decision, arguing this interpretation violates the NRC's obligations under the National Environmental Policy Act (NEPA).[489]

On 5 April 2021, the NRC granted Subsequent Renewed Operating Licenses for Surry-1 and -2 in the state of Virginia, owned by Dominion Energy, which will permit operations at the plant until 2052 and 2053 respectively.[490] On 24 August 2020, Dominion also submitted its application for Subsequent Renewed Operating Licenses for North Anna-1 and -2.[491] On 7 June 2021, Duke Energy submitted an application for Subsequent Renewed Operating Licenses for its Oconee-1, -2 and -3.[492] If granted the reactors would be licensed to operate until 2053 and 2054 respectively.

While not guaranteeing reactors continued operation, multiple applications are expected over the coming years for subsequent license renewals. On 17 March 2021, Florida Power & Light Company notified the NRC that it intends to apply for Subsequent Renewed Operating Licenses for its St Lucie-1 and -2 reactors before the end of 2021.[493] Duke Energy Corporation

486 - David A. Lochbaum, "Proposed Subsequent License Renewal of Peach Bottom Units 2 and 3: Exelon's Aging Management Programs Fail to Provide Adequate Measures for Consideration of Operating Experience Throughout the Period of Extended Operation", Report prepared for Beyond Nuclear, 16 November 2018; Attached to "Declaration of David A. Lochbaum—In the Matter of Exelon Generation Co., L.L.C., Peach Bottom Atomic Power Station, Units 2 & 3", Docket Nos. 50-277/278 SLR, U.S.NRC before the Secretary, 16 November 2018, see http://static1.1.sqspcdn.com/static/f/356082/28029077/1542673242727/PB-SLR_11192018_Attachments+to+Hearing+Request.pdf?token=6dfkmNSlZgmM33rZ%2Fx%2FV4Bp3%2FWk%3D, accessed 12 July 2019.

487 - U.S.NRC, "In the Matter of Exelon Generation Company, LLC Peach Bottom Atomic Power Station, Units 2 & 3—Beyond Nuclear, Inc.'s Motion For Leave To File New Contention Based On Draft Supplement 10 To Generic Environmental Impact Statement For Subsequent License Renewal Of Peach Bottom Operating License", Before The Atomic Safety And Licensing Board And The Commission, Docket Nos. 50-277/278 SLR, 3 September 2019, see https://www.nrc.gov/docs/ML1924/ML19246C301.pdf, accessed 5 July 2020.

488 - U.S.NRC, "In the Matter of Exelon Generation Company, LLC (Peach Bottom Atomic Power Station, Units 2 and 3)–Commission Memorandum and Order (CLI-20-11)", Docket Nos. 50-277-SLR and 50-278-SLR, 12 November 2020, see https://www.nrc.gov/docs/ML2031/ML20317A110.pdf, accessed 11 August 2021.

489 - Paul M. Bessette, Ryan K. Lighty and Scott D. Clausen, "NRC Reaffirms Its Decision Allowing SLR Applicants to Rely on License Renewal GEIS", Morgan Lewis, 25 November 2020, see https://www.morganlewis.com/blogs/upandatom/2020/11/nrc-reaffirms-its-decision-allowing-slr-applicants-to-rely-on-license-renewal-geis, accessed 11 August 2021.

490 - U.S.NRC, "Status of Subsequent License Renewal Applications", as of 4 August 2021, see https://www.nrc.gov/reactors/operating/licensing/renewal/subsequent-license-renewal.html, accessed 11 August 2021.

491 - Dominion, "North Anna Power Station Units 1 and 2 – Application for Subsequent License Renewal", August 2020, see https://www.nrc.gov/docs/ML2024/ML20246G696.pdf, accessed 14 August 2021.

492 - Duke Energy, "Application for Subsequent Renewed Operating Licenses – Oconee Nuclear Station (ONS), Units 1, 2, and 3", Docket Numbers 50-269, 50-270 and 50-287, Renewed License Numbers DPR-38, DPR-47 and DPR-55, 7 June 2021, see https://www.nrc.gov/docs/ML2115/ML21158A194.pdf, accessed 11 August 2021.

493 - Florida Power & Light Company, "Subsequent License Renewal Application Notification", 17 March 2021, see https://www.nrc.gov/docs/ML2107/ML21076A314.pdf, accessed 11 August 2021.

has said it plans to seek license extensions for all 11 of its reactors.[494] The Congressional moves to provide extended financial support for reactor operations is likely to encourage additional applications for 80-year operational licenses.

Reactor Closures

As a result of storm damage incurred on 10 August 2020, the 622 MW **Duane Arnold-1** reactor did not return to service and was permanently closed, the plant's majority owner, NextEra Energy Resources announced 25 August 2020.[495] It was previously scheduled for closure on 30 October 2020.

The single unit General Electric (GE) designed Mark-1 Boiling Water Reactor (BWR), the same as Fukushima Daichi unit 1, is located in Palo, 13 km northwest of Cedar Rapids and is the only commercial reactor in the mid-west U.S. state of Iowa.[496] The reactor cooling towers were significantly damaged in strong winds from a derecho, a straight-line storm of up to hurricane force, which caused offsite power loss and automatic reactor shutdown.[497]

The 46-year-old reactor was connected to the grid in May 1974.[498] In 2010, the NRC granted an additional 20-year operating license permitting operation until 2034.[499] In July 2018, NextEra Energy announced that it would close Duane Arnold in 2020 after renegotiation of a power purchase agreement that terminated a contract with the reactor as of October this year. Under the agreement, NextEra agreed to supply electricity to the Iowa grid from its lower cost wind energy capacity, which will save customers US$300 million in electricity costs, on a net present value basis, over 21 years, according to NextEra.[500]

In the other reactor closure during the past year, and forty-five years after first being connected to the grid, the **Indian Point-3** reactor closed on 30 April 2021, bringing to an end nuclear generation at the site which is located on the Hudson River, 48 km from Manhattan, New York.[501] Long considered a major safety risk to millions of people, the closure of the reactors was secured under the terms of a historic agreement in January 2017 between the

494 - Ari Natter, "The U.S. May Soon Have the World's Oldest Nuclear Power Plants", *Bloomberg*, 4 February 2020, see https://www.bloomberg.com/news/articles/2020-02-04/the-u-s-may-soon-have-the-world-s-oldest-nuclear-power-plants, accessed 2 July 2020.

495 - Kelly Andrejasich, "Storm damage prompts NextEra Energy to shut Duane Arnold nuclear plant early", *S&P Global*, 25 August 2020, see https://www.spglobal.com/platts/en/market-insights/latest-news/electric-power/082520-storm-damage-prompts-nextera-energy-to-shut-duane-arnold-nuclear-plant-early, accessed 11 August 2021.

496 - Adam Moore, "Duane Arnold's closure ends Iowa's nuclear chapter", *Corridor Business Journal*, 14 August 2018, see https://corridorbusiness.com/duane-arnolds-closure-ends-iowas-nuclear-chapter/, accessed 11 August 2021.

497 - U.S.NRC, Event Notification Report for August 11, 2020", U.S. Nuclear Regulatory Commission Operations Center, see https://www.nrc.gov/reading-rm/doc-collections/event-status/event/2020/20200811en.html, accessed 11 August 2021.

498 - PRIS, "Duane Arnold-1 Permanent Shutdown", IAEA, as of 11 August 2021, see https://pris.iaea.org/PRIS/CountryStatistics/ReactorDetails.aspx?current=667, accessed 11 August 2021.

499 - U.S.NRC, "Duane Arnold Energy Center - License Renewal Application Renewed License Issued on 12/16/2010", as of 28 August 2020, see https://www.nrc.gov/reactors/operating/licensing/renewal/applications/duane-arnold-energy-center.html#appls, accessed 11 August 2021.

500 - Aaron Larson, "Duane Arnold Nuclear Plant Will Close in 2020", *POWER Magazine*, 29 July 2019, see https://www.powermag.com/duane-arnold-nuclear-plant-will-close-in-2020/; and Seeking Alpha, "NextEra to shut Duane Arnold nuclear plant early after storm damage", 25 August 2020, see https://seekingalpha.com/news/3608797-nextera-to-shut-duane-arnold-nuclear-plant-early-after-storm-damage, both accessed 11 August 2021.

501 - U.S. EIA, "New York's Indian Point nuclear power plant closes after 59 years of operation", 30 April 2021, see https://www.eia.gov/todayinenergy/detail.php?id=47776, accessed 11 August 2021.

nuclear plant owner, Entergy, the non-governmental organization Riverkeeper and the state of New York.[502] Indian Point-2 closed on 30 April 2020.[503]

Entergy had invested over US$1 billion in the two remaining 1000 MW Units 2 and 3 in recent years. Unit 1, a smaller 250 MW reactor, was closed in 1974 just 12 years after it had started up. Indian Point-2 was connected to the grid on 26 June 1973, and Unit 3 on 27 April 1976. In closing the last reactor, Entergy highlighted that it had surpassed the world record for continuous operation of a light water reactor, having operated since refueling in April 2019 for 751 days.[504]

In April 2007, Entergy filed a license renewal application with the NRC for Indian Point-2 and -3, which were subsequently subject to sustained opposition from citizens groups over the following decade.[505] Operations of the two remaining Indian Point units were challenged on two basic environmental requirements: a coastal zone management certification and a water permit application. While Entergy had declared that it was exempt from needing the coastal zone management certification, New York State disagreed, and the issue continued in the Court of Appeals. According to the 2017 agreement, Indian Point-2 was required to close no later than April 2020 and Unit 3 one year later.

In terms of multiple safety issues with the Indian Point-2 and -3 over the decades, the most serious in recent years was the discovery of major corrosion in steel bolts on the reactor core baffle which surrounds the fuel and directs cooling water entering the reactor vessel.[506] If the baffle and former assembly do not remain intact, water can enter and leave the reactor vessel without passing through and cooling the core.

In highlighting the significance of the closure of Indian Point, Riverkeeper pointed to the energy efficiency and renewable energy projects implemented in New York State between the agreement for closure in 2017 and 2025, which will provide nearly triple the total amount of power Indian Point once generated.[507] The Natural Resources Defense Council (NRDC) stated:

> Indian Point was sited in the wrong place some 50 years ago—a location where a severe accident would jeopardize the health of millions of people and where no large-scale evacuation plan would be remotely feasible. The closure of Indian Point this week ends this risky chapter. The retirement will happen on schedule with no red flags from reliability monitors at NYISO [New York Independent System Operator], and against the backdrop of accelerated climate and clean energy progress in New York State that was almost unimaginable when the debate over Indian Point began decades ago.[508]

502 - Riverkeeper, "Indian Point Agreement", January 2017, see https://www.riverkeeper.org/wp-content/uploads/2017/01/Indian-Point-Closure-Agreement-January-8-2017.pdf, accessed 10 August 2021.

503 - WNISR, "Closure of 47-Year-Old Indian Point Reactor Near New York City", 30 April 2020, see https://www.worldnuclearreport.org/Closure-of-47-Year-Old-Indian-Point-Reactor-Near-New-York-City.html, accessed 10 August 2021.

504 - Entergy, "Entergy's Indian Point Unit 3 to Permanently Shut Down", 28 April 2021, see https://www.prnewswire.com/news-releases/entergys-indian-point-unit-3-to-permanently-shut-down-301279342.html, accessed 10 August 2021.

505 - Vivian Yee and Patrick McGeehan, "Indian Point Nuclear Power Plant Could Close by 2021", *The New York Times*, 6 January 2017, see https://www.nytimes.com/2017/01/06/nyregion/indian-point-nuclear-power-plant-shutdown.html, accessed 10 August 2021.

506 - UCS, "Core Former Baffle Bolt Event Indian Point Unit 2" 29 March, 2016, see https://cdn.allthingsnuclear.org/wp-content/uploads/2016/03/20160330-ip2-ucs-backgrounder-core-former-bolt-event.pdf, accessed 10 August 2021.

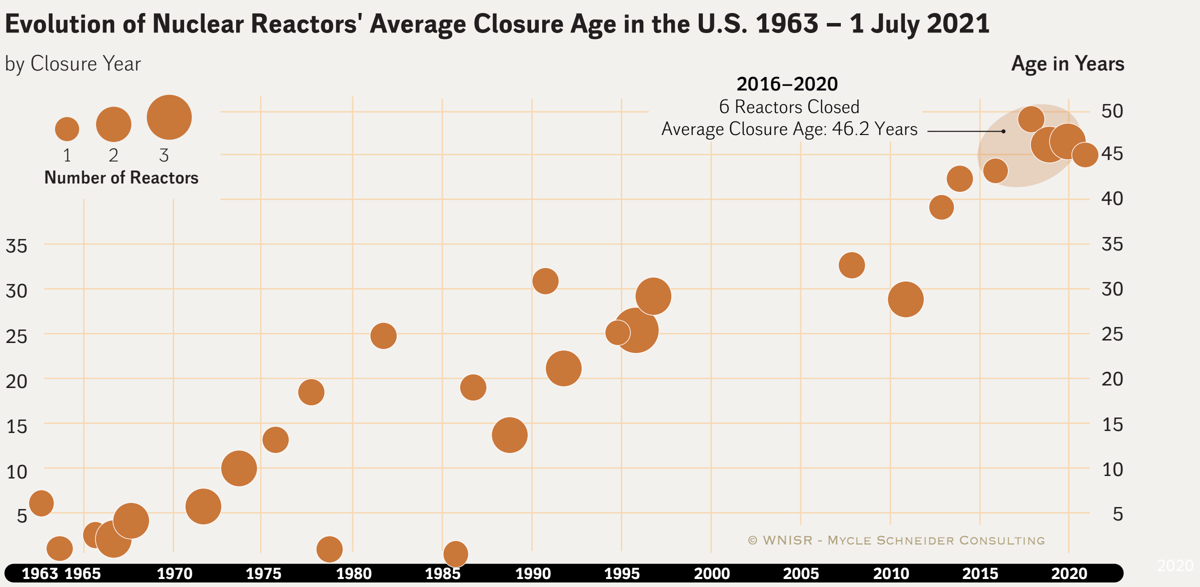
507 - Paul Gallay, "Closing Indian Point is the only way to assure clean and safe energy for New York", Riverkeeper, 12 April 2021, see https://www.riverkeeper.org/blogs/indian-point-blogs/closing-indian-point-is-the-only-way-to-assure-clean-and-safe-energy-for-new-york/, accessed 10 August 2021.

508 - Kit Kennedy, "Indian Point Is Closing, but Clean Energy Is Here to Stay", Climate & Clean Energy Program, NRDC, 28 April 2021, see https://www.nrdc.org/experts/kit-kennedy/indian-point-closing-clean-energy-here-stay, accessed 10 August 2021.

Entergy has also stated that low natural gas prices and increased operating costs of the reactors were key factors in its decision to close Indian Point.[509] A recent study highlighted that rather than increasing natural gas electricity generation to meet New York State 2025 clean energy targets, there will have to be a buildout of renewables, storage, and energy efficiency far exceeding the loss in generation from the Indian Point reactors.[510]

The average age of the six reactors closed in the U.S. over the five-year period 2016–2020 was 46.2 years (see Figure 35), which remains far below their licensed lifetimes of 60 years.

Figure 35 · Evolution of Average Reactor Closure Age in the U.S.



Sources: WNISR with IAEA-PRIS, 2021

509 - Mary Esch, "Curtain lowers on nuke plant a stone's throw from Manhattan", *Associated Press*, 29 April 2020, see https://apnews.com/41b32c474b9aa75bf4261bdac1816e22, accessed 3 July 2020.

510 - PSE, "Evaluating the potential for renewables, storage, and energy efficiency to offset retiring nuclear power generation in New York", April 2020, see https://www.psehealthyenergy.org/wp-content/uploads/2020/04/PSE-Research-Brief_-Indian-Point_4_13_20.pdf, accessed 3 July 2020.

Reactor Construction

Simply stated, it is to develop an unachievable plan, fail relatively quickly, and repeat the process to develop a new (and still unachievable) plan.

Don Grace, Vice President of Engineering for the Vogtle Monitoring Group,
on behalf of the Georgia Public Service Commission Public Interest Advocacy Staff,
on Southern Company approach to Vogtle Construction
June 2020[511]

The Vogtle Debacle

Only two commercial reactors are currently under construction on one site in the U.S., the AP-1000 reactors Vogtle-3, which officially began in March 2013, and Vogtle-4, which began in November 2013.[512] The reactors are being built in Burke County, near Waynesboro, in the state of Georgia, in the southeastern U.S. and are owned by Southern Company (parent company of majority Vogtle plant owner, Georgia Power).

In 2017, Southern Company gave fuel-loading times as November 2021 for Unit 3 and November 2022 for Unit 4, which compares with original planned startup dates in 2017 and 2018. However, the operational dates from Southern are at variance with the assessment made by the Georgia Public Services Commission (PSC) staff in its December 2016 quarterly progress report, which indicated a credible completion date of 2023.[513]

While the project during the past year has passed certain construction milestones, as in previous years and as reported in WNISR, evidence continues to emerge that reveals the enormous scale of the Vogtle project failure.

As of July 2021, construction of Unit 3 was 98 percent complete according to Southern Company, compares with 81.2 percent completed as of March 2020.[514] In the case of Unit 4, Southern Company reported that it was 84 percent complete.[515]

Critics of the Vogtle project had long predicted that there would be delays and that costs would be much higher.[516] The original project cost approved by the Georgia PSC was US$6.1 billion in 2009, which corresponds to a cost of US$2,440/kW (gross), whereas the 2017 estimate of US$23 billion translates to a cost of US$9,200/kW. The revised 2018 estimates in the range

511 - Georgia Public Service Commission, "In the Matter Of: Georgia Power Company's Twenty-Second Semi-Annual Vogtle Construction Monitoring ("VCM") Report–Direct Testimony of DonALD N. Grave P.E.–On Behalf of the Georgia Public Service Commission Public Interest Advocacy Staff", Docket No. 29849, 5 June 2020, see https://services.psc.ga.gov/api/v1/External/Public/Get/Document/DownloadFile/181461/63474, accessed 14 August 2021.

512 - WNISR, "Construction Start on US Vogtle Unit 4", 25 November 2013, see https://www.worldnuclearreport.org/Construction-Start-on-US-Vogtle.html, accessed 20 July 2021.

513 - Kristi E. Schwartz, "Evidence mounts that Vogtle project won't start up in 2020", *E&E News*, 8 February 2017, see https://www.eenews.net/energywire/2017/02/08/stories/1060049693, accessed 20 July 2021.

514 - Southern Company, "Building carbon-free nuclear energy Plant Vogtle Units 3 and 4", July 2021, see https://www.southerncompany.com/innovation/vogtle-3-and-4.html, accessed 19 August 2021.

515 - Aaron Larson, "Fuel Loading Only Major Milestone Left for Vogtle Unit 3 Nuclear Project", *POWER Magazine*, 30 July 2021, see https://www.powermag.com/fuel-loading-only-major-milestone-left-for-vogtle-unit-3-nuclear-project/, accessed 19 August 2021.

516 - For example, see NIRS,"MIT Nuke Study Uses Unsupportable Reactor Cost Estimates", Nuclear Information and Resource Service, Press Release, 16 September 2010, see https://www.commondreams.org/newswire/2010/09/16/mit-nuke-study-uses-unsupportable-reactor-cost-estimates, accessed 23 May 2018; and Travis Madsen et al., "The High Cost of Nuclear Power—Why America Should Choose a Clean Energy Future Over New Nuclear Reactors", Maryland PIRG Foundation, March 2009, see https://www.nirs.org/wp-content/uploads/nukerelapse/calvert/highcostnpower_mdpirg.pdf, accessed 28 May 2019.

of US$28 billion have increased costs to US$11,200/kW, a 4.6-fold increase over the approved original estimate.[517] These costs compare with the Massachusetts Institute of Technology (MIT) 2009-assessment of the prospects for new nuclear power based on overnight costs of $US\$_{2007}$4,000/kW ($US\$_{2018}$4,800/kW).[518]

As WNISR2018 reported, in December 2017, the Georgia PSC, following the recommendation from Southern Company, decided to continue to support the project. The Georgia PSC has backed the Plant Vogtle project from the start, including awarding the generous Construction Work In Progress (CWIP), where all construction costs incurred by Georgia Power are passed directly on to the customer. The Georgia Nuclear Energy Financing Act, signed into law in 2009, allows regulated utilities to recover from their customers the financing costs associated with the construction of nuclear generation projects—years before those projects are scheduled to begin producing benefits for ratepayers.

As a result of the CWIP legislation, out of Georgia Power's original estimated US$6. billion Vogtle costs, US$1.7 billion is financing costs recoverable from the ratepayer. The utility began recovering these financing costs from its customers starting in 2011. For that first year, the rule translates to Georgia Power electric bills' rising by an average of US$3.73 per month. Georgia Power estimated that this monthly charge would escalate so that by 2018, a Georgia Power residential customer using 1,000 kWh per month would have seen his/her bill go up by US$10 per month due to Vogtle-3 and -4. As a result of increased costs of the project and approval by the Georgia PSC, ratepayers had already paid US$2 billion to Georgia Power as of November 2017.[519] But given the long timescale of the project, including planned operational life, the actual costs to ratepayers will be much higher.

Under the financing terms agreed with the Georgia PSC, the longer the Vogtle plant takes to construct, the higher its costs, which have invariably been passed on to Georgia ratepayers, resulting in higher income streams for Georgia Power and therefore Southern. In reporting 2018 Southern earnings, CEO Thomas A. Fanning stated that 2018, "was a banner year for Southern Company (…) All of our state-regulated electric and gas companies delivered strong performance with full-year 2018 earnings of US$2.23 billion, compared with earnings of US$842 million in 2017.[520]

WNISR2019 reported extensively on the economics of the Vogtle project. According to an expert testimony to the PSC on 5 June 2020,

> The Staff CTC (cost to complete) analyses, which ignore the US$8.1 billion already incurred by the Company (Georgia Power) as of December 31, 2019, indicate that it is economic to complete the Project if the Company adheres to its current construction cost and the

517 - Liam Denning, "Nuclear Power's Big Problem Isn't That It's Nuclear", *Bloomberg*, 27 September 2018, see https://www.bloomberg.com/opinion/articles/2018-09-27/nuclear-power-s-big-problem-isn-t-that-it-s-nuclear, accessed 28 May 2019.

518 - John M. Deutch, Charles W. Forsberg, et al., "Update of the MIT 2003 Future of Nuclear Power", MIT Energy Initiative, Interdisciplinary Study, Massachusetts Institute of Technology, 2009, see http://web.mit.edu/nuclearpower/pdf/nuclearpower-update2009.pdf, accessed 5 August 2019.

519 - Southern Environmental Law Center, "Groups Intervene in Vogtle Cost Proceedings—Georgians Should Not Bear Financial Burden of Georgia Power's Project Mismanagement", Press Release, 6 November 2017, see https://www.southernenvironment.org/news-and-press/press-releases/groups-intervene-in-vogtle-cost-proceedings-georgians-should-not-bear-finan, accessed 28 May 2019.

520 - Southern Company, "Southern Company reports fourth-quarter and full-year 2018 earnings", *PR Newswire*, 20 February 2019, see https://www.prnewswire.com/news-releases/southern-company-reports-fourth-quarter-and-full-year-2018-earnings-300798574.html, accessed 28 May 2019.

> November 2021 and November 2022 regulatory COD [Commercial Operation Date] forecasts. The Staff analyses indicate that it is not economic to complete the Project if there is a delay of 24 months or longer beyond the current regulatory CODs.[521]

There were major doubts before this year that Georgia Power would meet its COD target dates, but this was confirmed during 2020–2021, including in relation to the start and completion of Hot Functional Tests (HFT).[522] In 2019, PSC staff had concluded that "at this time the status of the Project is uncertain," with major uncertainties whether the target date of HFTs scheduled for Unit 3 on 31 March 2020 could be achieved.[523] Fuel loading at that time was scheduled for 14 October 2020.

On 30 April 2020, Thomas Fanning, CEO of Georgia Power, stated that, "cold hydro testing is planned to begin in June or July, with hot functional testing beginning in August or September."[524] This schedule changed again, when in June 2020, Southern announced that cold testing would take place "this fall" to then be followed by hot testing.

Credit-rating agency Standard & Poor's said in a statement:

> The unexpected, late-stage changes to these planned activities is credit negative for Georgia Power because it signals that challenges with the project continue, increasing the likelihood of additional cost overruns and further schedule delays.[525]

HFT was then supposed to begin in January 2021 but was delayed and considered the primary cause for delay in commercial operation of the reactor. HFT of Vogtle-3 finally began on 25 April 2021 and was planned to be completed within 6–8 weeks.[526] Apparently, Southern Company reported to investors on 29 July 2021 that HFT had been completed.[527]

On 18 May 2021, Southern Company informed the Georgia Public Service Commission that delays in testing of the Vogtle-3 reactor would mean that operation would not start before

521 - Georgia Public Service Commission , "In The Matter Of: Georgia Power Company's Twenty-Second Semiannual Vogtle Construction Monitoring ("VCM") Report – Direct Testimony And Exhibits Of Tom Newsome, PE, CFA; Philip Hayet; Lane Kollen, CPA, CMA, CGMA – On Behalf Of The Georgia Public Service Commission Public Interest Advocacy Staff", Before The Georgia Public Service Commission, Docket No. 29849, 5 June 2020, see https://www.eenews.net/assets/2020/06/09/document_ew_04.pdf, accessed 3 June 2020.

522 - HFT is a series of tests in which essentially the entire plant is tested in an integrated fashion. The Reactor Coolant System (RCS) is heated in steps to the normal operating temperature and pressure (NOT and NOP) by running the Reactor Coolant Pumps. Significant tests include measurement of thermal expansion and vibrations of the RCS, verifying the ability to control RCS pressure using the pressurizer heaters and spray, and integrated operation of the secondary plant including supplying feedwater to the Steam Generators via the condensate and feedwater systems. In addition, the main turbine will be rolled to full operating speed of 1800 RPM to verify the operation.

523 - Georgia PSC, "In The Matter Of Georgia Power Company's Nineteenth Semi-Annual Vogtle Construction Monitoring Report—Direct Testimony And Exhibits Of Steven D. Roetger and William R. Jacobs, Jr., PhD—On Behalf Of The Georgia Public Service Commission Public Interest Advocacy Staff", Testimony Before The Georgia Public Service Commission, Docket No. 29849, 30 November 2018.

524 - *WNN,* "Major component installed at Vogtle 3", 14 May 2020, see https://world-nuclear-news.org/Articles/Major-component-installed-at-Vogtle-3, accessed 4 July 2020.

525 - Joniel Cha, "Resequencing of Vogtle nuclear plant expansion activities is credit negative: Moody's", *S&P Global*, 24 June 2020, see https://www.spglobal.com/platts/en/market-insights/latest-news/electric-power/062420-resequencing-of-vogtle-nuclear-plant-expansion-activities-is-credit-negative-moodys, accessed 4 July 2020.

526 - Georgia Power, "Vogtle Unit 3 begins Hot Functional Testing", as published on *PR Newswire*, 26 April 2021, see https://www.prnewswire.com/news-releases/vogtle-unit-3-begins-hot-functional-testing-301276472.html, accessed 21 July 2021.

527 - Southern Company, "Building carbon-free nuclear energy—Plant Vogtle Units 3 and 4", 30 July 2021. op. cit.; and *WNN*, "Vogtle in-service dates and cost forecast revised", 29 July 2021, see https://www.world-nuclear-news.org/Articles/In-service-dates-and-cost-forecast-revised-for-Vog, accessed 28 August 2021.

January 2022, at the earliest.[528] The Commission was told that Unit 3 was 98 percent complete, but Southern Nuclear Vice President Aaron Abramovitz said risk of delays and problems doesn't go away. "I would expect risk to decrease," he told regulators. "I would not expect risk to go to zero."[529]

While COVID-19 has impacted workers on the site, delays have also been caused by the need to replace electrical components and other work that the "company decided wasn't up to standard." Georgia Power told Commissioners that there was evidence "that contractors were declaring work complete without testing for deficiencies, relying on inspectors to catch it and fix any problems later." The company is currently engaged in hot functional testing of the first reactor and has encountered more expansion of metal parts as systems were heated up than anticipated. "There's a chance we may need to make some adjustments to the structural supports" Stephen Kuczynski, President and CEO of Southern Nuclear, told Commissioners of the thermal expansion issues. The PSC was informed that the current schedule for operation of Unit 4 was November 2022.

"Ratepayers will pay substantially more both prior to and after the Units begin providing service due to the delays and cost overruns."

Less than one month later, in June 2021, expert witness testimony from the lead analyst and consultant for the PSC Staff Public Interest Advocacy Team for Vogtle Construction Monitoring challenged Southern Company's projection for start of operations of Vogtle-3. Steven D. Roetger and William R. Jacobs, Jr gave evidence that cast major doubts on the reliability of schedules given by Southern.[530] This included the fact that in the three months between July 2020 and October 2020 the schedule for work slipped by three months, leading Roetger and Jacobs to conclude that, "Considering the Company's lack of performance regarding schedule adherence, the assumption that Hot Functional Testing (HFT) would 'start near the beginning of next year' was highly optimistic and not founded on past performance."[531]

"The primary drivers for the delay in the Commercial Operation Date (COD) from the Company's Vogtle Construction Monitoring (VCM) 23rd testimony are the delays in starting HFT, the extended duration of HFT and the duration between completion of HFT and Fuel Load," according to Roetger's and Jacobs.[532] The detailed reasons for the delays were provided to the PSC but were redacted from public disclosure, but relate to the "late completion and turnover of plant systems required for HFT."

Under the CWIP, electricity rates for Georgia consumers have gone up 3.4 percent to pay for earlier costs and Georgia Power projects rates will rise at least another 6.6 percentage points for a total increase of 10 percent.

528 - Jeff Amy, "Plant Vogtle now delayed until 2022 as costs mount, Georgia Power says", *Associated Press*, 18 May 2021, see https://eu.augustachronicle.com/story/news/2021/05/18/plant-vogtle-now-delayed-until-2022-costs-mount-georgia-power-says/5151589001/, accessed 21 July 2021.

529 - Ibidem.

530 - Georgia PSC, "In the Matter of Georgia Power Company's Twenty-Fourth Semi-Annual Vogtle Construction Monitoring Report—Direct Testimony of Steven D. Roetger, William R. Jacobs, Jr., Ph.D.—On Behalf of the Georgia Public Service Commission Public Interest Advocacy Staff", Docket No. 29849, 7 June 2021.

531 - Ibidem.

532 - The VCM's are held twice annually where the company provides schedule details to the PSC.

Georgia Power is currently expected to recover approximately US$3.9 billion under the Nuclear Construction Cost Recovery ("NCCR") tariffs imposed on customers during the construction period. "This is nearly double the US$2.1 billion the Company would have collected if the Units had been completed in accordance with the certification schedule of 11 April 2016 and 2017."[533] Under the NCCR, Georgia Power is permitted to request to add US$8.0 billion to its rate base once Units 3 and 4 are in commercial service. The Georgia PSC points out,

> This amount is more than 80 percent greater than the US$4.4 billion assumed at certification. This additional US$3.6 billion in rate base will increase ratepayer revenue requirements by approximately US$12 billion over the 60-year life of the Units and increase annual revenue requirements by an average of US$380 million and US$350 million during the first five and ten years in operation, respectively. In conclusion, ratepayers will pay substantially more both prior to and after the Units begin providing service due to the delays and cost overruns.[534]

Lawsuits Against the Vogtle Project

Multiple lawsuits against the Vogtle project initiated over the years have continued through the courts. As reported in WNISR2018, on 13 February 2018 a coalition of groups filed in Fulton County Superior Court a complaint challenging the Georgia PSC decision, declaring that it was unlawful, violating the PSC's own guidelines and Georgia state law.[535] On 21 December 2018, the court found that dissatisfied customers cannot raise concerns about the unfairness of Georgia PSC's process "until 2022 or later, after the project is complete… The court dismissed the appeal on technical grounds without addressing its substance," attorney Kurt Ebersbach of Southern Environmental Law Center (SELC) stated.[536] "The people of Georgia have been pre-paying for this mismanaged project since 2011, while the price tag has ballooned and the project timeline has slipped again and again," Liz Coyle, executive director of Georgia Watch said. "Unless the court reverses the commission's decision, Georgia Power customers remain exposed to significant financial risk with seemingly no end in sight."[537]

In October 2019, the Court of Appeals remanded the case back to the lower Court to determine whether the citizens groups had met their burden to show that postponing their appeal until after the project is finished would not provide them an adequate remedy.[538] In April 2020,

533 - Georgia Public Service Commission, "In The Matter Of: Georgia Power Company's Twenty-Second Semiannual Vogtle Construction Monitoring ("VCM") Report – Direct Testimony And Exhibits Of Tom Newsome, PE, CFA; Philip Hayet; Lane Kollen, CPA, CMA, CGMA", Docket No. 29849, 5 June 2020, op. cit.

534 - Ibidem.

535 - Dave Williams, "Plant Vogtle opponents appeal vote to complete nuclear project", *Atlanta Business Chronicle*, 12 February 2018, see https://www.bizjournals.com/atlanta/news/2018/02/12/plant-vogtle-opponents-appeal-vote-to-complete.html, accessed 28 May 2019.

536 - *Albany Herald*, "Groups Challenge Court Decision Regarding Plant Vogtle Over Cost Concerns", as published by Georgia Watch, 10 January 2019, see https://www.georgiawatch.org/groups-challenge-court-decision-regarding-plant-vogtle-over-cost-concerns/, accessed 28 May 2019.

537 - Ibidem.

538 - Georgia Watch, "Georgia Court Of Appeals Sends Plant Vogtle Challenge Back To Fulton County Superior Court", 30 October 2019, see https://georgiawatch.org/georgia-court-of-appeals-sends-plant-vogtle-challenge-back-to-fulton-county-superior-court/, accessed 4 July 2020.

Fulton County Court ruled that it lacked jurisdiction to consider the merits of the case until the reactors' construction is finished.[539]

The most recent challenge to the Vogtle construction project was in May 2020, when the Blue Ridge Environmental Defense League (BREDL) filed a challenge to an NRC License Amendment request from Southern.[540] BREDL contends that, under the guise of a one-inch change in the seismic gap between two critical walls in the Vogtle Unit 3 reactor, Southern has admitted to a much more serious structural problem, the "dishing" of the nuclear plant's concrete foundation which creates instability.[541] Southern contends that it's just a minor construction flaw, whereas BREDL expert witness, nuclear engineer Arne Gundersen, stated "that the sheer weight of the nuclear island building is causing it to sink into the red Georgia clay."[542] During a preliminary oral hearing of Southern's License Amendment request, the case was heard by the NRC's Atomic Safety and Licensing Board (ASLB) on 1 July 2020. On 10 August 2020, the ASLB issued Memorandum and Order, denying BREDL's intervention, and dismissing the two contentions and terminating the proceeding.[543] On 4 September 2020 BREDL filed with the NRC seeking Commission review of the ASLB decision.[544]

Vogtle Federal Loan Guarantees

Under the terms of the Department of Energy (DOE) Loan Guarantee Program, owners of nuclear projects are able to borrow at below-market Federal Financing Bank rates with the repayment assurance of the U.S. Government. DOE loan guarantees permitted Vogtle's owners to finance a substantial portion of their construction costs at interest rates well below market rates, and to increase their debt fraction, which significantly reduced overall financing costs. In justification for the loan guarantee to Vogtle, the Obama administration stated in 2010 that the Vogtle project represents an important advance in nuclear technology technology. Other innovative nuclear projects may be unable to obtain full commercial financing due to the perceived risks associated with technology that has never been deployed at commercial scale in the U.S. The loan guarantees from this draft solicitation would support advanced nuclear

539 - Southern Environmental Law Center, "Fulton County Superior Court Again Rules that Flawed Decision to Continue Vogtle Project May Not be Challenged Until Project is Finished", 21 April 2020, see https://www.southernenvironment.org/news-and-press/press-releases/court-again-rules-that-flawed-decision-to-continue-vogtle-project-may-not-be-challenged-until-project-is-finished, accessed 4 July 2020.

540 - BREDL, "BREDL And Our Chapter Concerned Citizens Of Shell Bluff File Petition Regarding Plant Vogtle Plant 3 License Amendment And Exemption", 12 May 2020, see http://www.bredl.org/nuclear/200511_BREDL_Petition_to_Intervene_Vogtle_3.htm; and U.S.NRC, "In the Matter of Southern Nuclear Operating Co.–License Amendment Application for Combined Licenses NPF-91, Vogtle Electric Generating Plant Unit 3—Petition For Leave To Intervene And Request For Hearing By The Blue Ridge Environmental Defense League And Its Chapter Concerned Citizens Of Shell Bluff Regarding Southern Nuclear Operating Company's Request For A License Amendment And Exemption For Unit 3 Auxiliary Building Wall 11 Seismic Gap Requirements, LAR-20-001", Docket No. 52-025-LA-3, NRC-2008-0252, 11 May 2020, see https://www.bredl.org/pdf6/200511_BREDL_Petition_to_Intervene_Vogtle_3_Docket_52-025-LA-3.pdf, both accessed 4 July 2020.

541 - BREDL, "Residents Fight to Bring Case Against Georgia Nuclear Plant Legal Brief", 15 June 2020, see http://www.bredl.org/press/2020/200615_PR_Reply_Filed_VEGP-3_Plant_Sinking.pdf, accessed 4 July 2020.

542 - Ibidem.

543 - U.S.NRC, "In the Matter of: Southern Nuclear Operating Company License Amendment Application for Combined License NPF-91 Vogtle Electric Generating Plant Unit 3—Blue Ridge Environmental Defense League's notice of appeal and brief in support of appeal from the Atomic Safety and Licensing Board decision denying admissibility of contentions in license amendment proceeding", 4 September 2020, see https://www.nrc.gov/docs/ML2024/ML20248J166.pdf, accessed 12 August 2020.

544 - See U.S.NRC, "NRC Staff Answer in Opposition to Blue Ridge Environmental Defense League's Appeal of LBP, Docket No 52 025, 28 September 2020, p.6, see https://www.nrc.gov/docs/ML2027/ML20272A257.pdf, accessed 12 August 2021.

energy technologies that will catalyze the deployment of future projects that replicate or extend a technological innovation.[545]

The loan-guarantee program has therefore played a critical role in permitting the Vogtle project to proceed but has failed to catalyze a nuclear revival, with no prospects of further new large nuclear plants being built in the U.S. in the coming decades. Oglethorpe Power Corporation (OPC), which has a 30-percent stake in Vogtle, confirmed in August 2017 that it had submitted a request to DOE for up to US$1.6 billion in additional loan guarantees. The company already had a US$3 billion loan guarantee from DOE. The other owners—Georgia Power and Municipal Electric Authority of Georgia (MEAG)—have secured US$8.3 billion in separate loan guarantees from DOE since 2010, when they were approved by the Obama administration. Both of these companies confirmed in August 2017 that they were seeking additional loan guarantee funding.

On 29 September 2017, DOE Secretary Perry announced approval of additional US$3.7 billion loan guarantees for the Vogtle owners, with US$1.67 billion to Georgia Power, US$1.6 billion to OPC, and US$415 million to MEAG.[546] A decision on terminating the Vogtle project would raise the prospect of repayment of the previous US$8.3 billion loan to Southern.[547] In April 2019, the DOE provided an additional loan guarantee of US$3.7 billion to Plant Vogtle construction, only the second loan guarantee issued under the Trump administration and the second to Plant Vogtle.[548] This brings the total loan guarantees provided for the Vogtle project by the DOE to US$12.03 billion.[549]

545 - Peter W. Davidson, "Fostering the Next Generation of Nuclear Energy Technology—Investing in American Energy", Loan Programs Office, U.S.DOE, 29 September 2014, see https://energy.gov/lpo/articles/fostering-next-generation-nuclear-energy-technology, accessed 6 July 2020.

546 - U.S.DOE, "Secretary Perry Announces Conditional Commitment to Support Continued Construction of Vogtle Advanced Nuclear Energy Project", 29 September 2017, see https://www.energy.gov/articles/secretary-perry-announces-conditional-commitment-support-continued-construction-vogtle, accessed 12 August 2020.

547 - Peter Maloney, "Westinghouse bankruptcy puts $8.3B in federal loan guarantees for Vogtle plant at risk", *Utility Dive*, 3 April 2017, see http://www.utilitydive.com/news/westinghouse-bankruptcy-puts-83b-in-federal-loan-guarantees-for-vogtle-pl/439508/, accessed 28 May 2019.

548 - Jacqueline Toth, "DOE Program's $3.7 Billion Loan Highlights Lack of Action on Other $40 Billion It Holds", Morning Consult, 8 April 2019, see https://morningconsult.com/2019/04/08/doe-programs-3-7-billion-loan-highlights-lack-of-action-on-other-40-billion-it-holds/, accessed 10 May 2019.

549 - Taxpayers for Common Sense, "DOE Loan Guarantee Program: Vogtle Reactors 3 & 4", 21 March 2019, see https://www.taxpayer.net/wp-content/uploads/2019/03/3-21-19-ENR-Vogtle-Fact-Sheet_MARCH-2019_-v.4.pdf, accessed 10 May 2019.

Guilty Pleas and On-going FBI Investigations Over V.C. Summer Project

This guilty plea shows that the investigation into the V.C. Summer nuclear debacle did not end with the former SCANA executives... we are committed to seeing this case through and holding all individual and corporate wrongdoers accountable.

Acting United States Attorney DeHart
10 June 2021.[550]

As reported in previous WNISR editions, the decision on 31 July 2017 by Santee Cooper and SCANA Corporation (the parent company of South Carolina Electric & Gas or SCG&E) to terminate construction of the V.C. Summer reactor project has seen ongoing financial and legal fallout for the companies and ratepayers of South Carolina during the past three years. At the time of cancellation, the total costs for completion of the two AP-1000 reactors at V.C. Summer was projected to exceed US$25 billion—a 75 percent increase over initial estimates.[551] The conspiracy to deceive regulators and ratepayers, which has been revealed by federal investigations, was intended to allow SCANA to apply for numerous rate increases to help pay for ongoing reactor construction. The rate increases were "fraudulently inflated bills to customers for the stated purpose of funding the project," according to federal filings.[552] Under legislation passed by the South Carolina Public Services Commissioners in 2008—but strongly opposed by civil society groups—construction costs for the V.C. Summer reactors were to be paid by state ratepayers. When SCANA was taken over by Dominion Energy in January 2019 it "committed to make extensive remedial efforts to redress ratepayers," which is estimated to be approximately US$4 billion. Exactly what this means remains unclear, as under current plans Dominion will be charging South Carolina ratepayers an additional US$2.3 billion over the next two decades for the collapsed V.C. Summer project.[553] The 8 June 2020 filing made it clear that Dominion will not be prosecuted, with a utility spokesman stating that "We have no further comment regarding this matter or the investigation".[554]

During the past year, executives from both SCANA and Westinghouse have been found guilty of unlawfully withholding information for years about the failure of the V.C Summer project both from regulators and shareholders.

550 - U.S. Attorney's Office District of South Carolina, "Westinghouse Director During Nuclear Debacle Pleads Guilty in Federal Court to Making False Statement to FBI", United States Department of Justice, 10 June 2021, see https://www.justice.gov/usao-sc/pr/westinghouse-director-during-nuclear-debacle-pleads-guilty-federal-court-making-false, accessed 20 July 2021.

551 - Robert Walton, "SCANA agrees to settle $2B class action suit over nuclear costs", *Utility Dive*, 26 November 2018, see https://www.utilitydive.com/news/scana-agrees-to-settle-2b-class-action-suit-over-nuclear-costs/542911/, accessed 26 May 2019.

552 - District Court of the United States for the District of South Carolina, "United States Vs Stephen Andrew Byrne – Plea Agreement", Criminal No 3:20 355, Made 21 May 2020, Filed 8 June 2020, see https://srswatch.org/wp-content/uploads/2020/06/Byrne-court-plea-June-8-2020.pdf; and *The State*, "SCANA conspirators helped Byrne spin lies about nuclear project, document alleges 9 June, 2020", Updated 15 June 2020, see https://www.thestate.com/news/local/crime/article243395241.html, both accessed 6 July 2020.

553 - Avery G. Wilks and Andrew Brown, "Ex-SCE&G official will cooperate as witness in criminal probe of failed VC Summer project", *The Post and Courier*, 9 June 2020, see https://www.postandcourier.com/business/ex-sce-g-official-will-cooperate-as-witness-in-criminal-probe-of-failed-vc-summer/article_e8a99396-aa4d-11ea-bcb3-77378b75c486.html, accessed 6 July 2020.

554 - Ibidem.

As of 1 July 2021, final sentences in these cases are pending. Former SCANA CEO Kevin Marsh, and others, according to the prosecutors, had participated in an illegal abuse of public trust by engaging in a deliberate plan to hide the extent of SCANA's financial troubles at the nuclear project from the public, from regulators and from investors in the publicly traded utility. United States Attorney Peter M. McCoy in the Marsh case told the press in February 2021, "What is most exciting about today is that justice has been served. For years, institutions and individuals have abused the public trust with little to no accountability. This includes corporations that have increased profits at the expense of their customers."[555]

The Director of Savannah River Site Watch (SRS Watch) Tom Clements stated stated that "The [US]$5 million fine is really like a traffic ticket to him…I assume he (Marsh) is going to suffer for two years in prison, but he really deserves a much longer prison sentence for what he's done to the state of South Carolina," said Clements, who predicted more people will eventually be charged.[556] Although agreeing to two years prison time, the final sentencing of the former SCANA CEO will not take place for months or even years as he is cooperating with FBI investigators as they continue gathering evidence for possible charges against others at SCANA, Westinghouse and beyond.

In the case brought against Carl Dean Churchman, former vice President of Westinghouse Electric Corporation and the director of the V.C. Summer project for the company, it was found that he was communicating "with colleagues from the Westinghouse Electric Corporation through multiple emails in which they discussed the viability and accuracy of (completion dates) and thereafter, he reported those dates to executives of SCANA and Santee Cooper during a meeting held on Feb. 14, 2017."[557] On 10 June 2021, Churchman, who was Westinghouse's vice-president of new plants and major projects at the time, pleaded guilty to the felony offence of lying to the FBI, prompting FBI Special Agent Susan Ferensic to state that "Today's plea highlights the FBI's determination to conduct a comprehensive investigation that yields the truth…We will continue to ask important questions and identify all involved in this failed nuclear project."[558]

A parallel legal case, brought by the Securities and Exchange Commission (SEC) against SCANA executives, was settled in December 2020. They were accused of civil fraud in being at the center of a scheme that artificially inflated SCANA's stock price in the period 2014-2017. The proposed settlement, announced by the SEC on 2 December 2020, requires SCANA to pay a US$25 million civil penalty, and SCANA and SCE&G to pay US$112.5 million in disgorgement plus prejudgment interest.[559]

555 - Avery G. Wilks and Conor Hughes, "Ex-SCANA CEO pleads guilty to fraud in SC nuclear fiasco: 'I'm sorry it's come to this'", *The Post and Courier*, 7 February 2021, see https://www.postandcourier.com/news/local_state_news/ex-scana-ceo-pleads-guilty-to-fraud-in-sc-nuclear-fiasco-im-sorry-its-come/article_6687ce9c-751c-11eb-8678-07d1d205c4db.html, accessed 20 July 2021.

556 - Ibidem.

557 - John Monk, "Former Westinghouse official to plead guilty in FBI probe of SCANA's nuclear failure", *The State*, 24 May 2021, see https://www.thestate.com/news/politics-government/article251639033.html, accessed 20 July 2021.

558 - U.S. Attorney's Office, District of South Carolina, "Westinghouse Director During Nuclear Debacle Pleads Guilty in Federal Court to Making False Statement to FBI", U.S. Department of Justice, 10 June 2021, op. cit.

559 - SEC, "Securities and Exchange Commission v. SCANA Corporation, et al., No. 3:20-cv-00882-MGL (D.S.C., filed December 2, 2020)", Litigation Release No. 24976, 3 December 2020, see https://www.sec.gov/litigation/litreleases/2020/lr24976.htm, accessed 20 July 2021.

Acting U.S. Attorney Rhett DeHart stated in June 2021, "It's clear that our investigation into the V.C. Summer nuclear debacle didn't end with the SCANA case," he said. "Our office is committed to seeing this investigation through and holding all individuals and companies who participated in this fiasco accountable."[560]

The cancellation of the V.C. Summer project adds to the history of 40 other stranded nuclear reactor projects in the United States whose construction started mostly in the 1970s and which were abandoned between 1977 and 1989.

Securing Subsidies to Prevent Closures

As WNISR has reported in recent years, utilities have been actively lobbying for state legislation and contracts that would provide significant financial support for the operation of their uneconomic reactors (see WNISR2018 – Annex 4). Between 2009 and 2025 a total of 25 reactors were scheduled for early retirement, of which 12 have already been closed, three more are scheduled for closure, six will close unless they can access new subsidies and two had their closure delayed following subsidy programs (see Figure 36 and Table 6).

As of 1 July 2021, legislation in five states (Connecticut, Illinois, New Jersey, New York and Ohio) had been enacted, (with one redaction in Ohio as a result of the FirstEnergy corruption scandal, see below) which in total provided state subsidies to 13 reactors at ten nuclear plants. All of these five states have unbundled, retail-choice electricity markets, where generators do not receive cost recovery from state regulatory commissions. These account for 9 percent of the utility-scale generating capacity in those five states and 13 percent of the U.S. nuclear generating capacity.[561]

Central to the future of nuclear power in the Pennsylvania-New Jersey-Maryland Interconnection LLC (PJM) wholesale electricity market are the rules expected to be proposed by the Federal Energy Regulatory Commission (FERC).[562] In June 2018, FERC invalidated the PJM market rules.[563] The FERC order relates to how the PJM sets the price of capacity it procures through its capacity market, known as the Reliability Pricing Model (RPM). They will affect how state subsidies, including ZECs, will be considered in the wholesale market. At issue is whether the subsidies being received by utilities for their nuclear plants will be factored into the capacity auction pricing. As reported in previous WNISRs, much of the legislation passed in the five states has been Zero Emission Credits or ZECs, which have evolved from small-scale renewables to thousands of megawatts from larger nuclear units. FERC has noted that "With

560 - Scott Judy, "Who's the Next Target in Feds' Nuke Plant Fraud Investigation?", *Engineering News Record*, 24 June 2021, see https://www.enr.com/articles/51918-whos-the-next-target-in-feds-nuke-plant-fraud-investigation, accessed 20 July 2021.

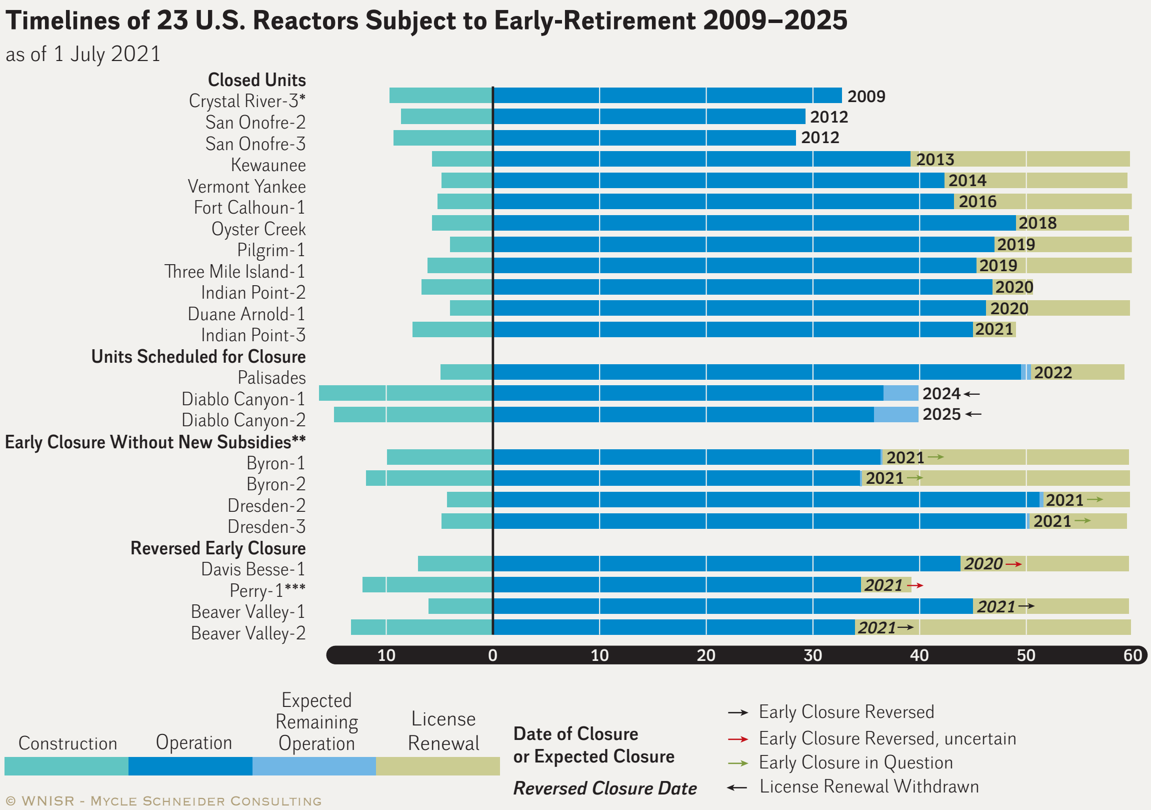
561 - U.S. EIA, "Five states have implemented programs to assist nuclear power plants", U.S. Energy Information Agency, 7 October 2019, see https://www.eia.gov/todayinenergy/detail.php?id=41534, accessed 7 July 2020.

562 - The Federal Energy Regulatory Commission, or FERC, is an independent agency that regulates the interstate transmission of natural gas, oil, and electricity. FERC also regulates natural gas and hydropower projects.

563 - Sonal Patel, "FERC Nixes PJM's Fixes for Capacity Market Besieged by Subsidized Resources", *POWER Magazine*, 5 July 2018, see https://www.powermag.com/ferc-nixes-pjms-fixes-for-capacity-market-besieged-by-subsidized-resources/?printmode=1, accessed 7 July 2020.

each such subsidy, the market becomes less grounded in fundamental principles of supply and demand."[564]

Figure 36 · Timelines of 23 Reactors Subject to Early Retirement in the United States



Sources: Various, compiled by WNISR, 2021

Notes:

* Crystal River: No production after 2009 (WNISR considers it closed as of this date). Official closure announced in 2013. Renewal application submitted in 2008, withdrawn in 2013. See U.S. NRC, "Crystal River – License Renewal Application", Updated 9 December 2016, see https://www.nrc.gov/reactors/operating/licensing/renewal/applications/crystal-river.html, accessed 8 September 2020.

** Reactors to be closed in 2021 in case Exelon is not able to secure subsidies. See Exelon, "Exelon Generation Submits Decommissioning Plans for Byron and Dresden Nuclear Plants", 28 July 2021, see https://www.exeloncorp.com:443/newsroom/exelon-generation-submits-decommissioning-plans-for-byron-and-dresden-nuclear-plants, accessed 31 July 2021.

*** License Renewal Application cancelled in 2018. See FENOC, "Perry Nuclear Power Plant—Change of Intent to Submit License Renewal Application", First Energy Nuclear Operating Company, 27 November 2018, see https://www.nrc.gov/docs/ML1833/ML18331A155.pdf, accessed 8 September 2020.

In December 2019, FERC released an order[565] directing PJM[566] to significantly expand its minimum offer price rule (MOPR) to mitigate the impacts of state-subsidized resources on the capacity market. The ruling has the potential to undermine renewable energy development and as such is likely to be legally challenged by renewable energy industry associations and

564 - FERC, "Order Rejecting Proposed Tariff Revisions, Granting In Part And Denying In Part Complaint, And Instituting Proceeding Under Section 206 Of The Federal Power Act", Docket Nos. EL16-49-000, issued 29 June 2018, p. 3, see https://elibrary.ferc.gov/eLibrary/filelist?accession_number=20180629-4005, accessed 24 August 2021.

565 - FERC, "Order Establishing Just And Reasonable Rate", Docket Nos. EL16-49000 and EL18-178-000, 169 FERC 61,239, issued 19 December 2019, see https://www.pjm.com/-/media/documents/ferc/orders/2019/20191219-el16-46-000-el18-178-000.ashx, accessed 7 July 2020.

566 - Adam Keech, "Capacity Market Minimum Offer Price Rule Order", Vice President of Market Operations, Market Implementation Committee, PJM, 8 January 2020, see https://www.pjm.com/-/media/committees-groups/committees/mic/2020/20200108/20200108-item-04a-ferc-order-on-mopr.ashx, accessed 7 July 2020.

environmental groups, which are particularly concerned about the ruling's de-facto support for continued fossil fuel use.[567] It was utilities with significant nuclear capacity that were most concerned by the FERC ruling. Dependent on capacity market revenues, ZECs or equivalent exist in Connecticut, Illinois, New Jersey, New York and Ohio (subsequently rescinded) and provide state subsidies to reactors.

Table 6 – 19 Early-Retirements for U.S. Reactors 2009–2025

Reactor	Owner	Decision Date	Closure/ Expected Closure Date (last electricity generation)	Age at Closure (in years)	NRC 60-Year License Approval
Oyster Creek	Exelon	8 December 2010	December 2019 brought forward to 17 September 2018	49	Yes
Crystal River-3	Duke Energy	5 February 2013	26 September 2009	32	Application withdrawn
Kewaunee	Dominion Energy	22 October 2012	7 May 2013	39	Yes
San Onofre-2 & -3	SCE/SDG&E	7 June 2013	January 2012	29 / 28	No application
Vermont Yankee	Entergy	28 August 2013	29 December 2014	42	Yes
Pilgrim	Entergy	13 October 2015	31 May 2019	47	Yes
Diablo Canyon-1 & -2	PG&E	21 June 2016	November 2024 & August 2025	40	Suspended
Fort Calhoun	OPPD	26 August 2016	24 October 2016	43	Yes
Palisades	Entergy	8 December 2016/ 28 September 2017	2022	51	Yes
Indian Point-2	Entergy	9 January 2017	30 April 2020	47	Yes
Indian Point-3			30 April 2021	44	
Three Mile Island-1	Exelon	30 May 2017	September 2019	45	Yes
Duane Arnold	NextEra	27 July 2018	30 October 2020 Brought forward to 10 August 2020	46	Yes
Byron-1 & -2	Exelon	28 July 2021[(a)]	September 2021	36 / 34	Yes
Dresden-2 & -3			November 2021	51 / 50	Yes

Sources: Various, compiled by WNISR, 2021

Notes

Early closure decisions for four reactors (Beaver Valley-1 and -2, Davis-Besse and Perry) have been reversed and those reactors have been removed from the table since the WNISR2020 version.

(a) - Exelon, "Exelon Generation Submits Decommissioning Plans for Byron and Dresden Nuclear Plants", 28 July 2021, see https://www.exeloncorp.com:443/newsroom/exelon-generation-submits-decommissioning-plans-for-byron-and-dresden-nuclear-plants, accessed 31 July 2021.

The long-expected FERC order did not offer an exemption for existing nuclear plants that currently receive state support. The FERC decision would require reactor operators receiving state zero-emission credit[568]s and much other subsidized resources, including energy procured through a state renewable portfolio standard, to bid their capacity into PJM without factoring in the subsidies. That could raise their capacity market bid price leading to them to fail to clear

567 - Jeff St. John, "FERC Denies Rehearings on PJM Capacity Orders, in a Blow to States' Renewables Plans", *GreenTechMedia*, 16 April 2020, see https://www.greentechmedia.com/articles/read/ferc-denies-rehearings-on-its-pjm-capacity-rulings-opening-door-for-legal-challenges, accessed 7 July 2020.

568 - Kathryne Cleary, "What the Minimum Offer Price Rule (MOPR) Means for Clean Energy in PJM", *Resources*, 21 January 2020, see https://www.resourcesmag.org/common-resources/what-minimum-offer-price-rule-mopr-means-clean-energy-pjm/#:~:text=In%20December%202019%2C%20the%20Federal,resources%20on%20the%20capacity%20market, accessed 7 July 2020.

the auction and thereafter stop receiving capacity market fees. Nuclear plants would have to bid into the capacity market at their net Avoidable Cost Rate (ACR), which equals a predetermined ACR minus any expected net revenues from the energy and ancillary services markets. The proposed ACR numbers (from 2018) show that nuclear had the highest possible ACR value of any technology, at US$631/MW-day.[569] If this number is set at a level too high, the result could be that the reactors do not clear the capacity market, with resulting risk of closure.[570]

As noted in an analysis by Resources for the Future, the FERC order also applies to resources that are eligible to receive state subsidies, which potentially include reactors that currently do not receive state financing.[571] Exelon, the largest nuclear reactor operator in the U.S., called the FERC decision "stunning", and that "by granting the request of fossil generators, this order completely undermines state clean and renewable energy programs and will cost thousands of jobs, increase air pollution and unnecessarily raise electricity bills by US$2.4 billion annually".[572]

The complex impact of the FERC MOPR ruling has been to raise questions over the future of the PJM capacity market, with the possibility of states deciding to withdraw from the regional market.

One consequence of the FERC ruling was a delay to the 2021 PJM auction (which are held twice annually). When it was held in June 2021, nuclear generation cleared the most additional capacity compared to the previous capacity auction, with an additional 4,460 MW.[573] Industry analysts noted that Public Service Enterprise Group Inc. (PSEG) and Exelon's Salem plant in New Jersey and PSEG's Hope Creek plant in New Jersey likely secured contracts by appealing for PJM's unit-specific exemption to the MOPR, which allows them to bypass default numbers PJM may assign a resource because of its status as a state-subsidized resource.[574] One explanation for the more successful auction for nuclear plants compared to the previous auction was the impact of the Biden administration's active support for nuclear power.[575] This was despite the 64-percent reduction in the auction price compared to 2018, with PJM confirming that for the period 2022–2023 the price was US$50/MW-day compared to the US$140/MW-day three years ago.[576]

Exelon, in a filing with the U.S. Securities and Exchange Commission, revealed that its Byron, Dresden and Quad Cities nuclear plants in Illinois all failed to sell their power at the PJM

569 - Ibidem.

570 - Ibidem.

571 - Ibidem.

572 - Exelon, "Exelon Statement on FERC's Minimum Offer Price Rule Order", 19 December 2019, see https://www.exeloncorp.com/newsroom/media-statement-on-ferc-mopr, accessed 7 July 2020; and *Nucleonics Week*, "Subsidized resources face challenges in Eastern capacity markets: analysts", 9 January 2020.

573 - Catherine Moorhouse, "Nuclear capacity increases by 4.5 GW in long-delayed 'MOPRed' PJM auction, coal loses 8 GW", *Utility Dive*, 3 June 2021, see https://www.utilitydive.com/news/nuclear-capacity-increases-by-44-gw-in-long-delayed-mopred-pjm-auction/601208/, accessed 11 August 2021.

574 - Ibidem.

575 - Ibidem.

576 - Scott Van Voorhis, "Fate of Illinois nuclear plants in balance after 3 fail to clear PJM auction and subsidy plan stalls", *Utility Dive*, 7 June 2021, see https://www.utilitydive.com/news/fate-of-illinois-nuclear-plants-in-balance-after-pjm-auction-fail-and-stall/601324/, accessed 11 August 2021.

auction, losing out to other power plants and energy resources.[577] Two reactors each at the Byron and Dresden sites are currently slated to be closed in September and November 2021 respectively, while Quad Cities is in receipt of Illinois state subsidies. PJM confirmed that the four reactors can retire without putting overall grid reliability at risk.[578]

A proposal from the PJM to the FERC MOPR ruling was issued on 30 June 2021.[579] Under the PJM proposal, state policies providing out-of-market payments to generating resources, such as nuclear plants, would be recognized as being a legitimate exercise of a state's authority over the electric supply mix. Those policies would not be subject to the MOPR "so long as the policy does not constitute the sale of a FERC-jurisdictional product that is conditioned on clearing in any RPM [Reliability Pricing Model] auction," the grid operator said in its proposal summary.[580] The proposals from PJM are planned to be incorporated into the next auction which to be held in December 2021, for the period 2023–2024.

While efforts to secure ZEC legislation stalled in Pennsylvania, the decision by the state Governor to join the Regional Greenhouse Gas Initiative (RGGI) has led to the choice to reverse the decision to close the Beaver Valley Units 1 and 2. Plant owner Energy Harbor Corp. notified the PJM Interconnection grid operator that it would rescind its March 2018 deactivation notices. The reactors were owned previously by Energy Solutions which had filed for bankruptcy in 2018. Beaver Valley Units 1 and 2 were scheduled to close in May and October 2021. The RGGI is a cap-and-trade program to limit carbon dioxide emissions from power plants.

"The decision to rescind the deactivations for Beaver Valley was largely driven by the efforts of Governor Wolf's administration to join the Regional Greenhouse Gas Initiative… and will begin to help level the playing field for our carbon-free nuclear generators" and will help it market "carbon free energy" to customers", said Energy Harbor President and Chief Executive Officer John Judge on 13 March 2020.[581] Analysis in October 2019 reported that a carbon price of US$3 to US$5 per ton would be enough to keep nuclear plants in Pennsylvania economically viable for the foreseeable future.[582] Carbon allowances were sold at US$5.65 per ton in the RGGI's most recent quarterly auction.[583] The states that are in the RGGI are Connecticut, Delaware, Maine, Maryland, Massachusetts, New Hampshire, New York, Rhode Island, Vermont and New Jersey; Virginia in early 2020 passed a law that paves the way for it to join.

577 - U.S. States Securities and Exchange Commission, "Form 8-K—Current Report", Registrant Exelon Corporation and Exelon Generation Company, 2 June 2021, see https://investors.exeloncorp.com/node/12696/html, accessed 11 August 2021.

578 - WIFR Newsroom, "Byron Nuclear Plant scheduled to shut down in Sept., Exelon says", 28 July 2021, see https://www.wifr.com/2021/07/28/byron-nuclear-plant-scheduled-shut-down-sept-exelon-says/, accessed 12 August 2021.

579 - PJM, "Summary of the Updated PJM MOPR Proposal", 30 June 2021, see https://pjm.com/-/media/committees-groups/cifp-mopr/2021/20210630/20210630-cifp-mopr-pjm-proposal.ashx, accessed 11 August 2021.

580 - *Nuclear News Wire*, "PJM board okays plan to ease concerns with MOPR ruling", American Nuclear Society, 14 July 2021, see https://www.ans.org/news/article-3067/pjm-board-okays-plan-to-ease-concerns-with-mopr-ruling/, accessed 11 August 2021.

581 - State Impact Pennsylvania, "Owners of Pa.'s Beaver Valley nuclear power station will keep it open because of state's climate plan", 13 March 2020, see https://stateimpact.npr.org/pennsylvania/2020/03/13/owners-of-pa-s-beaver-valley-nuclear-power-station-will-keep-it-open-because-of-states-climate-plan/, accessed 6 July 2020; and DailyEnergyInsider, "Energy Harbor Corp rescinds deactivation of Beaver Valley nuclear power facility", 18 March 2020, see https://dailyenergyinsider.com/news/24695-energy-harbor-corp-rescinds-deactivation-of-beaver-valley-nuclear-power-facility/, accessed 25 July 2020.

582 - Resources for the Future, "Options for Issuing Emissions Allowances in a Pennsylvania Carbon Pricing Policy", 21 October 2019, see https://www.rff.org/publications/issue-briefs/options-issuing-emissions-allowances-pennsylvania-carbon-pricing-policy/, accessed 6 July 2020.

583 - Darrell Proctor, "Pennsylvania Move to Join RGGI May Save Nuclear Plant", *POWER Magazine*, 15 March 2020, see https://www.powermag.com/pennsylvania-move-to-join-rggi-may-save-nuclear-plant/, accessed 6 July 2020.

The future of Exelon's nuclear fleet in Illinois remains unclear. In April 2021, a study for the state legislature reviewed the economics and resulting policy choices for state support for Exelon's Byron, Dresden, Braidwood, and LaSalle reactors for the periods 2021–2025 and 2021–2030.[584] The report concludes by noting that Illinois could consider a subsidy rate of US$1.00/MWh for Byron and US$3.50/MWh for Dresden which "would ensure that 95 percent of the five-year expected Net Present Values for each plant remains above zero at the Synapse discount rate in the Monte Carlo analysis," noting that "a US$3.00/MWh rate would collect approximately $100 million per year from ratepayers for the two plants." The authors recommend to Illinois legislatures that

> any subsidy for the output of the two plants should be based on each plant's financial need. No subsidy should be paid without demonstration of actual need. Such need could be determined by either actual costs and revenues or based on projected energy prices relative to the projections developed in this analysis. This process should occur annually and should be transparent and formulaic for all parties.

Given the track record and distinct lack of transparency on the part of Exelon and other nuclear utilities when seeking state subsidies, including ZECs, it is not clear that they will be able to meet these conditions.

Democratic Governor Pritzker has led efforts to pass an energy bill that would provide US$540 million in subsidies for Exelon's nuclear plants. But as of 1 July 2021, the bill was not voted on before the end of the state legislature session. In a filing to the SEC, Exelon warned that even two nuclear plants that successfully bid to provide power in the PJM auction remain in danger of "premature retirement." Exelon claims that this is due to "unfavorable market rules that favor (carbon) emitting generation."[585] Braidwood-1 and -2 and LaSalle-1 and -2 would be kept in operation through May 2023 in order to "provide time for the significant logistical and technical planning necessary to ensure a safe and orderly retirement."[586] The Braidwood reactors have secured operational licenses to 2046 and 2047 respectively, while the LaSalle reactors are licensed to 2042 and 2043 respectively. However, Exelon warned that early shutdown would take place "in the event policy changes are not enacted".[587] However, there is every possibility that either Exelon will be successful in its lobbying strategy at state level and secure subsidies to secure continued operation of most of its Illinois fleet, or equally, the successful lobbying of Congress members in Washington DC will secure Federal tax credits and other support sufficient to avoid closure.

584 - This and following report quotes from Synapse, "Exelon Illinois Nuclear Fleet Audit Findings and Recommendations", Prepared for Illinois Environmental Protection Agency, 14 April 2021, see https://www.synapse-energy.com/sites/default/files/Exelon_Illinois_Nuclear_Fleet_Audit_Report_REDACTED_21-002.pdf, accessed 10 August 2021.

585 - Scott Van Voorhis, "Fate of Illinois nuclear plants in balance after 3 fail to clear PJM auction and subsidy plan stalls", *Utility Dive*, 7 June 2021, op. cit.

586 - Ibidem.

587 - U.S. States Securities and Exchange Commission, "Form 8-K—Current Report", Registrant Exelon Corporation and Exelon Generation Company, 2 June 2021, op. cit.

Ohio Corruption Scandal Terminates Nuclear Subsidies Legislation

FirstEnergy's core values and behaviors include integrity, openness, and trust. As an organization, we are redoubling our commitment to live up to these values and the standards that we know our stakeholders expect of us.

Steven E. Strah, FirstEnergy president and chief executive officer
22 July 2021.[588]

In July 2020, the speaker of the Ohio House of Representatives, Larry Householder, was arrested by the FBI on charges of racketeering. It was alleged at the time that he and his associates had set up a US$60 million slush fund

> to elect their candidates, with the money coming from one of the state's largest electricity companies. (…) Prosecutors contend that in return for the cash, Householder, pushed through a huge bailout of two nuclear plants and several coal plants that were losing money.[589]

As a result of the leadership role of Householder, in 2019, legislation House Bill 6 (HB6) was passed and FirstEnergy's Davis-Besse and Perry reactors were granted US$1.3 billion of taxpayer-money to support to keep their uneconomic units on the grid. The conspiracy was "likely the largest bribery, money-laundering scheme ever perpetrated against the people of the state of Ohio," the U.S. attorney for the Southern District of Ohio, David M. DeVillers, said in a news conference.[590] Householder pleaded not guilty. In the year since, the scandal has escalated, leading to the admission of guilt by FirstEnergy, and the termination of HB6 and nuclear subsidies.

In October 2020, when FirstEnergy was still denying its guilt, it continued its efforts to prevent further disclosures, leading Miranda Leppla, Vice President of Energy Policy for the Ohio Environmental Council Action Fund, to state, "FirstEnergy's lack of transparency is a continuation from its resistance to prove it even needed the bailout it received in House Bill 6, despite requests from lawmakers during HB 6 hearings."[591]

Tom Bullock, executive director of the Citizen Utility Board, warned that "Ohio consumers have been harmed by HB 6, and the damage gets much worse on January 1 [2021] when US$150 million [in] nuclear bailout charges kick in…FirstEnergy says it's not complicit in alleged HB 6 bribery, but it's using legal maneuvers to block transparency, deny consumer refunds, and keep nuclear bailout money. Consumers need PUCO [Public Utilities Commission] to side with us and order FirstEnergy to cooperate."[592]

588 - FirstEnergy, "FirstEnergy Reaches Agreement to Resolve Department of Justice Investigation", 22 July 2021, see https://firstenergycorp.com/newsroom/news_articles/firstenergy-reaches-agreement-to-resolve-department-of-justice-i.html, accessed 12 August 2021.

589 - Justin Gillis, "Opinion—When Utility Money Talks", *The New York Times*, 2 August 2020, see https://www.nytimes.com/2020/08/02/opinion/utility-corruption-energy.html, accessed 29 August 2020.

590 - Giulia McDonnell Nieto del Rio, "Powerful Ohio Republican Is Arrested in $60 Million Corruption Scheme", *The New York Times*, 21 July 2020, see https://www.nytimes.com/2020/07/21/us/larry-householder-ohio-speaker-arrested.html, accessed 29 August 2020.

591 - Kathiann M. Kowalski, "FirstEnergy fights against disclosing more details about alleged HB 6 bribery cases", *Energy News Network*, 30 October 2021, see https://energynews.us/2020/10/30/firstenergy-fights-against-disclosing-more-details-about-alleged-hb-6-bribery-cases/, accessed 12 August 2021.

592 - Ibidem.

On 16 November 2020, FBI agents raided the home of Ohio PUCO Chairman Sam Randazzo.[593] He was appointed by Governor DeWine in February 2019, prior to which he was a longtime lawyer for the utility industry. In mid-July 2021, it was disclosed that FirstEnergy admitted in a deferred prosecution agreement that it paid Randazzo US$22 million between 2010 and 2019, prior to his appointment to chair of PUCO.[594] The Ohio PUCO, also in November 2020, began an audit of FirstEnergy to see whether the company broke any laws or regulations regarding its interactions with an ex-subsidiary while the companies pushed to secure HB6.

"FirstEnergy agreed to pay a US$230 million fine for bribing key Ohio officials"

On 29 December 2020, the Ohio Supreme Court ordered a halt to electric utilities collecting monthly fees under HB6.[595]

In March 2021, FirstEnergy informed Ohio regulators that it would refuse to refund customers US$30 million collected from revenue generated under the HB6 legislation.[596] The Ohio Consumers' Counsel had called on the Ohio PUCO to order FirstEnergy to "remedy what would be a miscarriage or perversion of justice" if the company was allowed to keep the rate guarantee money. "As we see it, the PUCO or the legislature shouldn't allow FirstEnergy to walk away from the House Bill 6 scandal with even a penny of Ohioans' money, and certainly not with the $30 million it charged consumers for recession-proofing," Consumers' Counsel Bruce Weston said in a statement.[597]

On 31 March 2021, Ohio Governor DeWine signed House Bill 128, which permanently cancels nuclear power subsidies paid under HB6.[598] FirstEnergy, also on 31 March 2021, reversed its previous position and agreed to refund US$26 million to consumers for charges it collected through HB6.

On 22 July 2021, it was announced that FirstEnergy agreed to pay a US$230 million fine for bribing key Ohio officials in its efforts to secure the HB6 US$1-billion ratepayer-funded bailout for two nuclear plants. The U.S. Department of Justice detailed that in court filings, FirstEnergy had admitted that

> it conspired with public officials and other individuals and entities to pay millions of dollars to public officials in exchange for specific official action for FirstEnergy Corp.'s benefit. FirstEnergy Corp. acknowledged in the deferred prosecution agreement that it paid millions

593 - Jeremy Pelzer, "FBI searches Public Utilities Commission of Ohio Chairman Sam Randazzo's home", *Cleveland.com*, 16 November 2020, see https://www.cleveland.com/open/2020/11/fbi-searches-public-utilities-commission-of-ohio-chairman-sam-randazzos-home.html, accessed 12 August 2021.

594 - Laura A. Bischoff, "Top state regulator paid millions for part-time work, FirstEnergy agreement shows", *The Columbus Dispatch*, 2 August 2021, see https://eu.dispatch.com/story/news/2021/08/02/firstenergy-paid-sam-randazzo-big-money-work-part-time/5436419001/, accessed 12 August 2021.

595 - *ABC6*, "Ohio Supreme Court issues order stopping electric utilities from collecting monthly fee", 29 December 2020, see https://abc6onyourside.com/news/local/ohio-supreme-court-issues-order-stopping-electric-utilities-from-collecting-monthly-fee, accessed 12 August 2021.

596 - Mark Gillespie, "FirstEnergy refusing to return subsidy cash to customers", *Associated Press*, 20 March 2021, see https://apnews.com/article/akron-ohio-archive-utilities-d2d8b22e574437d91b247b3e693252ef, accessed 12 August 2012.

597 - Ibidem.

598 - Jarrod Clay, "Gov. DeWine signs bill repealing parts of scandal-tainted House Bill 6", *ABC6*, 31 March 2021, see https://abc6onyourside.com/news/local/gov-dewine-signs-bill-repealing-parts-of-scandal-tainted-house-bill-6, accessed 12 August 2021

> of dollars to an elected state public official through the official's alleged 501(c)(4) in return for the official pursuing nuclear legislation for FirstEnergy Corp.'s benefit.
>
> The company also acknowledged that it used 501(c)(4) entities, including one it controlled, to further the scheme because it allowed certain FirstEnergy Corp. executives and co-conspirators to conceal from the public the nature, source and control of payments.
>
> FirstEnergy Corp. further acknowledged that it paid $4.3 million dollars to a second public official. In return, the individual acted in their official capacity to further First Energy Corp.'s interests related to passage of nuclear legislation and other company priorities.[599]

The fine is the "largest criminal penalty ever collected, as far as anyone can recall, in the history of this office," acting U.S. Attorney Vipal Patel said.[600] However, the fine is less than a quarter of the US$1 billion in earnings in 2020, and FirstEnergy's stock price soared after the three-year deferred prosecution agreement was announced.

The agreement with the Justice Department details how FirstEnergy bought key Ohio public officials—notably former Ohio House Speaker Larry Householder and former PUCO Chairman Sam Randazzo—with millions of dollars funneled through the dark money group Generation Now, controlled by Householder. Between 2017 and March 2020, FirstEnergy Corp. and FirstEnergy Solutions, now called Energy Harbor, donated US$59 million to Generation Now.[601] Householder led efforts to pass HB6 to bail out the nuclear plants and bankrolled a counter campaign to stop a ballot initiative that would have challenged HB6.

With the termination of Ohio subsidies for the two reactors at Davis-Besse and Perry, it remains unclear what impact it will have on any closure. The reactors are now operated by Energy Harbor, which was formed following the bankruptcy of FirstEnergy Solutions. The reactors were originally scheduled to be closed in May 2020 and May 2021, respectively. With the prospect of federal tax-credits legislation, there is a possibility both reactors will move from receiving state subsidies to federal support and continue to operate.

Progress Towards Securing Federal Subsidies

> *We're not going to be able to achieve our climate goals if our nuclear power plants shut down. We have to find ways to keep them operating.*
>
> Energy Secretary Jennifer Granholm
> 6 May 2021.[602]

The nuclear industry has made considerable progress during the past year to securing major Federal level financial support which could significantly improve the profitability of a large

599 - United States Attorney Office, Southern District of Ohio, "FirstEnergy charged federally, agrees to terms of deferred prosecution settlement", 22 July 2021, see https://www.justice.gov/usao-sdoh/pr/firstenergy-charged-federally-agrees-terms-deferred-prosecution-settlement, accessed 12 August 2021.

600 - *AP*, "FirstEnergy to pay $230M in settlement in Ohio bribery case", as published on *News5Cleveland*, 22 July 2021, see https://www.news5cleveland.com/news/state/firstenergy-to-pay-230m-in-settlement-in-ohio-bribery-case, accessed 12 August 2021.

601 - Laura A. Bischoff and Jessie Balmert, "FirstEnergy charged in Ohio bribery scheme, agrees to deferred prosecution settlement for $230 million", *Cincinatti Enquirer, 22 July 2021, see* https://eu.dispatch.com/story/news/politics/2021/07/22/fbi-us-attorney-ohio-public-corruption-development/8052546002/, accessed 12 August 2021.

602 - *C-SPAN*, "Energy Department Fiscal Year 2022 Budget Request", 6 May 2021, see https://www.c-span.org/video/?511438-1/energy-department-fiscal-year-2022-budget-request&start=1024, accessed 10 July 2021.

number of reactors in the existing U.S. nuclear fleet. Signs of increased support to the nuclear fleet emerged during the latter stages of the 2020 Presidential campaign, including Biden's US$2 trillion clean energy plan, which was designed to achieve a carbon emissions-free energy sector by 2035, and which includes keeping existing reactors in operation.

As WNISR2020 noted at the time, the plan itself was more circumspect on what it actually means for continued operation of reactors in the U.S. Several legislative initiatives in Congress have now made it clearer what support could potentially mean.

In the months following the election of Joe Biden, White House officials and newly appointed members of Cabinet, as well as Democratic Party members of Congress, have signaled the need to support existing nuclear reactors and to prevent further closures. On 6 May 2021, in House Appropriations subcommittee hearings for the Energy Department Fiscal Year 2022 Budget Request, DOE Secretary Jennifer Granholm stated that "The DOE has not historically subsidized plants but I think this is a moment to consider and perhaps in the American Jobs Plan or somewhere to make sure that we keep the current fleet active."[603]

On 1 August 2021, a bipartisan group of senators unveiled a near US$1 trillion infrastructure bill, which would invest billions of dollars in transmission and grid infrastructure, new advanced nuclear plants and current nuclear facilities, electric vehicle infrastructure, carbon capture and other clean energy resources. The 2,700-page bill was passed by 67-32 and is to advance to legislation.[604] The vote to advance the bill included the support of 17 Republicans. In terms of nuclear power, it allocates US$6 billion for the Department of Energy in the form of credits to be allocated to existing nuclear plants based on MWh electricity generation and to be available over a period from 2022–2026. The DOE Secretary is required to assign credits to each reactor that applies, and there is the option to extend for a further five years to 2031, which would bring the total to US$12 billion. It also sets aside an additional US$6 billion in funding for microreactors, small modular reactors and advanced nuclear reactors.[605]

John Kotek, senior vice president of policy development and public affairs at the Nuclear Energy Institute (NEI) called the bill "a welcome step forward," but, "additional action must be taken" to retain the existing fleet of nuclear power plants, including through a production tax credit.[606]

In what would be a major financial gain for utilities over the coming decade, Senate Democrats and House Democrats and Republicans are proposing S. 2291/H.R.4024, called the "Zero-Emission Nuclear Power Production Credit Act of 2021", which would establish tax credits for production of electricity using nuclear power at a rate of US$15/MWh.[607]

603 - Ibidem.

604 - Catherine Morehouse, "Bipartisan $1 trillion Senate infrastructure bill focuses on transmission, nuclear, carbon capture", *Utility Dive*, 3 August 2021, see https://www.utilitydive.com/news/bipartisan-1t-senate-proposal-focused-on-nuclear-carbon-capture-transmis/604348/, accessed 10 August 2021.

605 - United States Senate, "H.R. 3684 – To authorize funds for Federal-aid highways, highway safety programs, and transit programs, and for other purposes", 117th Cong., 1st Session, see https://www.epw.senate.gov/public/_cache/files/e/a/ea1eb2e4-56bd-45f1-a260-9d6ee951bc96/F8A7C77D69BE09151F210EB4DFE872CD.edw21a09.pdf, accessed 10 August 2021.

606 - Catherine Morehouse, "Bipartisan $1 trillion Senate infrastructure bill focuses on transmission, nuclear, carbon capture", *Utility Dive*, 3 August 2021, op. cit.

607 - United States Senate, "S.2291–A Bill To amend the Internal Revenue Code of 1986 to establish a tax credit for production of electricity using nuclear power", Referred to as the "Zero-Emission Nuclear Power Production Credit Act of 2021", 117th Congress, 1st Session, 24 June 2021, see https://www.congress.gov/117/bills/s2291/BILLS-117s2291is.pdf, accessed 10 August 2021.

Covering the period from 2022–2031, the legislation would reduce utility tax burdens proportional to the amount of nuclear electricity generated. Utilities eligible to apply are those operating reactors in the deregulated (merchant) electricity market. Welcoming the efforts of Senate and House Democrats, an industry coalition, including Westinghouse, Toshiba and Framatome, as well as the NEI and American Nuclear Society (ANS), noted that, "Federal action is urgently needed to preserve nuclear energy, the country's largest source of carbon-free electricity because energy markets and state and federal policies currently do not properly value nuclear's carbon-free power."[608]

The U.S. Energy Information Agency (EIA) reports that around half of the U.S. reactor fleet operate in the merchant market. Analysis from the Nuclear Information Resource Service (NIRS) reports 40 reactors in the deregulated market, but that seven of these would likely not qualify for the credits.[609] These include four reactors in New York state (FitzPatrick, Ginna, and Nine Mile Point-1 and -2) that are already in receipt of credits under ZEC state legislation which are at a higher rate per MWh than proposed by Congress. In addition, as NIRS notes, the closure of Palisades in Michigan in 2022, and the two reactors at Point Beach in Wisconsin which have secured high value contracts until 2032, would exclude these from being eligible.[610]

One consequence of the Congressional efforts, if successful, would be the likely cancellation of State level ZECs. NIRS details that eight reactors in Connecticut, Illinois and New Jersey that are currently receiving credits would likely terminate their agreement and opt for the more lucrative Federal subsidies. On the basis that 33 reactors would be able to secure credits under the proposed legislation, NIRS calculates that the total cost could be US$4.6 billion/year or US$45.6 billion through 2031.[611]

Deliberations on the Congressional legislation are set to resume from September 2021 when both House and Senate reconvene.

608 - ANS, BPC Action, Breakthrough Institute et al., Letter addressed to Benjamin L. Cardin, United States Senate, and to Bill Pascrell, United States House of Representatives, 16 June 2021, see https://www.epw.senate.gov/public/_cache/files/c/a/ca3d1000-2699-4530-89da-f1c1640b24bd/D4CC2108939EC924C226A0A322448EF0.ptc-letter-of-support-june-2021.pdf, accessed 10 August 2021.

609 - NIRS, "Crunching the Numbers: How Much Would a National Nuclear Bailout Cost?", 3 August 2021, see https://www.nirs.org/crunching-the-numbers-how-much-would-a-national-nuclear-bailout-cost/, accessed 10 August 2021.

610 - Ibidem.

611 - Ibidem.

FUKUSHIMA STATUS REPORT · TEN YEARS AFTER

OVERVIEW OF ONSITE AND OFFSITE CHALLENGES

Introduction

A decade has passed since the Fukushima Daiichi nuclear disaster began. Work to remove the spent fuel from the cooling pool of Unit 3 has finally been completed, while the work to remove the fuel debris has not yet begun on any reactor. In April 2021, the Japanese government decided that the contaminated water containing tritium (and other radioisotopes) would be discharged into the ocean, which caused national and international outrage. While the decontamination work in Fukushima Prefecture is continuing, tens of thousands of citizens remain displaced.

Onsite Challenges[612]

Current Status of Each Reactor

The injection of water into Fukushima Daiichi Units 1–3, where core-melt accidents took place in March 2011, is continuing. As of 1 July 2021, a total of 228 cubic meters per day were being circulated through the Units 1–3.[613] The temperature in the lower part of the reactor pressure vessel and the containment vessel is maintained at 14–20 degrees Celsius. The temperature in the storage pool, where the spent nuclear fuel is stored, is similar to last year at about 17-23 degrees Celsius[614]. The radiation level in the air has been decreasing little by little but remains high in the vicinity of the buildings; for example, a dose rate of 0.75 mSv/h has been detected near Unit 3.[615] The radiation dose inside the buildings is still extremely high. As the radiation dose inside the building continues to be excessively high, it has not been possible to carry out measurements at all locations.

The removal of spent fuel at Unit 4 was completed in December 2014. Work began in Unit 3 on 15 April 2019 and was completed on 28 February 2021, which is the first time that this task was completed for a reactor that suffered a core meltdown. Units 1 and 2 are still in the preparatory stage for debris removal from the pools. According to the latest schedule announced in

612 - In this section, unless noted otherwise, the following source has been used: Secretariat of the Team for Countermeasures for Decommissioning and Contaminated Water Treatment, "Outline of Decommissioning and Contaminated Water Management", METI, 25 March 2021, see https://www.meti.go.jp/english/earthquake/nuclear/decommissioning/pdf/mp202103.pdf, accessed 3 May 2021.

613 - TEPCO Holdings, "Storage and treatment of high level radioactive accumulated water (as of July 1, 2021)", Attachment-2, in TEPCO, "Situation of Storage and Treatment of Accumulated Water containing Highly Concentrated Radioactive Materials at Fukushima Daiichi Nuclear Power Station (507th Release)", 28 June 2021, see https://www.tepco.co.jp/en/hd/decommission/information/newsrelease/watermanagement/pdf/2021/watermanagement_20210628-e.pdf, accessed 19 August 2021.

614 - Secretariat of the Team for Countermeasures for Decommissioning and Contaminated Water Treatment, "福島第一原子力発電所 プラント関連パラメータ" ["Plant parameters of the Fukushima Daiichi Nuclear Power Plant"], METI, March 2021 (in Japanese), see https://www.meti.go.jp/earthquake/nuclear/decommissioning/committee/osensuitaisakuteam/2021/03/1-1.pdf, accessed 3 May 2021.

615 - TEPCO, "福島第一構内 サーベイマップ（2021年3月分）" ["Fukushima Daiichi Ground Survey Map (March 2021)"], March 2021 (in Japanese), see https://www.tepco.co.jp/decommission/data/surveymap/pdf/2021/f1-sv2-20210331-j.pdf, accessed 3 May 2021.

December 2019 (maintained as of March 2021), the spent fuel removal for Unit 1 will begin by FY2027–28, and for Unit 2 by FY2024–26. Originally scheduled to begin at both reactors in 2023, spent fuel removal from all six reactors at Fukushima Daiichi is planned to be completed by 2031.[616]

A decade after the Fukushima disaster began, the government is still examining how to remove the fuel debris from Units 1 and 2 and has not even begun to look into the methodology for Unit 3. According to the government's medium- to long-term roadmap, the removal of fuel debris from Unit 2 was scheduled to start by the end of 2021.[617] However, according to TEPCO's action plan, the removal is "expected to be delayed by about one year due to the spread of COVID-19."[618]

In March 2021, the Nuclear Regulation Authority (NRA) issued a report on the draft results of its investigation and analysis of the accident.[619] This report showed that the radiation dose near the top of the containment vessel lid (shield plug) was extremely high.[620] It is estimated that Cs-137 is present at about 0.1–0.2 PBq[621] in Unit 1, at least 20–40 PBq in Unit 2, and 30 PBq in Unit 3.

Contaminated Water Management

According to TEPCO, the amount of contaminated water generation has been reduced to about 140 m^3/day on average in FY2020 (compared to about 540 m^3/day, the level in FY2014 before measures like an underground wall and a frozen soil barrier were implemented). The amount of groundwater and rainwater flowing into the basements of the buildings has been reduced to about 100 m^3/day (compared to about 350 m^3/day, the level before measures were implemented).

In terms of contaminated water stored in over 1,000 tanks on the Fukushima Daiichi site, while concentrations of radioisotopes such as, strontium, iodine and cesium have been reduced through the use of several Advanced Liquid Processing Systems (ALPS), the operations have been plagued with problems. The result of which is that as of November 2020 at least 73 percent of the water was required to be processed again through ALPS in an attempt to reduce concentrations to a level permissible for discharge under Japanese regulations.[622] According to TEPCO data, as of August 2021, there was a total of 69 percent or 832,900 cubic

616 - Ritsuko Shimizu, "Japan delays fuel removal from two reactors at Fukushima Daiichi", *Reuters*, 27 December 2019, see https://www.reuters.com/article/us-japan-nuclear-idUSKBN1YU1BF, accessed 19 August 2021; and Agency for Natural Resources and Energy, "The Update of Fukushima Daiichi NPS", METI, March 2021, p. 7, see https://www.meti.go.jp/english/earthquake/nuclear/decommissioning/pdf/20210304_FPCJ_METI.pdf, accessed 26 August 2021.

617 - Ibidem; and The Inter-Ministerial Council for Contaminated Water and Decommissioning Issues, "Mid-and-Long-Term Roadmap towards the Decommissioning of TEPCO's Fukushima Daiichi Nuclear Power Station", 27 December 2019, see https://www.meti.go.jp/english/earthquake/nuclear/decommissioning/pdf/20191227_3.pdf, accessed 3 May 2021.

618 - TEPCO, "廃炉中長期実行プラン２０２１" ["Decommissioning medium-to-long term execution plan 2021"], 25 March 2021 (in Japanese), see https://www.tepco.co.jp/decommission/progress/plan/pdf/2021/20210325.pdf, accessed 3 May 2021.

619 - Study Group for the Analysis of the Accident at TEPCO's Fukushima Daiichi Nuclear Power Station, "Interim Report on the Investigation and Analysis of the Accident at TEPCO's Fukushima Daiichi Nuclear Power Station: Results of the Study from September 2019 to March 2021", Nuclear Regulation Authority, 5 March 2021 (in Japanese), see https://www.nsr.go.jp/data/000345038.pdf, accessed 3 May 2021.

620 - Measurements were carried out for Units 1, 2 and 3 in February 2017, November 2018 and November 2015 respectively.

621 - 1 PBq = 1,000 Trillion Bq.

622 - METI, "ALPS treated water – (Measures for Decommissioning of Fukushima Daiichi Nuclear Power Station)", November 2020, see https://www.meti.go.jp/english/earthquake/nuclear/decommissioning/pdf/alpsqa202011.pdf, accessed 26 August 2021.

meters of water that would undergo secondary processing in ALPS.[623] This is expected to take several years.

At the same time, ALPS was not designed to remove radioactive tritium or carbon-14,[624] After debating the handling of tritiated water from both technical and social perspectives, on 13 April 2021, the relevant ministerial meeting of the government decided to discharge the tritiated water into the ocean. According to the basic policy, the tritiated water will be diluted by a factor of at least 100 and will be released starting in 2023 and is expected to take at least three decades to discharge. In attempt to reduce opposition to the plans, the Japanese government has reached agreement that an IAEA Task Force will provide assistance to Japan during the preparation and implementation of the planned discharges.[625] Fishermen unions, local municipalities, citizens groups and environmental organizations have consistently opposed the government's decision.[626] Various countries, including China, South Korea and the Pacific Island Forum (PIF), have also voiced concern and opposition to the release plan.[627] Three independent United Nations Human Rights Special Rapporteurs issued a joint statement that, "The release of one million tons of contaminated water into the marine environment imposes considerable risks to the full enjoyment of human rights of concerned populations in and beyond the borders of Japan".[628]

Worker Exposure and COVID-19 Infections

As of February 2021, of the 6,822 workers involved in the decommissioning of the Fukushima Daiichi plant, 931 were TEPCO employees and 5,891 (86 percent) were employees of subcontractors. The maximum cumulated effective dose of external exposure was 6.10 mSv

623 - TEPCO Holdings, "Treated Water Portal Site", as of 19 August 2021, see https://www.tepco.co.jp/en/decommission/progress/watertreatment/index-e.html, accessed 19 August 2021.

624 - Shaun Burnie, "Stemming the Tide: The reality of the Fukushima radioactive water crisis", Greenpeace Germany, Published by Greenpeace East Asia and Greenpeace Japan, October 2020, see https://www.greenpeace.org/static/planet4-japan-stateless/2020/10/5e303093-greenpeace_stemmingthetide2020_fukushima_radioactive_water_crisis_en_final.pdf, accessed 19 August 2021.

625 - Japanese Government, "東京電力ホールディングス株式会社福島第一原子力発電所における・多核種除去設備等処理水の処分に関する基本方針（案）" ["Basic Policy on the Disposal of Water Treated by Radionuclide Removal Facilities at TEPCO's Fukushima Daiichi Nuclear Power Station (Draft)"], 13 April 2021 (in Japanese), see https://www.kantei.go.jp/jp/singi/hairo_osensui/dai5/siryou1.pdf, accessed 3 May 2021; and IAEA, "IAEA to Review and Monitor the Safety of Water Release at Fukushima Daiichi", Press Release, 8 July 2021, see https://www.iaea.org/newscenter/pressreleases/iaea-to-review-and-monitor-the-safety-of-water-release-at-fukushima-daiichi, accessed 19 August 2021.

626 - See for example: CNIC, "We strongly protest the decision to discharge ALPS treated water into the Pacific Ocean and demand the withdrawal of this policy", 13 April 2021, see https://cnic.jp/english/?p=5423, accessed 19 August 2021; and JF Zengyoren, "アルプス処理水海洋放出の方針決定に強く抗議・するＪＦ全漁連会長声明" ["We strongly oppose the policy decision to release ALPS-treated water into the ocean"], Japan Fisheries Cooperatives, 13 April 2021 (in Japanese), see https://www.zengyoren.or.jp/cmsupload/press/183/20210413seimei.pdf, accessed 3 May 2021.

627 - Catherine Wong, "China warns of action over Japan's decision to dump radioactive Fukushima water into the sea", *South China Morning Post*, 13 April 2021, see https://www.scmp.com/news/china/diplomacy/article/3129322/china-warns-action-over-japans-decision-dump-radioactive; also Guo Wenrui and Liang Jun, "Japan's 'low credibility' causes concerns among Asian countries on Fukushima nuclear wastewater release", *People's Daily Online*, 14 April 2021, see http://en.people.cn/n3/2021/0414/c90000-9838938.html; and *Yonhap*, "S. Korea voices 'grave concerns' over Japan's expected decision to release Fukushima water into sea", 12 April 2021, see https://en.yna.co.kr/view/AEN20210412008700325?section=national/diplomacy; and Pacific Island Forum, "Statement by Dame Meg Taylor, Secretary General of the Pacific Islands Forum, Regarding the Japan Decision to Release ALPS Treated Water into the Pacific Ocean", 13 April 2021, see https://www.forumsec.org/2021/04/13/statement-by-dame-meg-taylor-secretary-general-of-the-pacific-islands-forum-regarding-the-japan-decision-to-release-alps-treated-water-into-the-pacific-ocean/, all accessed 19 August 2021.

628 - UN Human Rights, "Japan: UN experts say deeply disappointed by decision to discharge Fukushima water", Office of the High Commissioner for Human Rights, 15 April 2021, see https://www.ohchr.org/EN/NewsEvents/Pages/DisplayNews.aspx?NewsID=27000&LangID=E, accessed 20 August 2021.

for TEPCO employees and 11.67 mSv for employees of subcontractors.[629] According to TEPCO, as of August 2021, 75 TEPCO employees and 140 subcontractors have been infected with COVID-19.

Offsite Challenges

Current Status of Evacuation

As of April 2021, 35,478 residents of Fukushima Prefecture are still living as evacuees (7,093 are living within the prefecture, 28,372 are living outside the prefecture, and 13 are missing).[630] The number of evacuees has decreased by about 3,000 since last year. According to Fukushima Prefecture, the peak number of evacuees was 164,865 as of May 2012.[631]

In the areas where evacuation orders have been lifted, the number of people who have returned to their hometowns hardly increased over the past year. According to a survey of five towns conducted by the Reconstruction Agency, in Okuma Town—where the Fukushima Daiichi Nuclear Power Plant is located—the evacuation order was partially lifted in April 2019, but the return rate is still only 2.5 percent (1.8 percent in 2020). Even Tomioka Town, where the evacuation order was partially lifted in April 2017, has a return rate of only 9.2 percent (7.5 in 2020).[632]

Food Contamination

Nationwide inspections for food contamination continue, with a total of 54,412 samples analyzed in FY2020, according to preliminary data, April 2020–February 2021, of which 127 samples exceeded the legal limits[633] (157 cases in FY2019).[634] In Fukushima Prefecture, 25 items were found to have high levels, of which 24 were game meat (wild boar, bear, pheasant) and one was an agricultural product.

The situation of food exports to foreign countries is still severe today. Of the 54 countries that began imposing import restrictions (e.g. banning Japanese food without certificate of origin or certificate of analysis for radioactivity) after the beginning of the disaster, as of March 2021,

629 - TEPCO, "福島第一原子力発電所にて放射線業務に従事した作業者の ・ 被ばく線量の評価状況について" ["Evaluation situation of exposure dose of workers of Fukushima Daiichi Nuclear Power Station"], 31 March 2021 (in Japanese), see https://www.tepco.co.jp/decommission/information/newsrelease/exposure/pdf/2021/exposure_20210331-j.pdf, accessed 3 May 2021.

630 - Fukushima Disaster Response Headquarters, "Immediate report on damage caused by the 2011 Tohoku-Pacific Coast Earthquake", Report No. 1775, 5 April 2021(in Japanese).

631 - New Fukushima Revitalization Promotion Headquarters, "Steps for Reconstruction and Revitalization in Fukushima Prefecture", Fukushima Prefecture, 25 August 2020, p.2, see https://www.pref.fukushima.lg.jp/uploaded/attachment/425053.pdf, accessed 24 August 2021.

632 - Reconstruction Agency, "令和２年度　原子力被災自治体における ・ 住民意向調査　調査結果（概要）" ["Results of the Survey on Residents' Intention in the Nuclear Accident-affected Municipalities (Summary)"], 19 February 2021 (in Japanese), see https://www.reconstruction.go.jp/topics/main-cat1/sub-cat1-4/210219_ikouchousa_zentai_gaiyou.pdf, accessed 4 May 2021.

633 - The standard value established by the MHLW: The level of radioactive cesium is 100 Bq/kg for food, 10 Bq/kg for drinking water, 50 Bq/kg for milk, and 50 Bq/kg for infant food.

634 - MHLW, "Sum up of radionuclides monitoring data reported in Japanese fiscal year 2020 (Up-to-date report from April 2020 to March 2021)", as of March 2021, see https://www.mhlw.go.jp/english/topics/2011eq/dl/Sum_up_March_20210729.pdf, accessed 26 August 2021.

only 40 have lifted their restrictions (34 as of the previous fiscal year), while 14 countries/ regions including the EU, the U.K., China, and South Korea continue to impose restrictions.[635]

Decontamination

The decontamination work for the Special Decontamination Area of Fukushima Prefecture under the direct control of the national government[636] was completed in March 2018, and the decontamination work for relevant municipalities including the rest of Fukushima Prefecture[637] was completed in March 2017 (this decontamination work did not include the Difficult-to-Return Zones). However, the reality is that decontamination has only been conducted over a small percentage of the overall land area contaminated.[638] Meanwhile, the management of the decontamination waste generated by these projects is now a major issue. The contaminated soil from the temporary storage sites[639] in Fukushima Prefecture is currently being transferred to intermediate storage facilities in eight areas. As of April 2021, 10.7 million m^3 of the total 14 million m^3 had been delivered (76 percent of the total amount).[640]

The law stipulates that the government is responsible for disposing of the waste at a final disposal site outside Fukushima Prefecture, to be carried out by a company wholly owned by the government, within 30 years after starting the interim storage of the waste.[641] However, at present, the government has taken no specific action toward the final disposal of contaminated waste generated due to the Fukushima disaster.

Conclusion

The tenth anniversary-year since the disaster began occurred in the context of the global COVID-19 pandemic. The Japanese government has emphasized progress made in decommissioning and decontamination, but the reality is that Japan is still in the early stages of managing the consequences of the accidents. Although the current overall plan for decommissioning remains unchanged, with scheduled completion between 2041 and 2051, it is

635 - Food Industry Affairs Bureau, "Status of countries and regions introduced import measures on Japanese foods after the TEPCO's Fukushima Daiichi Nuclear Power Plant accident", Ministry of Agriculture, Forestry and Fisheries, as of 28 March 2021, see https://www.maff.go.jp/j/export/e_info/pdf/kisei_gaiyo_en.pdf, accessed 3 May 2021.

636 - A high dose area within a 20km radius of the power plant, located around the difficult-to-return zone.

637 - It covers all eight prefectures, including Fukushima Prefecture, except for the Special Decontamination Area managed by the government.

638 - Aaron Clark, "Decade after Fukushima disaster, Greenpeace sees cleanup failure", *Bloomberg*, as published by *The Japan Times*, 4 March 2021, see https://www.japantimes.co.jp/news/2021/03/04/national/fukushima-greenpeace-radiation-health-3-11/; Greenpeace East Asia, "Fukushima Daiichi 2011-2021: The decontamination myth and a decade of human rights violations", March 2021, see https://www.greenpeace.org/static/planet4-japan-stateless/2021/03/ff71ab0b-finalfukushima2011-2020_web.pdf; both accessed 19 August 2021.

639 - Until final disposal, facilities store removed soil, waste, incinerated ash with levels exceeding 100,000 Bq/kg, etc. that were generated from decontamination activities in Fukushima Prefecture.

640 - Ministry of the Environment, "輸送（搬出済）量（2015年～）" ["Interim Storage Facility"], Government of Japan, April 2021, see http://josen.env.go.jp/chukanchozou/transportation/index.html, accessed 4 May 2021.

641 - Ministry of Internal Affairs and Communications, "中間貯蔵・環境安全事業株式会社法 ・ 平成十五年法律第四十四号", ["Japan Environmental Storage & Safety Corporation Act"], Government of Japan, August 2015 (in Japanese), see https://elaws.e-gov.go.jp/document?lawid=415AC0000000044, accessed 4 May 2021.

still not widely publicly debated in Japan that the feasibility of this plan is being questioned.[642] The population most impacted by the disaster, the citizens of Fukushima, by majority have low confidence in the current plans, and give the government low ratings for their handling of the disaster until now.[643] The government's decision to discharge contaminated water into the ocean has raised protests far beyond Japan. As for offsite management, the resettlement policy has turned out a failure as the very low return rates illustrate.

HEALTH EFFECTS OF THE FUKUSHIMA DAIICHI NUCLEAR POWER PLANT DISASTER

Introduction

The Fukushima nuclear power plant accidents triggered by the Great East Japan Earthquake and tsunami caused widespread radioactive contamination in eastern Japan. In Fukushima Prefecture, the area up to 20 km from the Fukushima nuclear power plant was designated as an evacuation zone as the annual exposure dose was estimated to exceed 20 mSv and the area between 20–30 km was designated as an indoor evacuation[644] zone. However, residents who were worried about radiation exposure self-evacuated from beyond the official evacuation zone, and the number of evacuees reached more than 160,000.

Before the accident, the public exposure dose limit was 1 mSv per year, but the government has lifted the evacuation order for areas that have been decontaminated to some degree and are estimated to entail a dose of less than 20 mSv per year. In March 2017, the government terminated housing support for evacuees from outside the evacuation zone and encouraged residents to return to their homes. However, estimates of the number of evacuees who have not taken up the return option range from about 36,000 according to Fukushima Prefecture, and more than 67,000, according to local governments in the prefecture.[645, 646] Most of the people who have returned to the evacuation zone are the elderly, and the return rate among the younger generation concerned about the health effects of radiation exposure, particularly for the children is less than 10 percent.[647]

642 - *The Mainichi*, "Fukushima chief: No need to extend decommissioning target", 4 March 2021, see https://mainichi.jp/english/articles/20210304/p2g/00m/0na/022000c; and Norihiko Kuwabara, "Radiation levels at Fukushima plant far worse than was thought", *The Asahi Shimbun*, 30 December 2020, see https://www.asahi.com/ajw/articles/14071742; also Sato Satoshi, "Decommissioning of the Fukushima Daiichi Nuclear Power Station – From Plan-A to Plan-B Now, from Plan-B to Plan-C", Greenpeace East Asia, 4 March 2021, see https://www.greenpeace.org/static/planet4-japan-stateless/2021/03/20cf92ab-decomrep_final2.pdf; all accessed 19 August 2021.

643 - Noriyoshi Ohtsuki, "Fukushima poll: 74% say nuclear disaster work not promising", *The Asahi Shimbun*, 24 February 2021, see https://www.asahi.com/ajw/articles/14216668, accessed 19 August 2021.

644 - Indoor evacuation refers to measures to stay indoors and prevent outside air from entering the room by closing windows and turning off ventilation fans and air-conditioners. After the Fukushima accidents began, the indoor evacuation zone was set at 5–30 km from the plant.

645 - *Kahoku Shimpo*, "福島の避難者集計に３万人以上の差 県と市町村、手法ばらばら" ["Difference of more than 30,000 in the total number of evacuees in Fukushima Prefectures and municipalities, methods are different"], 31 January 2021, see https://kahoku.news/articles/20210131khn000005.html, accessed 24 August 2021.

646 - Aoki Miki, "いないことにされる私たち" ["We who are pretended not to have existed"], *Asahi Shimbun Publishing*, 2021, ISBN978-4-02-251766-1.

647 - *Tokyo Shimbun*, "縮みゆく自治体　データで見る住民帰還 ＜あの日から・福島原発事故10年＞" ["Shrinking Local Governments: A Data-Based Approach to Returning Residents—From That Day: Ten Years After the Fukushima Nuclear Accident"], 18 January 2021, see https://www.tokyo-np.co.jp/article/79669, accessed 27 August 2021.

Principles of Radiation Health Effects

Health effects of radiation are determined by the exposure dose. For example, a dose of 7 Sievert (Sv) to the whole body in a short time will kill more than 99 percent of people, and 3–4 Sv will kill about 50 percent. Exposure to 1 mSv means that an average of one radiation beam passes through the nucleus of a cell[648] that contains DNA, the blueprint of the body. A dose of 7 Sv means that 7,000 beams penetrate the nucleus, cutting the DNA into pieces and thus killing the cells.[649] Complex DNA damage may occur even when a single radiation track passes through a cell, and the number of damages increases in proportion to the dose[650].

Mutations occur if the damage is repaired incorrectly,[651] which can cause cancer.

The so-called Linear No-Threshold (LNT) model assumes that there is no threshold for carcinogenesis and that the risk increases linearly with dose, because DNA damage can occur with a single radiation beam and increases with dose. The LNT model has been adopted by the International Commission on Radiation Protection (ICRP)[652], the World Health Organization (WHO)[653], and others as it is supported by epidemiological studies and experimentally.

Since cells that are actively dividing are more sensitive to radiation, children are significantly more susceptible to radiation damage than adults, and within an individual, cells in organs that are actively dividing, such as bone marrow and lymphatic cells, are more likely to be damaged than cells in other organs.

Diseases Other Than Cancer Caused by Radiation Exposure

Studies of A-bomb survivors have revealed that mortality from cardiovascular disease increases linearly with dose.[654] According to a Ukrainian government report, 25 years after the Chernobyl accident[655], there were more deaths from cardiovascular diseases than from cancer

648 - UNSCEAR, "Annex F – DNA repair and mutagenesis", in United Nations Scientific Committee on the Effects of Atomic Radiation, "Sources and effects of Ionizing Radiation—Volume II: Effects" UNSCEAR Report to the General Assembly, 2000.

649 - Radiation energy is orders of magnitude greater than the binding energy of the atoms (energy of chemical bonds) that make up the DNA. For example, even the beta rays of tritium, the lowest energy form of radioactivity released from nuclear facilities, have an average energy 1,000 times greater than chemical bonds, and the beta and gamma rays of radioactive iodine and cesium have an average energy 100,000 times greater. See John W. Gofman, "Radiation and Human Health", *Sierra Club Books, 1981.*

650 - Kai Rothkamm and Markus Löbrich. "Evidence for a lack of DNA double-strand break repair in human cells exposed to very low x-ray doses", Proceedings of the National Academy of Sciences of the United States of America, Vol.100, 5057-62, 29 April 2003.

651 - When two broken ends are incorrectly connected to each other, the intervening bases are lost, resulting in the alteration of the base sequence, leading to mutations, which can in turn cause carcinogenesis, the formation of cancer. (Nonhomologous end-joining). See Committee to Assess Health Risks from Exposures to Low Levels of Ionizing Radiation, "Health risks from exposure to low level of ionizing radiation", BEIR VII Phase 2, Board on Radiation Effects Research, Division on Earth and Life Studies, U.S. National Research Council of the National Academies, *National Academies Press*, 2006, see https://www.nap.edu/catalog/11340/health-risks-from-exposure-to-low-levels-of-ionizing-radiation, accessed 2 June 2021.

652 - ICRP, "The 2007 Recommendations of the International Commission on Radiological Protection", International Commission on Radiological Protection, ICRP Publication 103, Vol. 37, Nos. 2–4, 2007, see https://www.icrp.org/publication.asp?id=ICRP%20Publication%20103, accessed 24 August 2021.

653 - WHO, "Health risk assessment from the nuclear accident after the 2011 Great East Japan Earthquake and Tsunami – Based on a preliminary dose estimation", World Health Organization, 11 August 2013, see https://www.who.int/publications/i/item/9789241505130, accessed 24 August 2021.

654 - Yukiko Shimizu, Kazunori Kodama et al., "Radiation exposure and circulatory disease risk: Hiroshima and Nagasaki atomic bomb survivor data, 1950–2003", *BMJ*, 14 January 2010.

655 - Ministry of Ukraine of Emergencies, "Twenty-five Years after Chernobyl Accident: Safety for the Future", National Report of Ukraine, 2011.

(see also Chapter on Chernobyl – 35 Years After the Disaster Began). Cataracts are a definite effect of radiation and increase linearly with dose from less than 100 milli-gray to 2 gray[656]. Non-neoplastic diseases with high incidence among adult evacuees from Chernobyl included thyroiditis, neurological diseases, digestive diseases, and urological diseases. Immunity is carried out by cells of the myeloid and lymphoid lineages, and bone marrow cells and lymphocytes, are highly radiosensitive, thus exposure increases immune system diseases.

Survey on Health Effects

The following is an overview of the health effects that have been revealed in Fukushima Prefecture, the prefecture most affected by the 3/11 disaster.

Thyroid Radiation Dosimetry and Potassium Iodine

According to the Japanese Nuclear Emergency Preparedness Guide[657], the Nuclear Safety Commission (NSC) was supposed to issue an order to take iodine if the dose to the thyroid gland reached 13,000 counts per minute (cpm),[658] which is equivalent to 100 mSv. It was also decided that the person should be decontaminated in that case. Therefore, evacuees from the evacuation area had to undergo a contamination test, and if the contamination was above the limit, they had to be decontaminated before they could enter the shelter.

Many of the residents from the evacuation area were contaminated at levels exceeding 13,000 cpm, but it was very cold at that time and there was not enough hot water to decontaminate people or provide clothes to change for all of them. This is why the decontamination standard was raised to 100,000 cpm. As far as records are available, 102 residents exceeded 100,000 cpm and 900 were in the range of 13,000–100,000 cpm.[659] However, no iodine tablets were systematically distributed to the population. These initial measurements were not used for exposure-dose estimation, and it was concluded that no one was exposed to more than 100 mSv.

A fax the NSC had sent to the medical team of the Local Nuclear Emergency Response located in the evacuation zone Headquarters (NERHQ) went missing. That fax reportedly contained instructions to call on the general public to take iodine tablets. The Local NERHQ did not receive the fax, so it did not issue any instructions to the public. The governor of Fukushima Prefecture was also supposed to give the order, but he was not aware of it. In the absence of instructions from NERHQ or the governor, the heads of the municipalities were allowed to issue their own orders to take iodine tablets, but only four towns issued such orders. As a result, only about 10,000 residents took the iodine tablets even though Fukushima Prefecture

656 - One gray (Gy) is defined as the absorption of one joule of radiation energy per kilogram of matter. It serves as the basis for the calculation of the radiation dose given in sieverts (Sv).

657 - NSC, "原子力災害対策マニュアル", Partially Revised in 2019 (in Japanese), see https://www.kantei.go.jp/jp/singi/genshiryoku_bousai/kanji/dai13/siryou2.pdf, accessed 27 August 2021; and IAEA, "The Fukushima Daiichi Accident–Technical Volume 3–Emergency Preparedness and Response", 2015, see https://www-pub.iaea.org/MTCD/Publications/PDF/AdditionalVolumes/P1710/Pub1710-TV3-Web.pdf, accessed 24 August 2021.

658 - cpm (counts per minute): The number of rays (beta or gamma rays) that pass through the detector of a Geiger counter in one minute. 100 cpm is equal to 100 rays per minute.

659 - Study2007, "見捨てられた初期被曝" ["Abandoned initial radiation exposure"], *Iwanami Science Library*, 2015.

had ample stockpiles.[660] In July 2020, the closed minutes of the Fukushima Medical University Disaster Response Headquarters were made public, revealing that the distribution of iodine tablets to children in Hamadori and Nakadori had been discussed, and by 19 March 2011, the tablets had been distributed on a municipal basis. However, no instructions were given to take the iodine tablets because Dr. Shunichi Yamashita, who later became an advisor on radiation health risk management, had suggested that there was no need to take them.[661]

The Fukushima Prefectural Health Management Survey and the Thyroid Examination Program

Commissioned by the Ministry of the Environment (MOE), Fukushima Prefecture decided to conduct a prefectural residents' health survey. To estimate the exposure dose, information on individual behavior from the occurrence of the accidents to the end of June 2011 was collected by questionnaire, and the external exposure dose was estimated based on the behavioral records and environmental radiation dose.

The response rate of the questionnaire was 27.7 percent (568,632 persons) by March 2020. The effective doses due to the accidents were below 1 mSv in 62.2 percent of the cases, 1–2 mSv in 31.6 percent, 2–3 mSv in 5.5 percent, 3–4 mSv in 0.3 percent, and 4–5 mSv in 0.1 percent, with the maximum dose being 66 mSv, the mean value 0.9 mSv, and the median 0.6 mSv. It was decided to conduct a detailed survey on thyroid, mental health, lifestyle, and pregnant and nursing mothers.

The prefectural government outsourced everything from the planning of the thyroid examination to the analysis of the results to Fukushima Medical University (FMU). About 380,000 children at the age of 18 or younger (including in utero) at the time of the accident are eligible for thyroid examinations. Examinations are carried out every two years until the age of 20, and every five years thereafter using ultrasound equipment. If a nodule of 5.1 mm or more in diameter is found in the primary examination, a secondary examination is recommended, and if necessary, a fine-needle aspiration cytology[662] is performed. When the cells are malignant or suspected to be malignant, the case is reported by the FMU to the Fukushima Health Management Survey Oversight Committee (FHMSOC), the advisory body of Fukushima Prefecture, and made public at the same time.

High incidence of thyroid cancer and a flawed examination program

In July 2021, it was reported that a total of 260 malignant or suspected malignant cases were detected: 219 underwent surgery, and 218 were diagnosed as cancer (see Table 7). Since pediatric thyroid cancer is an extremely rare disease, usually diagnosed in one or two cases per million people per year, already in 2016, the Oversight Committee admitted that the number of

660 - NAIIC, "The Official Report of the Fukushima Nuclear Accident Independent Investigation Commission", Fukushima Nuclear Accident Independent Investigation Commission, National Diet of Japan, 2012, see https://dl.ndl.go.jp/info:ndljp/pid/3514606, accessed 8 June 2021; and IAEA, "The Fukushima Daiichi Accident–Technical Volume 3–Emergency Preparedness and Response, 2015, op. cit.

661 - Mai Asada, "浮かび上がる３.11後の安定ヨウ素剤をめぐる対応と県民健康調査の出発点 -福島県立医大の非公開議事録から" ["The post 3.11 response to stable iodine and the starting point of the prefectural health survey - From the closed minutes of Fukushima Prefectural Medical University"], 科学, Vol. 90, 2020, pp. 612–619.

662 - When a nodule is found in an organ, such as the thyroid gland, a piece of tissue is aspirated with a fine needle and cells are examined under a microscope to see if it is malignant or not.

cases is several dozen times higher than usual.[663] Furthermore, Table 7 shows that among the 135 patients diagnosed with cancer or suspected cancer in the second through fourth rounds, there were 46 patients whose prior examination results from two years earlier were in the A1 category, i.e. no detectable ultrasound findings. This suggests that thyroid cancer grew from undetectable to at least 5.1 mm within two years, indicating a fast growth rate.

Table 7 – Thyroid Cancers Identified in the Fukushima Prefectural Health Management Survey

	Round 1 (FY2011–2013)	Round 2 (FY2014–2015)	Round 3 (FY2016–2017)	Round 4 (FY2018–2019)	For age 25 (FY2017–202)	Total
Malignant or suspected	116	71	31	33	9	260
Previous Round Results		Round 1 results: A1: 33 A2: 32 B: 5 Not examined: 1	Round 2 results: A1: 7 A2: 14 B: 7 Not examined: 3	Round 3 results: A1: 6 A2: 18 B: 6 Not Examined: 3	Round 4 results: A2:2 B:2 Not Examined: 5	
Male / Female	39/ 77	32/39	13/18	14/19	2/7	
Age as of 3/11 (Average Age)	6–18 (14.9±2.6)	5–18 (12.6±3.2)	5–16 (9.6±2.9)	0–12 (7.9±2.9)	6–18 (17.1±0.7)	
Confirmed	102	55	29	27	6	219
Histologic Type	PTC: 100 Poorly differentiated TC: 1 Benign nodule: 1	PTC: 54 Other type of TC: 1	PTC: 29	PTC: 27	PTC: 5 FTC: 1	Confirmed as TC: 218
Participants (Participation rate)	300,472 (81.7%)	270,540 (71.0%)	217,921 (64.7%)	183,298 (62.3%)	7,621 (8.7%)	

Sources: FHMSOC, July 2021[664]

Notes:

TC: Thyroid Cancer; **PTC**: Papillary Thyroid Cancer; **FTC**: Follicular Thyroid Cancer

A1: No nodule / cyst - **A2**: Nodules ≤ 5.0mm or cysts ≤ 20mm - **B**: Nodules ≥ 5.1mm or cysts ≥ 20.1mm

FY: Fiscal Year

Participation Rate: Number of participants/target population

In March 2017, it was discovered that the thyroid examination program planned by the Fukushima Medical University (FMU) was flawed. This was revealed by the 3.11 Fund for Children with Thyroid Cancer (FCTC), a non-profit organization that supports children who have been diagnosed with thyroid cancer following the disaster. If a case is not diagnosed with malignancy or suspected malignancy directly during the secondary examination yet requires a closer observation, the patient is then transferred to a "clinical" follow-up, which is considered "ordinary" medical care utilizing national health insurance. It came to light that the patients who were diagnosed with cancer during this follow-up period, outside the framework of the Fukushima Health Management Survey, were not reported back to the Oversight Committee. In response to criticism that this would not give an accurate number of the affected people,

663 - FHMSOC, "県民健康調査における中間取りまとめ" ["Interim Report on Thyroid Examination in the Prefectural Health Survey"], Fukushima Health Management Survey Oversight Committee, March 2016, see https://www.pref.fukushima.lg.jp/site/portal/kenkocyosa-kentoiinkai.html, accessed 8 June 2021.

664 - FHMSOC, "第42回「県民健康調査」検討委員会", 42nd Fukushima Health Management Survey Oversight Committee, Fukushima Prefecture, 26 July 2021, see https://www.pref.fukushima.lg.jp/site/portal/kenkocyosa-kentoiinkai-42.html, accessed 20 August 2021.

FMU announced in July 2018 eleven additional cancer cases as of June 2017, but these consisted only of patients who had been operated on at FMU. It is now known that there are 19 such "unreported" cases as of December 2018, but no further effort has been made to update the unreported data. In addition to these 19 patients, the Fund for Children with Thyroid Cancer is aware of 18 patients who were not covered by the survey. The age, gender, and region of the 19 people were not disclosed, and it is uncertain if there is any overlap with the 18 people known to the Fund. If there is no overlap, FMU is analyzing the causal relationship between exposure and thyroid cancer while excluding 12.6 percent of the patients.

Thyroid radiation dose and causal relationship analysis between radiation dose and thyroid cancer incidence

The measurement of children's thyroid radiation doses was conducted under the direction of the Ministry of Education, Culture, Sports, Science and Technology. Despite the fact that the half-life of radioactive iodine-131 is eight days, measurements started only about two weeks after the release events, and only a total of 1,080 children[665] were measured at three locations beyond 30 km distance from the site. At all locations the environmental radiation levels were high. Thyroid exposure dose should have been the thyroid dose minus the air dose[666], but in all locations, the dose at the shoulder of the clothing was subtracted from the measured thyroid dose. In case of a negative value, the exposure dose was assumed to be zero. The results showed no exposure of more than 100 mSv, so no further measurements were made.

In addition, a professor at Hirosaki University started conducting his own measurements, but the Fukushima Prefectural Government stopped him, arguing that it would make the population feel uneasy.[667]

The causal relationship between exposure and thyroid cancer has been analyzed for the first and second rounds of the survey. The exposure doses used in the FMU analysis were estimated based on the contamination level of the affected people's residential areas measured from aircraft at the end of March 2011, which were classified into four areas in the order of descending doses: the Evacuation zone (13 municipalities), Nakadori, Hamadori and the Aizu region.

In the first round of analysis, no correlation between the level of contamination of the area and the thyroid cancer incidence was established, so the Oversight Committee announced that the high incidence of thyroid cancer was unlikely to be caused by radiation.

In the second round of analysis, the results correlated with the level of contamination (see Figure 37–A). After these results were reported, FMU changed the regional classification according to the radiation dose estimated by the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR), as shown in Figure 37–B, and re-analyzed the results

665 - About 370,000 children were eligible for thyroid examination in Fukushima prefecture.

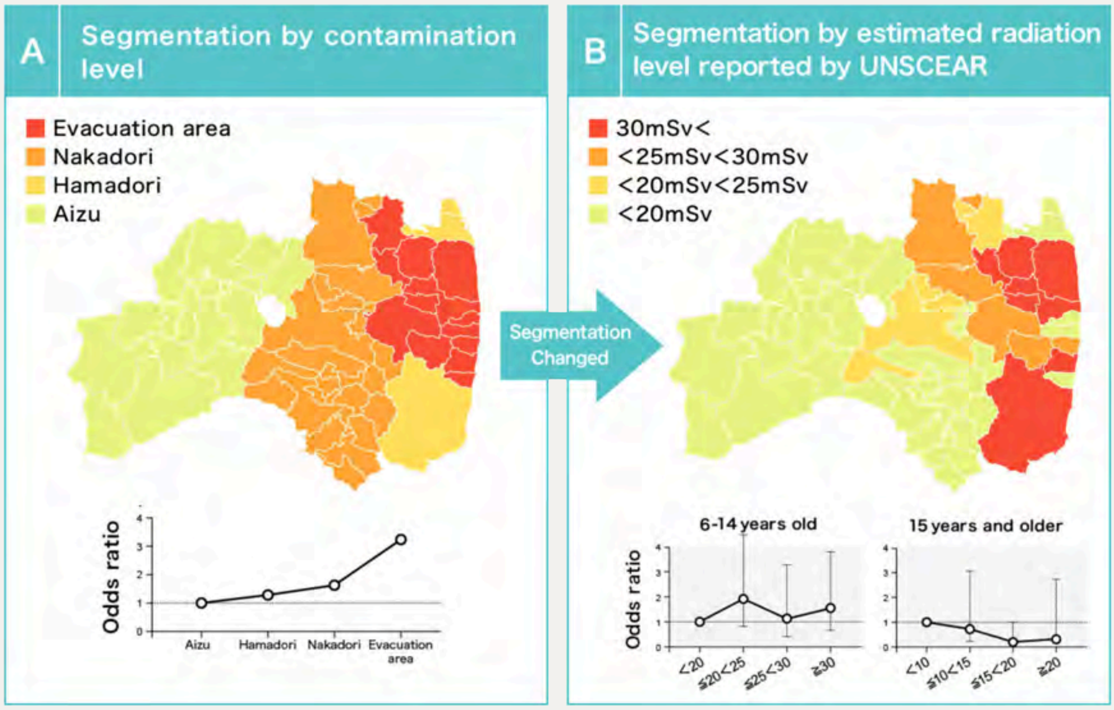
666 - Niiyama Mamayuki, "川俣町公民館での3月28日の甲状腺サーベイについて" ["Thyroid Survey at Kawamata Town Public Hall on 28–30 March"], Expert Meeting Regarding the Status of Health Management of Residents Following the Accident at Tokyo Electric Power Company's Fukushima Daiichi Nuclear Power Station, Ministry of the Environment, Government of Japan, 2014 (in Japanese), see https://www.env.go.jp/chemi/rhm/conf/conf01-03.html, accessed 8 June 2021.

667 - NAIIC, "The Official Report of the Fukushima Nuclear Accident Independent Investigation Commission", National Diet of Japan, 2012, op. cit.

by dividing the patients into two groups: those aged 6-14 years and those aged 15 years and older, excluding, without explanation, one 5-year-old child.

As shown in Figure 37–B, under these assumptions, no dose-proportional increase of thyroid cancer was identified. On the basis of this result, FMU and the Oversight Committee announced that "no association between the thyroid cancers and exposure can be recognized", ignoring the regional differences demonstrated in Figure 37–A. In addition, the result showing a decreasing cancer incidence rate with increasing radiation dose among those over 15 years of age raises questions about the analytical method, but no explanation was provided.[668]

Figure 37 · Classification of contaminated areas and grouping of patients in causal relationship analysis



Sources: Fund for Children with Thyroid Cancer, FHMSOC, 2021[669]

Notes:

• The Odds ratio is a statistical measure of the likelihood of an event occurring in two groups. An odds ratio of 1 in group A and group B means that the number of people in group A and group B with thyroid cancer is the same, group A/B greater than 1 means that more people in group A have the disease, and group B less than 1 means that fewer people have the disease.

• The segmentation shown in Figure B corresponds to the exposure range of 6–14-year-old children.

668 - Fukushima Prefecture, "市町村別UNSCEAR推計甲状腺吸収線量と悪性ないし悪性疑い発見率との関連" ["Association between UNSCEAR-estimated absorbed thyroid doses by city and detection rates of malignant or suspected"], The 35th Meeting of the FHMSOC, see https://www.pref.fukushima.lg.jp/uploaded/attachment/330129.pdf, accessed 25 August 2021.

669 - Fund for Children with Thyroid Cancer, "Thyroid Examinations in Fukushima Prefecture after the TEPCO Nuclear Accident", March 2021, see https://www.311kikin.org/english/nuclear-accident-thyroid-cancer/article03/, accessed 25 August 2021.

The Oversight Committee points to the possibility of over-diagnosis as the cause of the high incidence, suggesting ultrasound examination diagnosed many cancers that will not be clinically diagnosed or linked to death in the future. However, over-diagnosis has been ruled out by surgeons who have performed most of the surgeries based on their surgical findings.[670]

The results of the analysis by researchers other than FMU using the data published by the Oversight Committee showed that there was a causal relationship with exposure.[671] The difference in the analytical methodology is that the first and second rounds were combined and analyzed, or the regional classification was changed or both. The UNSCEAR 2020 report[672] does not mention the "unreported" patients, but uncritically evaluates the paper published by FMU and criticizes the results of other papers.

Reports on the Nuclear Hazard Impact Study from the Ministry of the Environment[673]

Survey on health effects of radiation as part of the Nuclear Hazard Impact Study Project

To examine the impact of the 3/11 disaster on disease and mortality trends, the Ministry of the Environment has set up a comparative survey of the prevalence of cardiovascular diseases, lifestyle-related diseases, congenital abnormalities, and suicides between pre-3/11 and post-3/11 situations in Fukushima, in seven additional prefectures with partially contaminated areas (Iwate, Miyagi, Ibaraki, Tochigi, Gunma, Saitama, and Chiba), and Fukushima's neighboring prefectures of Yamagata and Niigata.[674]

Site-specific cancer-incidence and mortality rates in these 10 prefectures have been reported. While mortality rates have continued to decrease and morbidity rates have remained flat or decreased in all sites, incidence rates in Fukushima Prefecture seem to be on the rise since 2012 for thyroid, cervical, prostate, and breast cancer. However, the increase in morbidity from 2011 to 2012 in several sites in Fukushima Prefecture may be due to voluntary screening visits.[675]

670 - Shinichi Suzuki, "Surgical Treatment of Pediatric Thyroid Cancer in Japan" ["日本における小児・若年者の甲状腺がん診療"], Presented at the Second International Symposium of the Radiation Medical Science Center for Fukushima Health Management Survey, Fukushima Medical University, 2–3 February 2020 (in English and Japanese), see http://kenko-kanri.jp/en/news/2nd_intl_symposium_report_published.html, accessed 8 June 2021.

671 - Toshihide Tsuda, Akiko Tokinobu et al., "Thyroid Cancer Detection by Ultrasound Among Residents Ages 18 Years and Younger in Fukushima, Japan 2011 to 2014", *Epidemiology*, Vol.27, Issue 3, May 2016, pp. 316–322, see https://journals.lww.com/epidem/Fulltext/2016/05000/Thyroid_Cancer_Detection_by_Ultrasound_Among.3.aspx, accessed 25 August 2021; and Toshiko Kato, "Area Dose Response of Prevalent Childhood Thyroid Cancers after the Fukushima Nuclear Power Plant Accident", *Clinical Oncology & Research*, Volume 2(6): 7-7, December 2019; also Hidehiko Yamamoto, Keiji Hayashi and Hagen Scherb, "Association between the detection rate of thyroid cancer and the external radiation dose-rate after the nuclear power plant accidents in Fukushima, Japan", *Medicine*, 96, 37, September 2019; and Hiroshi Toki, Takahiro Wada et al., "Relationship between environmental radiation and radioactivity and childhood thyroid cancer found in Fukushima health management survey", *Scientific Reports*, Vol. 10, 2020.

672 - UNSCEAR, "UNSCEAR 2020 Report: Sources, effects and risks of ionizing radiation", 2020, see https://www.unscear.org/unscear/en/publications.html, accessed 8 June 2021.

673 - See the Reports: Ministry of the Environment, "放射線健康管理・健康不安対策事業（放射線の健康影響に係る研究調査事業）報告書", Government of Japan, Undated (in Japanese; only abstracts are in English), see https://www.env.go.jp/chemi/rhm/reports.html, accessed 8 June 2021.

674 - Yamagata and Niigata are also partially contaminated. Therefore, this was not a comparison between contaminated and non-contaminated areas.

675 - Matsuda Tomohiro, "福島県内外での疾病動向の把握に関する調査研究—がん死亡・罹患の動向把握 2020FY", National Cancer Center, Center for Public Health Sciences, 2020 (in Japanese), see http://www.env.go.jp/chemi/R2_4_sobue_3.pdf, accessed 8 June 2021.

In terms of diseases other than cancer, deaths from acute myocardial infarction (heart attack) increased by 10-20 percent in Fukushima Prefecture in 2011 for both men and women in the age groups of 40-69, and 70 and over. Despite a downward trend thereafter, it remained highest among the 10 prefectures until the final year of survey (2015). Within Fukushima Prefecture, in March 2011, cardiac-related deaths were the highest in the evacuation areas and decreased in the partial and non-evacuation areas, in that order.[676]

Insurance billing for heart disease, hypertension, and diabetes among people aged 40 and older has increased significantly in Fukushima Prefecture for both men and women since 2011. The rate of metabolic syndrome[677] is around 14.5 percent nationwide, but amongst people displaced from the evacuation zone, the rate increased from 15.8 percent in 2010 to 18.1 percent in 2011. In 2017, it had gone up to 20.7 percent, which remains the highest in the prefecture. There may be an effect of radiation exposure, but it remains uncertain because the doses have not been examined. The evacuees have lost their jobs, their families have been split up, and they have been forced to live in poor conditions in temporary housing, so it is possible that their sudden change in lifestyle has affected them.

The incidence of congenital anomalies in Fukushima Prefecture is reported to be the same as the national average.

According to the White Paper on Suicide and Prevention[678] the number of suicides in Japan had been decreasing nationwide since 2009 but increased in 2011 in the prefectures most affected by 3/11. In 2011, the number of suicides per million citizens was 13.1 in Iwate, 2.4 in Miyagi, 0.3 in Ibaraki and 5 in Fukushima. In 2012, the numbers began to decline in most prefectures and, in 2019, reached 2.5 in Iwate, 0.4 in Miyagi, zero in Ibaraki but increased to 6.5 in Fukushima. The nine-year total is 53 in Iwate, 57 in Miyagi, one in Ibaraki and 115 in Fukushima. Within Fukushima Prefecture, the rate increased the most amongst people displaced from the evacuation areas and remains the highest through 2019.

The number of deaths and missing persons due to the earthquake and tsunami is 1,466 and 1,275 respectively in Fukushima, compared to 8,745 and 6,674 in Miyagi, and 4,243 and 3,479 in Iwate[679]. On the other hand, the total number of disaster-related deaths[680] in the nine and a half years after the earthquake was 2,319 in Fukushima compared to 469 in Iwate and 929 in Miyagi.[681]

676 - Imano Hironori, "福島県内外での疾病動向の把握に関する調査研究(分担)—循環器疾患とその危険因子に関する県単位での動向把握" ["Cardiovascular disease trends in Fukushima and neighboring prefectures before and after the Fukushima Daiichi Nuclear Power Plant Accident"], Osaka University, 2020 (in Japanese), see http://www.env.go.jp/chemi/R2_4_sobue_2.pdf, accessed 8 June 2021.

677 - Metabolic syndrome is a combination of diabetes, high blood pressure (hypertension) and obesity.

678 - Ministry of Health, Labor and Welfare, "自殺対策白書" ["White Paper on Suicide Prevention"], 2019 (in Japanese), see https://www.mhlw.go.jp/toukei_hakusho/hakusho/, accessed 8 June 2021.

679 - Ministry of Agriculture, Forestry and Fisheries, "東日本大震災地震と津波の被害状況 [Great East Japan Earthquake and Tsunami Damage Report]", *aff*, May 2011, see https://www.maff.go.jp/j/pr/aff/1105/spe1_01.html, accessed 25 August 2021.

680 - Disaster-related death: A death that is not directly caused by a disaster, but occurs during or after evacuation, and for which a causal relationship to the disaster is recognized. This includes death by suicide, worsening of chronic diseases due to reduced access to medical care (loss of hospital functions, difficulty in visiting hospitals), health impairment due to prolonged and severe evacuation environment and loss of livelihood, etc.

681 - Reconstruction Agency, "東日本大震災における震災関連死の死者数—（令和 3 年 3 月 31 日現在調査結果）" ["Number of deaths related to earthquake in the Great East Japan Earthquake—(Survey Results as of March 31, 2021"], as of March 2021, Updated June 2021, see https://www.reconstruction.go.jp/topics/main-cat2/sub-cat2-6/20210630_kanrenshi.pdf, accessed 29 August 2021; and Reconstruction Agency, "震災関連死の死者数等について" ["Disaster-related death"], Various Reports (in Japanese), see https://www.reconstruction.go.jp/topics/main-cat2/sub-cat2-6/20140526131634.html, accessed 25 August 2021.

Health Problems of Nuclear Power Plant Workers

Of 24,832 workers who worked on the accident site during the six months following the initial accidents, the maximum exposure dose was 679 mSv, and 174 workers (0.7 percent) are documented to have been exposed to more than 100 mSv. The average exposure dose was 12.4 mSv[682,683]. However, reliability of these values is questionable because the radiation doses immediately after the accident were only measured in groups due to the lack of individual dosimeters.[684]

The Study Group on Long-Term Healthcare of Workers at the TEPCO Fukushima Nuclear Power Plant[685] has been established to conduct a health survey of 20,000 workers, but only 35 percent of the workers have responded to the survey. Most of the workers are employed by subcontractors, so they have to take time off work in order to be included in the survey and receive regular health checkups[686]. In the ten years since the accidents, no coherent health survey report on workers has been released.

An additional low-dose external and internal exposure has been incurred from the decontamination work triggered by the 20-mSv return policy as well as the work associated with handling, shipment, and storage of millions of cubic-meters of the contaminated soil which have been removed from farmland and residential areas and even reused for roadbed construction, embankments, etc.[687] This poses a major health issue with its effects yet to be known.

Conclusion

Japan has been under a state of emergency for the 10 years since the Fukushima disaster began, but nobody has officially taken responsibility for the events. Residents who evacuated to various areas have filed more than 30 lawsuits against TEPCO and the Japanese government for compensation for damages caused by the evacuation (see Section on Judicial Decisions on Damages and Criminal Liability for the Fukushima Nuclear Accidents). While there is no doubt

682 - MHLW, "東電福島第一原発作業員の" ["TEPCO Fukushima Daiichi Nuclear Power Plant Worker Study group on long-term health management, etc. Report"], Ministry of Health Labour and Welfare, 1 May 2015 (in Japanese), see https://www.mhlw.go.jp/file/06-Seisakujouhou-11200000-Roudoukijunkyoku/0000191126.pdf, accessed 25 August 2021; and further reports see MHLW, "東京電力福島第一原子力発電所における緊急作業従事者等の長期的健康管理" ["Long-term health management of emergency workers at TEPCO's Fukushima Daiichi Nuclear Power Station"], Undated, see https://www.mhlw.go.jp/stf/seisakunitsuite/bunya/koyou_roudou/roudoukijun/anzen/fukushima/index.html, accessed 9 July 2021.

683 - The average cumulative dose for 10 years for nuclear workers in Japan is 13.8mSv. Radiation Effects Association, "低線量放射線による – 人体への影響に関する疫学的調査 （第V期調査 平成 22 年度～平成 26 年度）", Radiation Epidemiological Study, Fifth Study Report, March 2015 (in Japanese), see http://www.rea.or.jp/ire/english/, accessed 9 July 2021.

684 - NAIIC, "The Official Report of the Fukushima Nuclear Accident Independent Investigation Commission", National Diet of Japan, 2012, op. cit.

685 - MHLW, "Expert Meeting on the Long-term Healthcare of Workers at the TEPCO Fukushima Daiichi Nuclear Power Plant—Report", September 2011, see https://www.mhlw.go.jp/english/topics/2011eq/workers/tepco/lhc/pr_110926_a02.pdf, accessed 25 August 2021.

686 - *NHK*, "原発事故・7年後の「英雄たち」1万2000人の作業員が健康調査に応じない理由" ["Reason why 12,000 'hero' workers do not respond to health surveys seven years later"], 12 March 2018 (in Japanese), see https://www.nhk.or.jp/gendai/kiji/084/, accessed 9 July 2021.

687 - Ministry of the Environment, "飯舘村長泥地区における再生利用実証事業" ["Recycling Demonstration Project in Iitate Village, Nagadoro District"], Updated August 2021 (in Japanese), see http://josen.env.go.jp/chukanchozou/facility/recycling/project_iitate/, accessed 25 August 2021.

about cancer rates, especially thyroid cancer, dozens of times above national average, TEPCO and the Japanese government keep denying any causal link with the events of 3/11.

As government witnesses, 17 experts including Dr. Shunichi Yamashita, submitted a joint opinion in 2016 that stated that health effects below 100 mSv could not be proven.[688] Several co-authors of this joint opinion are now in charge of the Environment Ministry's study on the health effects and disease trends due to 3/11.[689]

Dr. Shunichi Yamashita, who a few days after 3/11 said that "The effects of radiation do not actually come to people who are smiling and laughing. It comes to those who are crying and worrying"[690], as Director General of the National Institute of Radiological Sciences now heads the Core Center for coordinating and guiding four Advanced Radiation Emergency Medical Support Centers[691]. Thus, the same experts that have been downplaying post-accidental low-dose exposure risks today hold key positions that drive current radiation protection policies. These circumstances have contributed to the increasingly widespread perception that the risk of low-dose exposure would be unprovable in the Fukushima case—despite clear evidence such as the high incidence of childhood thyroid cancer.

ESTIMATED COSTS OF FUKUSHIMA DISASTER: OFFICIAL AND INDEPENDENT ASSESSMENTS

Introduction

Ten years after the catastrophic accidents happened at Tokyo Electric Power Company (TEPCO)'s Fukushima Daiichi nuclear power plant, the full picture of the consequences remains unclear. However, it is important to estimate how much the disaster will cost to understand the full range of impacts. This chapter attempts to provide a best estimate based on the methodology and assumptions developed by the independent think-tank Japan Center for Economic Research (JCER) in two recent reports.[692, 693] The total costs of the Fukushima accident considered here include: decommissioning of Fukushima reactors, treatment and disposal of contaminated water, final disposal of radioactive waste, and compensation to victims of the accident as well as to the local community, which is broader than the government estimate. Please note that the cost estimate does not include indirect

688 - The opinion article submitted to the Kyoto District Court on 26 October 2016 has not been published online.

689 - Ministry of the Environment, "放射線健康管理・健康不安対策事業（放射線の健康影響に係る研究調査事業）報告書", Government of Japan, Undated (in Japanese; only abstracts are in English), see https://www.env.go.jp/chemi/rhm/reports.html, accessed 27 August 2021.

690 - Shunichi Yamashita, then Fukushima Prefecture Radiation Health Risk Management Advisor and Vice-President of Fukushima Medical University, Lecture, 2011, see https://www.facebook.com/565918463587729/videos/570098366503072/, accessed 14 June 2021. Note: intervention starts at about 30 min.

691 - National Institute for Quantum and Radiological Science and Technology, "National Institute of Radiological Sciences", Undated, see https://www.qst.go.jp/site/carem/, accessed 10 June 2021.

692 - JCER, "Accident Cleanup Costs Rising to 35-80 trillion yen in 40 years: Considering the postponing of decommissioning with 'Confinement-managing' scenario as a possible option. Urgent need for measures to manage contaminated water", Japan Center for Economic Research, 3 July 2019, see https://www.jcer.or.jp/english/accident-cleanup-costs-rising-to-35-80-trillion-yen-in-40-years, accessed 10 May 2021.

693 - JCER, "Accident Cleanup Costs May Rise to 50-70 Trillion yen: It's Time to Examine legal liquidation of TEPCO", 7 March 2017, see https://www.jcer.or.jp/english/accident-cleanup-costs-may-rise-to-50-70-trillion-yen, accessed 10 May 2021.

costs such as: costs to replace nuclear generation due to the accident, additional costs due to early decommissioning, lost value of utility stocks etc. Although there is still much uncertainty in the assumptions, it is useful to consider an independent cost assessment. The purpose is to inform the public and policy makers of the scale of the disaster through critical analysis of the government estimates done in 2016 and in 2021.

Estimates by the Government in 2016 and 2021

The earliest cost estimate of the Fukushima accident was done by the TEPCO Management and Finance Investigation Committee set up after the accident in 2011. The report, published on 3 October 2011, estimated that total economic costs will be ¥5.7 trillion (US$$_{2021}$74 billion). The breakdown of the cost estimate was: decommissioning ¥1.2 trillion (US$15.6 billion) and compensation ¥4.5 trillion (US$58.6 billion), including a one-time compensation of ¥2.6 trillion (US$34 billion) and continuous compensation of ¥1.9 trillion (US$25 billion). This estimate does not include any expenses for decontamination nor any costs of final disposal of radioactive waste.[694]

"Government estimates are neither complete nor do they appear reliable, as their methodologies are not transparent for analysis."

A 2014-estimate increased 55 percent over the initial 2011-assessment to ¥11.6 trillion (US$115 billion) with the following breakdown: decommissioning ¥2 trillion (US$19.8 billion), decontamination ¥2.5 trillion (US$24 billion), interim storage facilities for contaminated soil ¥1.1 trillion (US$10billion), compensation ¥6 trillion (US$59.3 billion)[695].

The third 2016-cost estimate was elaborated by a new Committee for Reforming TEPCO and Overcoming 1F [Fukushima Daiichi] Challenges established by the Japanese Government. The total estimated cost was ¥22 trillion (US$206 billion), and its breakdown is the following: decommissioning ¥8 trillion (US$75 billion), compensation ¥8 trillion (US$75 billion), decontamination 6 trillion (US$56 billion)[696].

On 13 July 2021, the Ministry of Economy, Trade and Industry (METI) released its latest cost estimates for various power generation sources, including nuclear power.[697] The total power generating costs now include so-called "government administration costs" which correspond to public expenditures on nuclear power and were estimated to be ¥23.8 trillion (US$224 billion).

The report also contains a new estimate of the accident costs. Other costs were slightly modified but remained close to the 2016 data (see Table 8).

694 - TEPCO Management and Finance Investigation Committee, "委員会報告" ["The Committee Report"], METI, 3 October 2011 (in Japanese), see http://www.cas.go.jp/jp/seisaku/keieizaimutyousa/dai10/siryou1.pdf, accessed 10 May 2021.

695 - *NHK News*, "震災３年 原発事故の損害額１１兆円超に" ["3 years after the earthquake, total cost of the nuclear accident will reach over 11 trillion yen"], 22 March 2014 (in Japanese), see http://www3.nhk.or.jp/news/genpatsu-fukushima/20140311/1516_songaigaku.html, accessed 10 May 2021.

696 - Committee for Reforming TEPCO and Overcoming 1F Challenges, "Recommendations for Reforming TEPCO", METI, 20 December 2016.

697 - Power Generation Cost Analysis Working Group, "基本政策分科会に対する—発電コスト等の検証に関する報告" ["Report on Power Generation Costs etc. to the Basic Policy Committee"], Agency for Natural Resources and Energy, METI, 13 July 2021 (in Japanese), see https://www.enecho.meti.go.jp/committee/council/basic_policy_subcommittee/2021/045/045_005.pdf, accessed 20 July 2021.

Table 8 – Summary of Government Estimates of Fukushima Disaster Costs 2012–2021 (in US$$_{2021}$ Billion)

	2011	2014	2016	2021
Decommissioning	15.6	19.8	75.1	75.0
Decontamination	NA	35.6	56.3	52.5
Compensation	58.6	59.3	75.1	74.0
Others	NA	NA	NA	21.6
Total	74.3	114.7	206.5	223.1

Sources: TEPCO Management and Finance Investigation Committee, 2011; *NHK News,* 2014, The Committee for Reforming TEPCO and Overcoming 1F Challenges, 2016 and METI, 2021.[698]

However, these government estimates are neither complete nor do they appear reliable, as their methodologies are not transparent for analysis. Apparently, they are based on informal hearings or on preliminary analysis based on limited sources of information.[699]

As Table 8 shows, the 2016 estimate of US$ 206.5 billion is almost the double of the previous one and close to three times the original estimate, and the government admitted for the first time that some of the costs will be paid for by the Japanese taxpayer.

Table 9 – Government Cost Sharing Scheme as of 2016 (in percent)

	TEPCO	Other Utilities	Independent Power Producers	Tax	Total
Decommissioning	100.0	0	0	0	100
Decontamination	48.5	48.5	2.9	0	100
Compensation	66.7	0	0	33.3	100
Total	71.9	18.0	1.1	9.0	100

Sources: The Committee for Reforming TEPCO and Overcoming 1F Challenges, "Recommendations for Reforming TEPCO", 20 December 2016

Table 9 summarizes the cost-sharing scheme of the Fukushima disaster costs as planned by the government in 2016. Although TEPCO will share more than 70 percent of the total cost, it became clear for the first time that 9 percent of the total cost could be charged to Japanese citizens through taxes. This raised more questions about the government estimates, and independent cost assessments appear indispensable.

698 - TEPCO Management and Finance Investigation Committee, "委員会報告" ["The Committee Report"], 3 October 2011, op. cit.; and Committee for Reforming TEPCO and Overcoming 1F Challenges, "Recommendations for Reforming TEPCO", METI, 20 December 2016; also Power Generation Cost Analysis Working Group, "基本政策分科会に対する—発電コスト等の検証に関する報告" ["Report on Power Generation Costs etc. to the Basic Policy Committee"], METI, 13 July 2021, op. cit.

699 - Eri Ohsaka, Kenichi Oshima, et al., "Toden Kaikaku to Fukushima Genshiryoku Hatsuden Jiko No Sekinin: Kaikaku Teigen Ni Itaru Giron to Sono Go No Kensho" ["Reform of Tokyo Electric Power Co' and Responsibility of Fukushima Nuclear Power Plant Accident: Assessment of Discussion leading to Reform Recommendations"], Keiei Kenkyu, *Management Research*, Vol. 72, No. 1, 2021. Original hearing information was published at the 6th meeting of TEPCO Reform Committee; see TEPCO Reform Committee, "Gensiryoku Songai Baisho Hairo Tou Shien Kiko" ["Nuclear Damage Compensation and Decommissioning Facilitation Corporation); and Nuclear Damage Compensation and Decommissioning Facilitation Corporation, "有識者ヒアリング結果報告" ["Report on Hearing Results of Experts"], 9 December 2016 (in Japanese), see https://www.meti.go.jp/committee/kenkyukai/energy_environment/touden_1f/pdf/006_02_00.pdf, accessed 10 May 2021.

An Independent Estimate by JCER in 2017

In 2017, the Japan Center for Economic Research (JCER) came up with a different cost estimate based on their own methodology and assumptions. The report concluded the cost could rise to ¥50–70 trillion (US$460~660 billion). (See Table 10)

Table 10 – JCER Estimates (2017) versus Government Estimate (2016) (in $US\$_{2021}$ billion)

	Gov (2016)	JCER-A	JCER-B
Decommissioning	75	103	301
Decontamination	56	282	282
Compensation	75	78	75
Total	**207**	**463**	**658**

Sources: METI, 2016; JCER, 2017[700]

Assumptions for the above estimates are the following.

- **Decommissioning.** The government estimate is based on the decommissioning cost of Three Mile Island (TMI), which was a partial meltdown in 1979 and the molten fuel was contained in the pressure vessel. In the Fukushima case, the three meltdowns at Units 1–3 led to the fuel penetrating the pressure vessels making the basic situation technically much more complex. Also, the government estimate does not include final disposal of radioactive waste from the decommissioning. Typically, only 1–2 percent of the total waste volume being generated by the decommissioning of a reactor is radioactive. JCER assumes that all the waste produced by the decommissioning of Units 1–3 will become radioactive waste. Accordingly, the total decommissioning cost increases from US$75 billion to US$103 billion.
- **Contaminate Water Management.** For option A, JCER assumed that the over one million tons of contaminated water will be released to the sea according to the government plan, so no additional cost is added, although costs may increase if further separation of other radioisotopes is needed (which is highly likely for a large part of the stored water). For option B, instead of releasing the contaminated water to the sea, JCER assumed separation of tritium from the treated water, but again does not add any cost estimate for further separation of other isotopes. The cost of tritium separation is estimated based on the costs experienced at Fugen (prototype ATR) facility, which is ¥20 million/ton (~US$0.19 million/ton)[701]. Assuming the total tritium water is about 1 million tons, another ¥20 trillion (~US$190 billion) was added for Option B.
- **Additional compensation.** For option A, due to releasing the tritium water to the sea, JCER assumed additional compensation to the local fishermen with a population of about 1,500 persons. They assumed a compensation amount of ¥10 million (~US$94,000) per person in the initial year and gradually declining to zero over a 40-year period. Then the total additional compensation amount reaches to ¥300 billion (~US$2.8 billion).

700 - JCER, "Accident Cleanup Costs May Rise to 50-70 Trillion yen: It's Time to Examine legal liquidation of TEPCO", Japan Center for Economic Research, 7 March 2017; and The Committee for Reforming TEPCO and Overcoming 1F Challenges, "Recommendations for Reforming TEPCO", METI, 20 December 2016.

701 - The cost of tritium separation could be lower, as there are proposals based on commercially available technologies. For example, see Sergei Floria and Alexander Kostilev, "Demonstration project for verification test of tritium separation technology—Final Report", Rosatom, 2016.

- **Decontamination.** The government estimate does not include final disposal cost of contaminated soil and other radioactive wastes coming out of decontamination work in the Fukushima area. Total volume is assumed to be 22 million tons (as of 2017) and JCER applied the actual cost of low-level waste disposal at Rokkasho village of ¥8–19 billion for 10,000 tons. So JCER's estimate was ¥30 trillion (US$282 billion).

An Updated Estimate by JCER in 2019

While the government has not updated its own estimate of total accidental costs since 2016, JCER made an updated estimate in 2019.

This time, given it is not clear whether TEPCO can take out all melted fuel debris from the reactors, JCER came up alternative case of postponement of decommissioning of the reactors 1–3 for 40 years (Option C). In addition, JCER updated tritium separation cost due to increase in volume of treated water from 1 million tons to 2 million tons (Option E). JCER also updated the cost of decontamination due to decrease in volume of radioactive waste from 22 million tons to 14 million tons. Option D is an updated version of Option B in 2017. As a result, JCER's estimates are now US$322 billion (Option C), US$385 billion (Option D) and US$758 billion (Option E). (See Table 11.)

Table 11 – Updated JCER's Estimate (2019) and Original Estimate (2017)

	2017-A	2017-B	2019-C	2019-D	2019-E
Decommissioning	103	301	40	103	476
Decontamination	282	282	186	186	186
Compensation	78	75	96	96	96
Total	**463**	**658**	**322**	**385**	**758**

Sources: JCER, 2017, 2019

The new estimates above (rounded) are based on the following assumptions:

"JCER's 2019-cost estimate ranges from US$322 billion to US$758 billion"

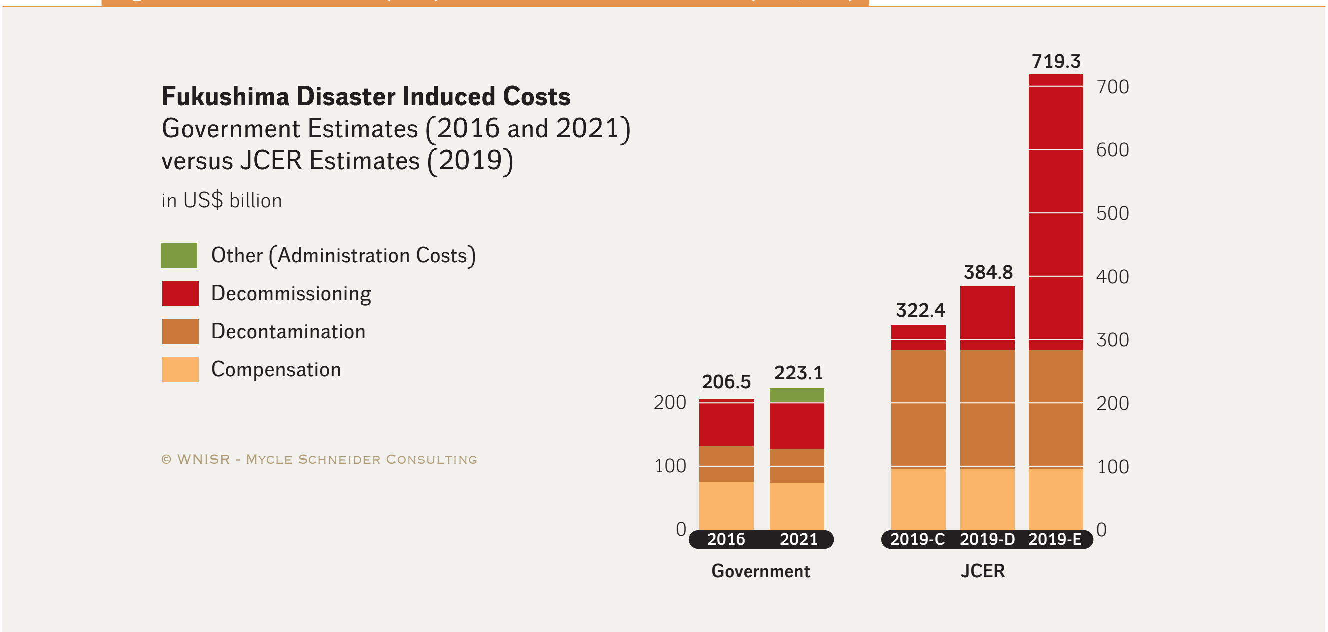
- **Decommissioning.** In scenario 2019-C, JCER assumed that decommissioning will be delayed until 2050, so that decommissioning costs would be minimum. If decommissioning is postponed, which would be a significant change from the current plan to take out all debris and clean up the land as soon as possible, JCER assumed that it would be necessary to purchase land owned by residents of "difficult-to-return zones". Land purchase prices of all lands is estimated to total ¥1.1 trillion (US$10 billion). For option C, decommissioning cost would be ¥3.25 trillion plus ¥1.1 trillion thus ¥4.3 trillion (US$40 billion). This estimate does not include potential additional costs after 2050, and costs of possible measures like the construction of a containment structure are also not included. Therefore, this estimate should be considered as on the lower end for scenario C.
- For scenario D, JCER assumed the same decommissioning cost as in 2017-A which is ¥11 trillion (US$103 billion).

- **Contaminated Water Management.** The assumption on the amount of contaminated water to be managed was increased from one to two million tons. This increase is based upon the hypothesis that cooling of fuel debris will continue until 2030, which results in an additional 800,000 tons. The management cost of treated water, which was not included in the 2017 estimate, is now estimated to be ¥150 billion (US$1.4 billion) by 2030. After 2030, JCER assumed that the management costs will gradually taper off, and will reach zero by 2050. As a result, ¥3.25 trillion (US$30 billion) is added as part of decommissioning cost.
- For scenario E, JCER considered tritium-separation costs for two instead of one million tons of contaminated water, which is estimated at ¥40 trillion (~US$370 billion). Thus, the total decommissioning cost of scenario E reaches ¥51 trillion (US$476 billion).
- **Decontamination.** Since the Ministry of Environment reduced its estimate for the amount of rubble and soil generated in the process of decontamination from 22 to 14 million m³, the estimate of final disposal costs was reduced from ¥30 trillion (US$280 billion) in 2017 to 20 trillion yen (US$186 billion) in 2019.
- **Compensation.** The amount of compensation to be paid by TEPCO had already increased to more than ¥8.7 trillion (US$80 billion) by 2017 and is now estimated by METI to reach ¥10 trillion (US$92 billion). Additional compensation to local communities of ¥0.3 trillion (US$3 billion) might have to be added to the compensation. Therefore, the total compensation amount in the three 2019-scenarios is estimated at ¥10.4 trillion (US$96 billion).

In total, JCER's 2019-cost estimate ranges from US$322 billion to US$758 billion [all in 2021 prices] depending on whether decommissioning will be done by 2050 or postponed to after 2050.

Figure 38 compares the government and JCER estimates.

Figure 38 · JCER Estimates (2019) versus Government Estimates (2016/2021)



Sources: METI, 2016; METI, 2021; JCER, 2019

Conclusions

In summary, the government estimate of the cost of the Fukushima disaster of US$200 billion made in 2016 is neither comprehensive nor up to date and clearly underestimates the total costs. Although JCER's estimates are also based on rough assumptions, they show much higher numbers, depending on a variety of assumptions, ranging from about US$320 billion to US$760 billion. The biggest difference between the government and JCER estimates comes from the fact that the official estimate does not include final disposal costs for radioactive waste generated by decommissioning and decontamination. Another big factor is the cost of water purification. While tritium separation could turn out lower than estimated by JCER, likely additional separation work for other radioisotopes have not been included at all in any cost estimate.

The analysis above entails a number of policy implications.

"It appears critically important to explore a variety of scenarios for decommissioning that provide a sound environmental, health and economic basis for decision-making."

Exploring Various Options for Decommissioning

The government estimates are based on fixed assumptions and no assessment of various scenarios has been carried out. In its 2017-estimate, JCER explores the option to separate tritium from contaminated water. In its 2019-estimate, JCER considered the option to postpone decommissioning of the reactors until 2050. This option has never been publicly discussed by the government, but it is very unlikely that all fuel debris can be removed from the site in the timeframe envisaged by the government and TEPCO (see Fukushima Status Report: Overview of Onsite and Offsite Challenges). Both of JCER's option assessments suggest that different choices could significantly impact costs upwards or downwards. Therefore, it appears critically important to explore a variety of scenarios for decommissioning that provide a sound environmental, health *and* economic basis for decision-making.

Economic Competitiveness of Nuclear Power Reflecting the Total Costs of the Disaster

The generation costs of nuclear power in Japan have not been reassessed based on the new cost estimates of the Fukushima disaster. The most recent nuclear electricity cost-estimate by the government (METI) was carried out in 2021 and estimated at >¥11.5/kWh (>US$¢10.8/kWh)[702]. This included estimated costs associated with the 3/11 events and assumed then those total costs would be limited to ¥23.8 trillion (US$223 billion). It was translated into ¥15.7 trillion (US$147 billion) for a model plant[703]. As a result, for the first time, the estimated nuclear

702 - Power Generation Cost Analysis Working Group, "基本政策分科会に対する—発電コスト等の検証に関する報告" ["Report on Power Generation Costs etc. to the Basic Policy Committee"], METI, 13 July 2021, op. cit.

703 - METI's model plant: 1,200 MWe, average capacity factor 70%, discount rate 3%. No detailed breakdown of the power-generation cost-estimate has been published yet. But basic assumptions are; capital cost is ¥480 billion (US$4.1 billion) versus ¥440 billion in the 2016 estimate, based on the assumption of ¥400,000/kW, decommissioning ¥75 billion (US$0.7 billion) vs. ¥71.6 billion in 2016, additional safety ¥136.9 billion (US$1.3 billion) vs. ¥60.1 billion in 2016, Rokkasho reprocessing ¥14.4 trillion (US$140 billion) vs. ¥12.6 trillion in 2016. MOX fabrication ¥2.4 trillion (US$23 billion) vs. ¥2.1 trillion in 2016. See Working Group on Power Generation Cost Assessment, METI, 13 July 2021, op. cit.

generation costs are no longer the cheapest power generation source in Japan. According to the new government estimates, the lower end of the indicated range[704] represents rooftop solar as the cheapest source at ¥9.5–14.5/kWh followed by LNG at >¥10.5–14.5/kWh.

JCER reassessed the estimated generation cost for nuclear power based on its 2017-estimate for the costs of the Fukushima disaster. JCER assumed construction cost would double to ¥740,000/kW (US$6,770/kW) up from ¥370,0000/kW (US$3,390/kW). Accordingly, the estimated cost of nuclear electricity generation increased by almost half to ¥14.7/kWh (US$c13.5/kWh).

Access to Information and Independent Oversight

There is a lack of access to information on the implications—economic, but also environmental and societal in general—of the decommissioning process. There is also a lack of an effective, independent oversight organization. The government 2016-cost estimate, officially released by METI, was carried out by the TEPCO Committee for Reforming TEPCO and Overcoming 1F [Fukushima Daiichi] Challenges and the underlying assumptions were never fully disclosed. It is therefore impossible to scrutinize those numbers. Besides, no update has been carried out since.

JUDICIAL DECISIONS ON DAMAGES AND CRIMINAL LIABILITY FOR THE FUKUSHIMA NUCLEAR ACCIDENTS

Introduction

Over the past decade, since the Fukushima nuclear power plant disaster began, many court cases have been filed by residents around nuclear power plants. The present chapter provides an overview of some of the most significant lawsuits, including attempts to establish a link between the responsibilities for the disaster and complaints filed against Fukushima owner-operator TEPCO and the Japanese Government. Another series of cases has been filed against all operating reactors and restart attempts by nuclear operators except for one (Higashidori). Some were lost by the plaintiffs, some succeeded. These cases have been profoundly impactful and continue to reshape the judicial decision-making in the nuclear sector in Japan.[705]

704 - There is no average figure indicated.

705 - This piece uses citations from all-Japanese Hanrei Jihou, the most authoritative case journal in the public domain, when they were available, and the courts' websites when they were not, or the websites of plaintiffs' groups and others when the first two references were not available. Although the URLs of the courts' websites cannot be copied, it can be easily searched by the general public by entering the court and date indicated in the article.

Historic Ikata Case: Japanese Supreme Court Demands High Level of Nuclear Safety

During Japan's first nuclear power plant lawsuit, brought against the Ikata nuclear power plant, Hideo Uchida, Chairman of the Nuclear Reactor Safety Review Board of the Japan Atomic Energy Commission (JAEC) at the time of his testimony, and then the first Chairman of the former Nuclear Safety Commission (NSC), testified that the safety of nuclear power plants was absolutely assured, citing the "Rasmussen Report"[706] on nuclear power plant safety.[707] The plaintiffs' claims were dismissed by the Supreme Court in 1992.[708]

The decision appears to be flawed in its interpretation of nuclear safety as the court limited the matters to be judged in administrative litigation to basic design, where relative safety should be ensured, and its judgement gave significant discretion to the government.

However, this ruling did include some important content, specifically:

- that nuclear power plants have the potential to cause serious disasters;
- that the government's examination of nuclear power plants is designed to prevent such a disaster from occurring under any circumstances ("not even one in ten thousand times" in the Japanese idiom);
- that the judiciary should make decisions based on current scientific knowledge, not based on outdated knowledge at the time of licensing; and
- that the burden of proof for safety is on the government, not the plaintiffs.

Fukushima Case: Judicial Decisions Regarding the Responsibility of TEPCO and the State

On 11 March 2011, the Great East Japan Earthquake (hereafter 3/11) occurred, causing a total loss of power at the Fukushima Daiichi Nuclear Power Plant, submersion of the emergency diesel power system, and a series of meltdowns in Units 1–3 (see Fukushima Status Report: Overview of Onsite and Offsite Challenges).

In July 2002, the National Headquarters for Earthquake Research Promotion (a government institute) raised the issue in its "long-term assessment" that a consensus of leading earthquake and tsunami scientists acknowledge three major tsunami-causing earthquakes exceeding magnitude 8 to have occurred in the past 400 years along the Japan Trench between the Tohoku region and the Boso coast, including the area offshore of the Fukushima Daiichi

706 - The "Rasmussen Report" directed by MIT's Norm Rasmussen, with its official name "Reactor Safety Study", WASH-1400, (NUREG 75/014) published by the then newly established U.S. Nuclear Regulatory Commission (NRC) in October 1975, was the first formal Probabilistic Risk Assessment for nuclear power plants. It concluded that "nuclear power plants have achieved a relatively low level of risk compared to many other activities in which our society engages". In January 1979, two months before the Three Mile Island partial meltdown, the NRC issued a severe critique of the report, stating "absolute values of the risks presented by WASH-1400 should not be used uncritically either in the regulatory process or for public policy purposes" and that "the Commission does not regard as reliable the Reactor Safety Study's numerical estimate of the overall risk of reactor accident". See U.S.NRC, "Nuclear Regulatory Commission Issues Policy Statement on Reactor Safety Study and Review by Lewis Panel", 19 January 1979, see https://www.nrc.gov/docs/ML1802/ML18022B145.pdf, accessed 3 July 2021.

707 - Hosomi Shū, "されど真実は執拗なり：伊方原発訴訟を闘った弁護士・藤田一良" ["But the Truth is Persistent: Kazuyoshi Fujita, a Lawyer Who Fought the Ikata Nuclear Power Plant Lawsuit"], *Iwanami Shoten*, 2016, p.64–76

708 - *Hanrei Jihou, No.* 1441 p.37

Nuclear Power Plant, and that such tsunami-causing earthquakes were likely to occur again in the future.[709]

In 2004, a large tsunami caused by an earthquake off the coast of Sumatra hit a nuclear power plant in Kalpakkam in southern India. In response to this event, in 2006, Japan's Nuclear and Industrial Safety Agency (NISA) demanded that electric utilities adopt strict tsunami countermeasures.[710] However, Tokyo Electric Power Company (TEPCO) did not take any additional measures.

In February 2008, at a meeting attended by TEPCO's top executives, Kazuhiko Yamashita, who was then second in command of the Nuclear Power Division, proposed a plan to implement countermeasures in accordance with the long-term assessment mentioned above, which was approved by the president and other directors.

In March 2008, simulation results based on the long-term assessment showed that a tsunami could potentially reach a height of 15.7 meters, this being almost three times higher than the design basis standard of 5.7 meters above sea level.

This result was reported by TEPCO's Civil Engineering Research Group to then Vice President Muto in June of the same year, and in response the Vice President instructed them to consider countermeasures for equipment, including a method to reduce the tsunami run-up height to 4-meter ground (ground 4 meters above the Onahama Peil (O.P.)) where the emergency seawater pumps were installed, and to arrange permits for the installation of an offshore breakwater. However, in July 2009, Vice President Muto instructed the Civil Engineering Research Group to postpone the tsunami countermeasures and to ask the Japan Society of Civil Engineers, which is made up of academics with links to the power companies and that receives funding from the power industry, to reexamine the design basis tsunami.

Instead of submitting the results of this simulation to the government and Fukushima Prefecture immediately, TEPCO executives reported the results to the government on 7 March 2011, just four days before the accident.

The primary responsibility for the Fukushima accident lies with TEPCO for failing to adopt tsunami countermeasures in response to the government's tsunami forecast (the "long-term assessment"), while secondary responsibility lies with the government for not requiring TEPCO to implement tsunami countermeasures based on its own earthquake and tsunami assessment.

Judicial decisions on whether or not the government is responsible for the accident are divided: the Sendai High-Court decision on 30 September 2020 and the Tokyo High-Court decision on 19 February 2021 have acknowledged the government's responsibility, while a separate Tokyo High-Court decision of 18 February 2021 rejected the responsibility of the state. All three of these cases have been appealed, and the Supreme Court's decisions are expected to be issued within the coming year. These judgements will be important.[711]

709 - Committee on Earthquake Research, "三陸沖から房総沖にかけての地震活動の長期評価について" ["Long-Term Assessment of Seismic Activity off Sanriku to Boso-Oki"], Earthquake Research Promotion Headquarters, Government of Japan, 31 July 2002, see https://www.jishin.go.jp/main/chousa/kaikou_pdf/sanriku_boso.pdf, accessed 30 August 2021.

710 - The following paragraphs are based on evidence presented to the court in the TEPCO criminal trial.

711 - See Courts in Japan, "裁判例検索", Undated, see https://www.courts.go.jp/app/hanrei_jp/search1, accessed 3 September 2021.

TEPCO Criminal Case

A manslaughter case against three TEPCO executives sought to establish criminal responsibility for the accident. The Tokyo District Court, presided by Judge Kenichi Nagabuchi, acquitted all defendants on 19 September 2019.[712] The court ruled that the safety review standards for nuclear power plants were not based on the premise of ensuring absolute safety. The court also emphasized that there were scholars who disagreed with the "long-term assessment" and concluded that the executives were not obligated to take measures based on the "long-term assessment". This decision is in direct contradiction to the aforementioned decision that found the government liable for state compensation. This decision can be evaluated as a de-facto rejection of the Supreme Court's decision in the Ikata case, which ruled that the safety of nuclear power plants *must* be ensured to prevent serious disasters from occurring.

Despite the acquittal, the facts and evidence uncovered by the criminal trial provided much of the basis for the High Court's decisions in favor of the plaintiffs in the "Nariwai" and "Chiba" civil lawsuits, in which the government was found liable.

TEPCO Civil Liability Case[713]

The TEPCO shareholder representative lawsuit, which has been underway to clarify the civil liability of TEPCO executives, began intensive witness examination in February 2021. The former head of the Volcano and Earthquake Department of the Japan Meteorological Agency (JMA), who was also a member of the Long-Term Assessment Subcommittee, testified clearly that the "long-term assessment" was highly reliable.

Meanwhile, Yukinobu Okamura, who was a member of NISA's safety review committee while working on tsunami deposits at a government-established research institute, told TEPCO officials who said they wanted to continue the tsunami deposit survey: "The scale of the Jogan tsunami [of 869 AD] will never decrease, even if you continue the survey. Continuing the survey is of no further use. You should start countermeasure work right now".

These two important testimonies point to the responsibility of TEPCO.

Furthermore, Atsuo Watanabe and Masashi Goto, former Toshiba nuclear power plant engineers, testified that waterproofing and sea walls to prevent tsunami inundation were technically easy to implement and that such countermeasures could have been implemented by the time of the accident.

Five former TEPCO executives are currently being questioned by the court.

The Tokyo District Court has decided that judges will visit the site of the Fukushima Daiichi Nuclear Power Plant in October 2021. According to TEPCO, this will be the first time that judges visit the Fukushima Daiichi Nuclear Power Plant site.

More than 50 TEPCO shareholders have sued five former executives for compensation over damages caused by the accident at the Fukushima Daiichi Nuclear Power Plant, and the shareholders have asked the judge to visit the site.

712 - *Hanrei Jihou*, No. 2431, 11 March 2020.

713 - This section is based on information gathered by Lawyer Yuichi Kaido, who is working on the case.

The judge said, "I would like to see the location of the nuclear power plant firsthand before making a decision on responsibility for the accident".

Judges have inspected the surrounding area on a number of occasions in civil trials over compensation for the nuclear power plant accidents, but they have never visited the Fukushima Daiichi site itself.

In the first trial of the criminal case in which the three former TEPCO executives were forcibly indicted, the designated lawyer acting as the prosecutor requested the judge to inspect the site. However, the judge rejected the request.

Residents Win Lawsuits, Preventing Restarts

After 3/11, citizens who had doubts about the safety of nuclear power plants swiftly launched actions against almost all nuclear power plants in Japan, filing civil suits, provisional injunctions, and administrative actions against the operation of one or more reactors.

As of April 2021, there have been eight court decisions that have accepted the opinions of the plaintiffs and suspended the operation of nuclear power plants.

The first of these was a decision by the Fukui District Court on 21 May 2014, presided by Judge Hideaki Higuchi, to stop the operation of the Ohi Nuclear Power Plant.[714]

This decision was based on the following principles:

- that the foundational personal rights of human life are of supreme value;
- that the operation of nuclear power plants falls under the category of freedom of economic activity, and economic rights should be subordinated to the right to life and health; and
- the fact that earthquakes exceeding the base earthquake ground motion have occurred five times in the past clearly shows that the method of determining the base earthquake ground motion is wrong.715

This decision can be evaluated as a milestone in which the judiciary acknowledged the severity of the Fukushima nuclear accident. On 14 April 2015, Judge Higuchi issued a provisional injunction order against the operation of Takahama Units 3 and 4, thereby halting the operation of reactors that were actually in operation. This decision was critical of the fact that it was difficult to find any rationality in basing the design basis earthquake ground motion for nuclear power plants on an average concept of earthquakes, and it had been shown to be unreliable not only in theoretical terms, but also in terms of its actual performance.

Subsequently, two further provisional injunctions were issued by the Otsu District Court to stop the operation of the plant due to inadequate earthquake motion assumptions and evacuation plans.

714 - *Hanrei Jihou*, No. 2228, P.72.

715 - Ibidem.

Volcanic Controversy over the Sendai Nuclear Power Plant

Kagoshima District Court Decision

The Sendai Nuclear Power Plant is located in the western part of Kagoshima Prefecture close to a number of volcanoes, including the Aira Caldera and Sakurajima. On 22 April 2015, the Kagoshima District Court, presided by Judge Ikukatsu Maeda, rejected residents' petition for an injunction against the operation of Units 1 and 2 of the Sendai Nuclear Power Plant.[716] The decision judged that pyroclastic eruptions (eruptions involving the ejection of rocks) can be predicted long in advance, and while acknowledging that there are a certain number of volcanologists who believe that the possibility of catastrophic eruption activity is not sufficiently small, they do not constitute the majority of the volcanological community, and the court consequently judged the possibility of such volcanic activity to be sufficiently small.

Decision by the Miyazaki Branch of the Fukuoka High Court

On 6 April 2016, the Miyazaki Branch of the Fukuoka High Court, presided by Judge Tomoichiro Nishikawa approved the restart of the Sendai Nuclear Power Plant and dismissed the residents' appeal.[717] However, the decision acknowledged many of the residents' factual claims regarding the volcano. Significantly, it judged that the content of the "Volcano Guide" produced by the Nuclear Regulation Authority (NRA), which assumes that the timing and scale of an eruption can be accurately predicted a considerable time in advance, is unreasonable.

It also ruled that the government should, in principle, declare a site unsuitable if there is a volcano thought to have triggered during its largest eruption in the past a volcanic event that cannot be designed against, i.e. a pyroclastic flow reaching the site of the nuclear power plant.

The decision also found unreasonable Kyushu Electric Power's assessment that the eruption potential of five caldera volcanoes was sufficiently small.

Nevertheless, the court ruled that the only way to determine the risk of volcanic eruptions is to base it on socially accepted notions regarding the extent to which the Japanese society accepts the risk. The court then dismissed the residents' case on the basis of such socially accepted notions, saying that it is socially accepted to ignore and tolerate the risk of natural disasters whose effects, although extremely serious and severe, have never been experienced in the historical period, unless the plaintiffs prove the possibility of such a disaster occurring.

Controversy Over Ikata and the Aso Eruption

Provisional dispositions filed in four District Courts

In August 2016, the Ikata nuclear power plant located in Shikoku was restarted. In response, provisional injunction cases were filed one after another in the four regions surrounding the plant, in the Hiroshima District Court in March 2016, in the Matsuyama District Court in May 2016, in the Oita District Court in June 2016, and in the Iwakuni Branch of the Yamaguchi District Court in March 2017. While the four injunction cases were eventually defeated, four

716 - *Hanrei Jihou*, No. 2290, P147.

717 - *Hanrei Jihou*, No. 2290, P90.

civil lawsuits aiming at the shutdown of the plant are still pending in the four district courts, as well as a new provisional injunction case filed in March 2020 in the Hiroshima District Court.

In these cases, the location of the Median Tectonic Line as a fault, its distance from the nuclear power plant, its activity, and the angle of the fault were also points of contention, as well as the potential impact of an eruption of Mount Aso on the Ikata Nuclear Power Plant.

Hiroshima High-Court Decision declaring the site unsuitable

On 13 December 2017, the Hiroshima High Court, presided by Judge Tomoyuki Nonoue, issued a provisional injunction against the operation of Unit 3 of the Ikata Nuclear Power Plant, for a limited period until 30 September 2018, in an immediate appeal against the decision of the Matsuyama District Court.[718] This was the first time that the High Court had granted an injunction against the operation of a nuclear power plant since 3/11.

In accordance with the evaluation procedure of the NRA's "Volcano Guide", the decision was based on the fact that the possibility of volcanic activity of Aso Caldera, located 130 km from the Ikata site, could not be judged to be sufficiently small during the reactor operation period, and that the scale of such an eruption could not be estimated. The decision maintained that since it is impossible to estimate the scale of an eruption, the scale of the Aso 4 eruption of approximately 90,000 years ago (volcanic eruption index VEI 7) should be assumed. Since the possibility that the pyroclastic flow of the Aso-4 eruption reached the Ikata site cannot be evaluated as sufficiently small, the location of the nuclear power plant is therefore unsuitable.

The part of the judgment relating to volcanoes cited the opinions of many volcano experts, and the strong backing of experts such as the Volcanological Society of Japan had a great influence on the decision.

Regarding the aforementioned theory of social acceptance, the decision accepted that it may be considered socially acceptable to ignore the risks of a catastrophic eruption in light of the following points: that the frequency of catastrophic eruptions with a volcanic eruption index of VEI 7 or higher is said to be about once every ten thousand years when considering all volcanoes in Japan; that a catastrophic eruption at Aso would cause a crisis of national survival far beyond the damage caused by the Fukushima Daiichi Nuclear Power Plant accident; that natural disasters with a significantly low frequency of occurrence are not written into regulations, with the exception of the "Volcano Guide"; and that the government has not stipulated any countermeasures other than monitoring of volcanic activity, and there has been no significant public concern or skepticism about this.

However, the decision seems to be contrary to the purpose of the Nuclear Reactor Regulation Law and the new regulatory standards which change the framework of judgment criteria by making a limited interpretation on the basis of socially accepted notions regarding natural disasters. NRA issued the "Volcano Guide" stipulating it should be based on the latest scientific and technological knowledge.

718 - *Hanrei Jihou*, No. 2357, P190.

Subsequently, on 25 September 2018, another judge of the same Hiroshima High Court struck down this objection to the provisional disposition, on the grounds that it was socially accepted to ignore catastrophic volcanic eruptions.[719]

Hiroshima High Court grants fresh injunction on the grounds of inadequate earthquake countermeasures and volcanic ash countermeasures.

On 17 January 2020, the Hiroshima High Court, in an immediate appeal against the decision of the Iwakuni Branch of the Yamaguchi District Court, granted an injunction against the operation of the Ikata Nuclear Power Plant, pointing out the inadequacy of earthquake and volcanic-ash countermeasures in the event of a major eruption.[720] This decision represents an important judgement on the level of safety required at nuclear power plants, stipulating the following points:

- A high level of safety should be required, in the sense that a severe accident like the Fukushima accident should never be allowed to occur;
- In judging whether or not there is a specific danger from nuclear power plants, it cannot be denied that it is necessary to interpret and apply this principle or the spirit of this principle (exclusion of a Fukushima-type event);
- When there are conflicting views among experts on an issue, the court should not readily adopt the view representing the less conservative position simply because it is the dominant or prevailing view.

This decision by the Hiroshima High Court could be considered a common-sense and well-balanced judicial decision.

Hiroshima High-Court Decision overturned on appeal

However, on 18 March 2021, the Hiroshima High Court, presided by Judge Kunihiko Yokomizo, reversed the aforementioned Hiroshima High Court decision on immediate appeal.[721]

This decision places the burden of proving a concrete danger of violation of personal rights on the residents' side, for reasons such as the court's lack of expertise in cases where indefiniteness of science exists. This decision constitutes an attempt to overturn even the norm stipulated by the 1992 Ikata Supreme-Court decision mentioned at the beginning of this section (see Historic Ikata Case).

Osaka District-Court revokes license of Ohi Nuclear Power Plant

On 4 December 2020, the Osaka District Court, presided by Judge Hajime Morikagi, ruled to revoke the license for the modification of the installation of Units 3 and 4 of the Ohi Nuclear

719 - For case proceedings and material, see 伊方原発運転差止広島裁判, Undated, see https://saiban.hiroshima-net.org/.

720 - Hiroshima High Court, "平成31(ラ)48 伊方原発３号機運転差止仮処分命令申立却下決定に対する即時抗告事件 令" ["Immediate appeal against the decision to dismiss the Ikata Nuclear Power Plant Unit 3 operation injunction–provisional disposition order"], accessed via Courts in Japan, 17 January 2020, see https://www.courts.go.jp/app/files/hanrei_jp/478/089478_hanrei.pdf, accessed 9 August 2021.

721 - Hiroshima High Court, "令和2(ウ)4 — 保全異議申立事件", 18 March 2021, see https://www.courts.go.jp/app/hanrei_jp/detail4?id=90237, accessed 31 August 2021.

Power Plant.[722] This is the first time since 3/11 that residents' claims have been accepted in an administrative lawsuit.

The main point of contention in this case was the magnitude of the earthquake motion that could hit the plant. In the framework of its decision, the court followed the framework of the 1992-Supreme-Court Decision in the Ikata nuclear power plant case, and judicially examined whether there were any unreasonable points in the regulatory standards, and whether there were any errors or omissions that could not be overlooked in the process of investigation, deliberation and judgement by the regulatory commission.

The plaintiffs' main point of contention was that the design basis earthquake ground motion of the nuclear power plant had been underestimated. Earthquake ground motion is determined by the characteristics of the rupture at the epicenter, the characteristics of seismic wave propagation, and the characteristics of how the seismic waves are affected by the ground structure near a given point. The plaintiffs criticized the "Irikura-Miyake formula," which is an empirical formula used at many nuclear power plants to derive the earthquake magnitude based on the area of the fault, saying that most of the data came from overseas, leading to underestimation. They argued that the "Takemura formula", which is a similar empirical formula, should be adopted instead. The court showed some understanding on this point, saying "there is room to accept a certain degree of rationality in using the Takemura formula", but ultimately rejected the plaintiffs' argument.[723]

Even before 3/11, the standards for the calculation of design basis earthquake ground motion required that the uncertainty of parameters, such as the length and depth of the epicenter fault and the tilt angle of the fault, be considered in combination as necessary in the process. However, in the "Earthquake Motion Review Guide" established by the NRA, a provision was added after 3/11 that the empirical formula gives earthquake magnitude as an average value and that the variation of the empirical formula must be taken into account.[724] The court took note.

On 30 January 2020, the Osaka District Court explained that the government should at least take into account this variation using the standard deviation when calculating the design basis earthquake ground motion. In response, as justification for not performing the calculations properly, the defendant—the Japanese government—argued that there was no need to take into account the variability of the empirical equation when the uncertainty in the parameter settings was already taken into account. The Osaka District Court was scathing about this attitude from the government.[725]

Ten years have passed since the Fukushima nuclear power plant accident, and the critical issue in the subsequent lawsuits over the restart of nuclear power plants has been whether the safety of nuclear power plants can be ensured against predicted earthquakes and volcanic activity.

722 - Osaka District Court, "平成24(行ウ)117 — 発電所運転停止命令義務付け請求事件", 4 December 2020, see https://www.courts.go.jp/app/hanrei_jp/detail5?id=90400, accessed 31 August 2021.

723 - Ibidem.

724 - NRA, "Review Guide for Design Basis Ground Motions and Seismic Design Policy", 19 June 2013.

725 - According to a report from the lawyers in charge of the case to the National Liaison Committee of Lawyers for a Nuclear Power Free Japan, which the author is a co-chair of.

Judge Morikagi, who wrote the Osaka District Court decision, is an elite jurist who once worked in the Administrative Bureau of the Supreme Court. It is noteworthy that doubts about nuclear power are now emerging among mainstream judges.

Mito District Court Rules Against Restart of Tokai Daini

On 18 March 2021, the Mito District Court, presided by Judge Eiko Maeda, issued an injunction against the operation of the Tokai Daini Nuclear Power Plant.[726]

Tokai Daini is one of the nuclear power plants directly affected by 3/11, an aging reactor that was first connected to the grid 43 years ago. Many of the local authorities in the surrounding area have expressed their opposition to any restart of the plant, citing doubts about its safety and the difficulty of developing an evacuation plan.

The court ruled the framework for judging the safety of nuclear power plants to be that any gaps or inadequacies in any of the first through fifth levels of defense-in-depth protection represent a concrete danger.

Although no serious flaws were identified with regard to the first to fourth layer of defense-in-depth, with regard to the fifth level of protection, which includes evacuation plans, the court ruled that despite there being 940,000 residents in most exposed priority areas in a nuclear disaster—the Precautionary Action Zone (PAZ) and Urgent Protective Action Planning Zone (UPZ)[727]—a feasible evacuation plan and a structure to implement it are far from being in place, and that the plaintiffs who live in this area are in concrete danger of violation of their personal rights.

Close reading of the verdict reveals concerns regarding the approval of the nuclear power plant site in such a densely populated area. Although the court rejected the plaintiffs' claims regarding earthquakes and volcanoes, the language of the verdict suggests reservations regarding nuclear safety, in effect representing the view that there is no guarantee that a severe accident could never occur. This decision to suspend the operation of the Tokai Daini Nuclear Power Plant may therefore be evaluated as having been made on the grounds that "there is no effective evacuation plan in place" should the worst happen.

The judgement recognizes that it is difficult to ensure the safety of nuclear power plants and that an accident would cause a great deal of damage. This judgement makes it clear that an inability to identify fatal flaws in the first to fourth levels of defense-in-depth protection does not make it acceptable to lay out flimsy evacuation plans.

726 - Mito District Court, "平成24(行ウ)15—東海第二原子力発電所運転差止等請求事件", 3 March 2021, see https://www.courts.go.jp/app/hanrei_jp/detail4?id=90255, accessed 31 August 2021.

727 - PAZ refers to the area about 5 km around the plant, and UPZ refers to the area about 5–30 km around the plant.

Conclusion

Since the Japan Supreme Court's first ruled on nuclear safety in 1992, the judicial system has evolved. But it is the decade since the Fukushima disaster began that brought most of the changes, with judges showing increasing independence from powerful nuclear utilities, with their perceived overwhelming technical expertise, and from the Government.

While legal experts see TEPCO as primarily responsible for the Fukushima disaster, three regional High Court Decisions were split as to Government responsibility. Two courts ruled in favor, one against holding the Government accountable. All three decisions are pending before Japan's Supreme Court.

Three TEPCO executives were acquitted in 2019 by the Tokyo District Court in a criminal case. The TEPCO shareholder representative lawsuit, launched to clarify the potential civil liability of TEPCO executives, is underway and began witness examination in February 2021.

The decisions pending before the nation's Supreme Court and the criminal case against TEPCO will provide key jurisprudence for future cases.

In March 2021, for the first time, a court ruled against the restart of a reactor on the grounds of a missing credible evacuation plan.

As of April 2021, there have been eight court decisions in favor of plaintiffs suspending the operation of nuclear power plants.

CHERNOBYL · 35 YEARS AFTER THE DISASTER BEGAN

INTRODUCTION

Thirty-five years ago, on 26 April 1986, the world witnessed its worst nuclear accident. At 1:23 (GMT+3) that morning, during a planned safety system test that involved electricity shut down, due to a faulty reactor design and series of operator errors, the reactor core at Unit 4 of the Chernobyl nuclear power plant experienced a critical power excursion. Within seconds, nominal energy output of the reactor core surged by a factor of more than 100, followed by a steam and then a hydrogen explosion that tore through the roof of the reactor building.[728, 729] The resulting fires raged for ten days, spewing radioactive plumes from the molten nuclear fuel and the burning graphite reactor core, high into the atmosphere, spreading over much of the northern hemisphere.

Much has changed since 1986, following the Chernobyl disaster. The country where the accident happened—the Soviet Union—disappeared and fifteen new ones, including Belarus, the Russian Federation, and Ukraine, emerged, in no small part due to Chernobyl's political and social fallout.[730] The RBMK reactor design implicated in the accident is no longer in use outside Russia. Thousands lost their lives, hundreds of thousands their homes and livelihoods, millions resigned to live in radioactive contamination. Some 200 villages and towns in Belarus and Ukraine have vanished from the map; more are likely to follow as their inhabitants pass. Hundreds of billions of dollars have been spent on dealing with the aftermath of the accident or were written down as economic loss. After the severe post-Soviet transition crisis, Ukraine, aided by the international community, managed the closure of the other three reactors at Chernobyl and built a long-term confinement for Unit 4. Once restricted to the public, the exclusion zone has become a tourist destination. Yet 35 years on, the story of Chernobyl is far from over. Some of the most formidable challenges lie ahead.

ONSITE CHALLENGES

New Safe Confinement (NSC)

In November 2016, the Ukrainian government inaugurated the New Safe Confinement (NSC), an arch-like structure that covers Unit 4 and the old concrete sarcophagus hastily built over the reactor shortly after the accident. The arch is the largest land-based movable structure

728 - Kazuo Yoshida, Fumiya Tanabe et al., "Analyses of Power Excursion Event in Chernobyl Accident with RETRAN Code", *Journal of Nuclear Science and Technology*, Vol. 23, Issue 12, December 1986.

729 - Mycle Schneider, "The Chernobyl Disaster: A Human Tragedy for Generations to Come", in International Physicians for the Prevention of Nuclear War, "Rethinking Nuclear Energy and Democracy After September 11, 2001", 2004.

730 - Mariana Budjeryn, "Chernobyl's effects go far beyond what you're seeing on HBO. It shook up geopolitics for years", *The Washington Post*, 15 July 2019, see https://www.washingtonpost.com/politics/2019/07/15/chernobyls-effects-go-far-beyond-what-youre-seeing-hbo-it-shook-up-geopolitics-years/, accessed 17 May 2021.

ever built.[731] The NSC is meant to hermetically seal off Unit 4 from the environment and has a projected lifetime of at least 100 years.[732]

Its construction was financed from the Chernobyl Shelter Fund, established in 1997 and closed in October 2020733, which attracted over €1.6 billion (US$$_{2021}$1.8 billion) in contributions from 45 donor states and organizations, including the European Bank for Reconstruction and Development (EBRD), the largest donor and the manager of the Fund.[734] The NSC is complete with auxiliary structures such as a medical and radiation protection facility, integrated system for monitoring radiation data and seismic activities, information on the structural integrity of the old shelter, and other safety parameters important for the operation of the NSC.[735]

While the completion of the Chernobyl NSC was a widely celebrated milestone, many challenges remain. Ninety-five percent of the original nuclear fuel in the Unit 4 core—some 170 tons of irradiated fuel rods, their zirconium cladding, graphite control rods, and sand dumped in 1986 on the core to extinguish the fire, all melted together to form the so-called Fuel-Containing Materials (FCMs)—remain buried in the reactor basement. The risk of nuclear activity inside the FCMs escalating into self-sustaining fission and causing another accident, remains. The old sarcophagus was leaky and admitted rainwater which acted as moderator, slowing down neutrons and increasing their chance of hitting and splitting the uranium nuclei. In the past, scientists sprinkled neutron-absorbing gadolinium nitrate to prevent the FCM from reaching criticality, an imperfect measure since the sprinklers could not penetrate some basement rooms, blocked by debris.[736]

With the construction of the NSC, the hope was that the risk of a run-away reaction in the FCM would be averted, and indeed, over the past four years, the neutron count in most of the areas has been stable or declining. In one room, however, it nearly doubled over the past four years, for reasons scientists have struggled to explain.[737] Should the FCM reach criticality, the NSC would contain the radioactive release. The concern, however, is that a steam explosion from a sudden boiling of leaked water could send the old sarcophagus crumbling. The structure is already on the verge of collapse, and in July 2019, the Chernobyl-plant management contracted a company to take it apart by 2023, a project that will have to be carried out in conditions of high radiation-exposure risk.[738] Ultimately, the plan is to remove the FCMs from the reactor basement and store them securely in a geological repository.[739]

731 - EBRD, "Unique engineering feat concluded as Chernobyl arch has reached resting place", European Bank for Reconstruction and Development, 29 November 2016, see https://www.ebrd.com/news/2016/unique-engineering-feat-concluded-as-chernobyl-arch-has-reached-resting-place.html, accessed 17 May 2021.

732 - EBRD, "The Chernobyl Shelter Implementation Plan", Undated, see https://www.ebrd.com/what-we-do/sectors/nuclear-safety/chernobyl-shelter-implementation.html, accessed 17 May 2021.

733 - Simon Evans, "Goodbye Chernobyl Shelter Fund", EBRD, 20 October 2020, see https://www.ebrd.com/news/2020/goodbye-chernobyl-shelter-fund.html, accessed 30 July 2021.

734 - EBRD, "Chernobyl Shelter Fund", Undated, see https://www.ebrd.com/what-we-do/sectors/nuclear-safety/chernobyl-shelter-fund.html, accessed 30 July 2021.

735 - EBRD, "The Chernobyl Shelter Implementation Plan", Undated, op. cit.

736 - Richard Stone, "'It's like the embers in a barbecue pit.' Nuclear reactions are smoldering again at Chernobyl", *Science*, 5 May 2021, see https://www.sciencemag.org/news/2021/05/nuclear-reactions-reawaken-chernobyl-reactor, accessed 6 May 2021.

737 - Ibidem.

738 - SSE ChNPP, "Contract Signed to Construct Infrastructure for Shelter Dismantling", Chornobyl NPP, 2 August 2019, see https://chnpp.gov.ua/en/infocenter/news/5375-contract-signed-to-construct-infrastructure-for-shelter-dismantling, accessed 17 May 2021.

739 - Although plans for a geological repository exist, no specific location or project has been commissioned.

Spent Fuel and Radioactive Waste

Another issue at Chernobyl is the spent nuclear fuel. After the accident on Unit 4, the other three reactors continued operating, until they were eventually closed: Unit 1 in 1996, Unit 2 in 1991 and Unit 3 in 2000. Over the course of its operation from 1977 to 2000, the Chernobyl nuclear power plant accumulated some 21,000 spent fuel assemblies, dozens of them damaged during the accident at Unit 4, containing close to 2,500 tons of heavy metal.[740] These have been removed from reactor pools and stored in a centralized wet-type Interim Spent Nuclear Fuel Storage facility (ISF-1) that was commissioned at Chernobyl in 1986 and consists of five pools. Four of the pools have since been filled to 99-percent capacity, the fifth is held in reserve.[741]

In 2000, after the last Chernobyl reactor was closed, EBRD and other international donors agreed to finance the construction of a plant for processing liquid radioactive waste and a dry-type storage facility, ISF-2, into which spent fuel from ISF-1 as well as some 2,000 spent fuel absorbers and over 23,000 activated connecting rods (fuel assembly parts) would be transferred to be stored for up to 100 years.[742] The liquid waste processing facility was completed in 2018 and is meant to operate for 10 years.[743] It is equipped to solidify liquid nuclear waste from the existing storage facility into a cement compound, and package it into 200-liter drums and reinforced concrete overpacks to be deposited in a long-term storage facility.[744]

By September 2019, the ISF-2 dry storage facility, the largest of its kind in the world and built by U.S. company Holtec International[745], completed "cold" tests and in December 2020 conducted a "hot" test, during which some 186 spent fuel assemblies were transferred to the facility, prepared for dry storage, loaded into cannisters, deposited into concrete dry storage vaults, and sealed by IAEA inspectors.[746] In April 2021, the Ukrainian regulator granted the license to begin full-scale operation of spent fuel transfer from the ISF-1 pools to the ISF-2 dry storage.[747]

740 - Mainly uranium, about 1 percent plutonium. Matthew French, David Nixon et al., "Packaging of Damaged Spent Fuel," Amec Foster Wheeler, 14 December 2016, see https://rwm.nda.gov.uk/publication/packaging-of-damaged-spent-fuel/?download, accessed 3 August 2021.

741 - State Agency of Ukraine on Exclusion Zone Management, "Informatsiina Dovidka Shchodo Realizatsiii Proektu 'Budivnytstvo Skhovyshcha Vidpratsiovanoho Iadernoho Palyva (SVIaP-2)" ["Information Regarding the Implementation of the Project "Construction of Spent Nuclear Fuel Storage (ISF-2)"]", Undated, see http://dazv.gov.ua/budivnytstvo-nbk-ta-svyap-2/informatsijna-dovidka-shchodo-realizatsiji-proektu-budivnitstvo-skhovishcha-vidpratsovanogo-yadernogo-paliva-svyap-2.html, accessed 17 May 2021.

742 - State Agency of Ukraine on Exclusion Zone Management, "Promizhne Skhovyshche Vidpratsiovanoho Iadernoho Palyva 'Sukhoho' Typu (SVIaP-2) [Dry-Type Interim Spent Nuclear Fuel Storage Facility (ISF-2)]", Undated, see http://dazv.gov.ua/informatsijni-materiali-dlya-zmi/promizhne-skhovishche-vidpratsovanogo-yadernogo-paliva-sukhogo-tipu-svyap-2.html, accessed 7 June 2021.

743 - SSE ChNPP, "Liquid Radioactive Waste Treatment Plant (LRTP)", 4 March 2019, see https://chnpp.gov.ua/en/187-projects/completed-projects/436-2010-09-13-07-21-32436, accessed 30 July 2021.

744 - Ibidem.

745 - This followed an abandoned project by the French nuclear industry : "The history of its construction is not simple as the first contractor – French company 'Framatome' – somehow ended up having made the building with cracks in its concrete body and could not decide how to remove water from the damaged FEs", SSE ChNPP, "Chornobyl Zone "Storage Facilities" or Why ISF Is Not a Repository", n.d., see https://chnpp.gov.ua/en/194-presscenter/unofficially/4886-storage-facilities-of-chernobyl-exclusion-zone-or-why-isf-is-not-a-repository, accessed 30 July 2021.

746 - SSE ChNPP, "Chernobyl NPP successfully completes transfer of spent nuclear fuel within 'hot tests' at ISF-2", Chornobyl NPP, 15 December 2020, see https://chnpp.gov.ua/en/infocenter/news/5714-chornobyl-npp-successfully-completes-transfer-of-spent-nuclear-fuel-within-hot-tests-at-isf-2, accessed 3 August 2021.

747 - SSE ChNPP, "Permit obtained for retrieval of standard spent nuclear fuel", Chornobyl NPP, 21 May 2021, see https://chnpp.gov.ua/en/infocenter/news/5827-permit-obtained-for-retrieval-of-standard-spent-nuclear-fuel, accessed 3 August 2021.

Several solid radioactive waste storage facilities have been operated and upgraded to handle waste generated during operation of the Chernobyl reactors as well as waste generated during the operation of the NSC.[748] In addition, the solid radioactive waste facilities began receiving wastes stemming from the reprocessing in Russia of spent VVER fuel from Ukraine's other nuclear power plants.[749] Holtec International is currently building the Central Spent Fuel Storage Facility (CSFSF) for VVER reactor spent fuel close to the ISF-2. Ultimately, Ukraine plans to cease returning its spent nuclear fuel to Russia and store it locally, as a cost-saving measure and a way to minimize the dependence of its nuclear sector on Russia.[750]

The construction of the NSC, the liquid nuclear waste processing facility, and the dry storage are part of the initial two stages of the Ukrainian government's four-stage, long-term program for decommissioning the Chernobyl plant.[751] The full completion of the second stage, involving the dismantling of the most radioactive equipment and mothballing of Units 1, 2, and 3, is expected by 2022, although financing challenges might cause delays.

Stage three, involving maintenance of the mothballed reactors to achieve reductions in ambient radiation to acceptable levels, is due to last until 2045.[752] Stage four, involving the full dismantlement of the three reactors and site clean-up, is expected to be completed by around 2065.[753]

Tourism, Conservation, and Research

The State Agency of Ukraine on Exclusion Zone Management (SAUEZM), created in 2014 under the Ministry of the Environment and Natural Resources, has embarked on a campaign to develop the Ukrainian section of the Chernobyl Exclusion Zone (CEZ), an area 30 km in radius cordoned after the accident, along several directions. One is tourism: SAUEZM has made a push to attract visitors to Chernobyl's Soviet time-capsule attractions, such as the abandoned town of Prypiat and the Soviet-era Dyatel (Woodpecker) radar. The idea is to capitalize on Chernobyl's dark mystery and at the same time to demystify, "through transparency", nuclear energy and long-terms effects of Chernobyl.[754] The number of visitors to the CEZ went from

748 - SSE ChNPP, "Industrial complex for solid radioactive waste management (ICSRM)", Chornobyl NPP, 20 July 2021, see https://chnpp.gov.ua/en/187-projects/completed-projects/438-2010-09-13-07-24-49438, accessed 3 August 2021.

749 - Cabinet of Ministers of Ukraine, "Directive of the Cabinet of Ministers of Ukraine No. 385 On the Adoption of the Concept of State Economic Program for the Management of Spent Nuclear Fuel of the Domestic Nuclear Power Plant for the Period until 2024", 5 June 2019, see https://zakon.rada.gov.ua/laws/show/385-2019-%D1%80#Text, accessed 28 May 2021.

750 - Ibidem. Ukraine is assessing the possibility of reprocessing spent nuclear fuel at France's Orano la Hague facility, see IPFM, "Ukraine to Explore Reprocessing Its Spent Fuel in France", last modified 3 May 2018, see http://fissilematerials.org/blog/2018/05/ukraine_to_explore_reproc.html, accessed 8 June 2021.

751 - Verkhovna Rada, "Про Загальнодержавну програму зняття з експлуатації Чорнобильської АЕС та перетворення об'єкта 'Укриття' на екологічно безпечну систему " ["Law of Ukraine No. 886-VI – On the National Program for Chornobyl NPP Decommissioning and Shelter Transformation into an Ecologically Safe System'"], Parliament of Ukraine, Approved 15 January 2009, Amended as of 1 January 2019, see https://zakon.rada.gov.ua/laws/show/886-17#Text, accessed 29 May 2021.

752 - Ibidem.

753 - Ibidem.

754 - Ministry of Ecology and Natural Ressources of Ukraine, "Chonobyl' staie brendom - v Ukraiini vpershe stvoreno logotyp zony vidchuzhennia [Chernobyl becomes a brand - a logo for the exclusion zone is created in Ukraine]", 19 February 2021 (in Ukrainian), see https://mepr.gov.ua/news/36869.html, accessed 29 May 2021.

under 1,000 in 2004 to nearly 200,000 in 2019.[755] The Ukrainian government seeks UN World Heritage status for the Chernobyl Exclusion Zone, hoping this would boost annual number of visitors to one million.[756]

The tourism campaign is under heavy criticism from scientists. The CEZ remains one of the most radiologically contaminated places on Earth. The influx of tourists not only risks exposing thousands to radioactive dust, hot particles,[757] and contaminated plants, but also disturbs the unique environment, in which scientists have been conducting research into longitudinal effects of radiation on the flora and fauna.[758]

Another area of development is conservation. The removal of the human population from the Chernobyl zone and the subsequent restricted human access resulted in the return of wildlife, including elk, wild boar, deer, and wolves.[759] Indeed, some endangered species have been introduced to the CEZ for conservation purposes, including the European bison and the Przewalski wild horse.[760] In 2016, a presidential decree established the Chernobyl Radiation and Ecological Biosphere Reserve, straddling the border with Belarus.[761]

Some researchers dispute the "booming wildlife" thesis, however, and find evidence of a negative correlation between the size of animal populations and their exposure to ionizing radiation. While depopulation of the CEZ might have allowed some wildlife to return to Chernobyl, its abundance is significantly tempered by radiation effects.[762] In addition, studies using meta-analysis of datasets across some 30 species, found an unusually high rate of radiation-related genetic mutation, with plants showing higher rates than animals.[763] The study suggests that transgenerational population-wide effect of radioactive contamination could be significant, possibly in humans as well.

Wildfires, once a rarity, have become more frequent in the CEZ, most of them started by arsonists. Particularly intensive wildfires raged in the zone in April 2020, reactivating radionuclides and sending radiation levels soaring.[764] With the area becoming dryer due

755 - Tom Anstey, "A record number of people are visiting Chernobyl and Ukraine's government is planning to welcome even more", *Planet Attractions*, 28 January 2021, see https://www.planetattractions.com/news/A-record-number-of-people-are-visiting-Chernobyl-and-Ukraine%E2%80%99s-government-is-planning-to-welcome-even-more/186, accessed 17 May 2021.

756 - Ibidem.

757 - Plutonium particles are of particular concern as the inhalation of a particle of several millionth of a gram can lead to lung cancer. Plutonium cannot be detected by Geiger counters and dosimeters.

758 - Katie Mettler, "Ukraine Wants Chernobyl To Be a Tourist Trap. But Scientists Warn: Don't Kick Up Dust", *The Washington Post*, 12 July 2019, see https://www.washingtonpost.com/travel/2019/07/12/ukraine-wants-chernobyl-be-tourist-trap-scientists-warn-dont-kick-up-dust/, accessed 17 May 2021.

759 - T.G. Deryabina, S.V. Kuchmel et al., "Long-Term Census Data Reveal Abundant Wildlife Populations at Chernobyl", *Current Biology Magazine*, Vol. 25, Issue 19, 5 October 2015, PP. R824–R826.

760 - Peter E. Schlichting, Valery Dombrovski and James C. Beasley, "Use of Abandoned Structures by Przewalski's Wild Horses and Other Wildlife in the Chernobyl Exclusion Zone", *Mammal Research*, Vol. 65, No. 1, 14 August 2019, January 2020, pp. 161–165.

761 - The Chernobyl Radiation and Ecological Biosphere Reserve, "Чорнобильський радіаційно-екологічний біосферний заповідник" ["Chernobyl Radiation and Ecological Biosphere Reserve"], Undated, see https://www.zapovidnyk.org.ua/index.php?fn=novp&f=php&pid=2019-04-16-19-58-58-9209, accessed 17 May 2021.

762 - Karine Beaugelin-Seiller, Jacqueline Garnier-Laplace et al., "Dose reconstruction supports the interpretation of decreased abundance of mammals in the Chernobyl Exclusion Zone", *Scientific Reports*, Vol. 10, No. 1, 21 August 2020, see https://www.nature.com/articles/s41598-020-70699-3, accessed 8 June 2021.

763 - Anders Pape Møller and Timothy A. Mousseau, "Strong effects of ionizing radiation from Chernobyl on mutation rates", *Scientific Reports*, Vol. 5, No. 1, 10 February 2015.

764 - Jane Braxton Little, "Forest Fires Are Setting Chernobyl's Radiation Free", *The Atlantic*, 10 August 2020, see https://www.theatlantic.com/science/archive/2020/08/chernobyl-fires/615067/, accessed 17 May 2021.

to climate change and increased human traffic in the CEZ, chances of wildfires are likely to increase in the future.[765]

SAUEZM has also advertised the CEZ as an attractive site for investment in renewable energy, particularly solar, leveraging the legacy power storage and transmission infrastructure and the low cost of land.[766] While the aim is laudable, Ukraine's energy sector governance, incentive structure for developing renewables, and regulatory environment remain unfavorable and are not designed to serve any solar power ambitions in the CEZ.[767]

OFFSITE CHALLENGES

The long-term social, health, and environmental effects of Chernobyl are as profound as they are diffuse and remain a matter of ongoing research and contention. Some 100 radioactive isotopes were released into the environment as a result of the Chernobyl accident, the most radiologically relevant of which are iodine-131, strontium-90, caesium-137, and plutonium-239, -240, and -241. While the half-life of iodine-131 is only 8 days, strontium-90 and caesium-137 have a half-life of 29 and 30 years respectively, and plutonium-239—24,000 years. Plutonium contamination is largely concentrated in the area close to the accident site, where the concentration of plutonium in the soil is higher than that attributed to nuclear weapons test fallout, for instance, from the former Semipalatinsk test range in Kazakhstan.[768] Other radioactive elements were carried far and wide by the prevailing winds and deposited on soil and vegetation by the rains. According to various estimates, about 40 percent of European territory has been contaminated by caesium-137, potentially affecting some 400 million people.[769]

As of 2004, nearly 8.4 million people were exposed to the Chernobyl radiation in Belarus, Russia, and Ukraine.[770] Some 120,000 people have been resettled from the highly contaminated area immediately after the accident, and a further 220,000 in subsequent years.[771] Twenty years after the accident, some 5 million people, including 1 million children, were still living in contaminated areas in the former Soviet Union, including 270,000 in "strict control zones,"

765 - Ibidem.

766 - SAUZEM, "Investytsiynyy proekt Chornobyl Solar" ["Investment Project Chernobyl Solar"], 31 October 2016 (in Ukrainian), see http://dazv.gov.ua/vidnovliuvana-enerhetyka/investitsijnij-proekt-chornobyl-solar-yakim-peredbacheno-budivnitstvo-parku-sonyachnoji-energetiki-u-zoni-vidchuzhennya.html, accessed 17 May 2021.

767 - Sergej Sumlenny, "Eine Riesenverschuldung gegenüber den Erneuerbaren: Selenskyjs Energiepolitik könnte katastrophale Folgen für die Ukraine haben" ["A gigantic debt towards renewables: Zelenskyi's Energy Policy Could Have Catastrophic Consequences for Ukraine"], Heinrich-Böll Foundation, in *Ukraine-Analysen*, 17 February 2021 (in German), Issue 246, see https://laender-analysen.de/ukraine-analysen/246/eine-riesenverschuldung-gegenueber-den-erneuerbaren-selenskyjs-energiepolitik-koennte-katastrophale-folgen-fuer-die-ukraine/, accessed 28 May 2021.

768 - Yasuyuki Muramatsu, Werner Rühm et al., "Concentrations of ^{239}Pu and ^{240}Pu and Their Isotopic Ratios Determined by ICP-MS in Soils Collected from the Chernobyl 30-km Zone", *Environmental Science & Technology*, Vol. 34, No. 14, 1 July 2000.

769 - European Commission, "Atlas of Caesium Deposition on Europe After the Chernobyl Accident", 1998, see https://op.europa.eu/fr/publication-detail/-/publication/110b15f7-4df8-49a0-856f-be8f681ae9fd, accessed 27 June 2021; and Ian Fairlie, "TORCH-2016 – The Other Report on Chernobyl – An Independent Evaluation of the Health-Related Effects of the Chernobyl Nuclear Disaster", Version 1.1, 31 March 2016, see https://www.ianfairlie.org/wp-content/uploads/2016/03/chernobyl-report-version-1.1.pdf, accessed 8 June 2021.

770 - UN-OCHA, "Chernobyl: Needs Remain Great 18 Years After Nuclear Accident", United Nations Office for the Coordination of Humanitarian Affairs, Press Release, IHA/896, 26 April 2004, see https://www.un.org/press/en/2004/iha896.doc.htm, accessed 9 June 2021.

771 - The Chernobyl Forum, "Chernobyl's Legacy: Health, Environmental and Socio-Economic Impacts and Recommendations to the Governments of Belarus, the Russian Federation and Ukraine", The Chernobyl Forum: 2003–2005, IAEA, April 2006, pp. 10–11, see https://hps.org/documents/chernobyl_legacy_booklet.pdf, accessed 17 May 2021.

although since, the number likely decreased due to low birth rates and population outflow.[772] Some 600,000 had been registered as liquidators, people who have participated in dealing with the aftermath of the accident in 1986–1989, 240,000 of whom worked directly in mitigation activities at the reactor and in the exclusion zone.[773] Many of these people received high initial doses of radiation, others sustained long-term exposure to low-dose radiation, but at levels well above normal.

Officially, the death toll of the world's worst nuclear accident is astonishingly low. Prior to 2005 only some 50 deaths were directly attributed to the accident: 28 people, firemen and cleanup crew, perished from acute radiation sickness in the first three months after the accident, two died from injuries sustained in the explosion, the other 20 or so died over the next months and years.[774]

The long-term health effects among exposed populations—cancers, cataracts, diseases of the cardiovascular and digestive systems—are vastly more widespread and more difficult to estimate given that they have and will unfold over decades and over generations. So are the psychological effects of Chernobyl.

In 2006, a number of reports, prepared under UN auspices, estimated that the Chernobyl accident will result in some 9,000 excess cancer deaths—4,000 in Belarus, Russia, and Ukraine and 5,000 outside of the former Soviet Union—from radiation-induced cancers.[775] These mortality figures have been disputed as overly conservative by a number of independent experts.[776] According to the analysis of prominent U.S. nuclear physicist Richard Garwin, based on the overall radiation release and per capita exposure, the real death toll would likely be closer to 24,000.[777] A 2009-report by a team of Russian and Belarussian scientists claimed that Chernobyl's death toll from radiation-related diseases would surpass 200,000 in Europe

772 - UN-OCHA, "Chernobyl: Needs Remain Great 18 Years After Nuclear Accident", 26 April 2004, op. cit.; and The Chernobyl Forum, "Chernobyl's Legacy: Health, Environmental and Socio-Economic Impacts and Recommendations to the Governments of Belarus, the Russian Federation and Ukraine", April 2006, op. cit.

773 - Burton Bennett, Michael Rapacholi and Zhanat Carr, "Health Effects of the Chernobyl Accident and Special Health Care Programmes", Report of the UN Chernobyl Forum, Expert Group "Health", World Health Organization, 2006.

774 - IAEA, "Frequently Asked Chernobyl Questions", International Atomic Energy Agency, 7 November 2016, see https://www.iaea.org/newscenter/focus/chernobyl/faqs, accessed 17 May 2021; and United Nations, "Chernobyl: The True Scale of the Accident – 20 Years Later, UN Report Provides Definitive Answers, Ways to Repair Lives", Press Release, 6 September 2005, see https://www.un.org/press/en/2005/dev2539.doc.htm, accessed 29 June 2021.

775 - The Chernobyl Forum, "Chernobyl's Legacy: Health, Environmental and Socio-Economic Impacts and Recommendations to the Governments of Belarus, the Russian Federation and Ukraine", op. cit.; and Bennett, Rapacholi and Carr, "Health Effects of the Chernobyl Accident and Special Health Care Programmes", WHO, 2006, op. cit. See also UN, "UN issues landmark health report on Chernobyl: excess cancer cases, deaths", Press Release, 18 April 2006, see https://news.un.org/en/story/2006/04/175672-un-issues-landmark-health-report-chernobyl-excess-cancer-cases-deaths, accessed 29 June 2021; and UN, "Chernobyl: The True Scale of the Accident", 6 September 2005, see https://www.un.org/press/en/2005/dev2539.doc.htm, accessed 17 May 2021; and WHO, "World Health Organization report explains the health impacts of the world's worst-ever civil nuclear accident", 26 April 2006, see https://www.who.int/mediacentre/news/releases/2006/pr20/en/, accessed 9 June 2021.

776 - Ian Fairlie and David Sumner, "The Other Report on Chernobyl (TORCH) – An Independent Scientific Evaluation of Health and Environmental Effects 20 Years after the Nuclear Disaster Providing Critical Analysis of a Recent Report by the International Atomic Energy Agency (IAEA) and the World Health Organisation (WHO)", 6 April 2006; and op. cit. Ian Fairlie, "TORCH-2016 – The Other Report on Chernobyl – An Independent Evaluation of the Health-Related Effects of the Chernobyl Nuclear Disaster", March 2016.

777 - Richard L. Garwin, "Outside View: Chernobyl's real toll", *UPI*, 9 November 2005, see https://www.upi.com/Defense-News/2005/11/09/Outside-view-Chernobyls-real-toll/35281131572398/, accessed 17 May 2021.

and approach 20,000 in the rest of the world.[778] While the report met a critical reception, the authors' claim that the Soviet regime intentionally obscured real numbers in the three years following the accident, has much credence, as does the emphasis on the long gestation period of many radiation-induced illnesses. Other independent reports estimate expected death toll from radiogenic cancers alone at 40,000 globally over the next 50 years.[779]

Thyroid cancer, caused by the absorption of radioactive iodine primarily in children and adolescents, remains a major health risk for the populations of Belarus, Ukraine, and the four most contaminated regions of Russia. Between 1991 and 2005, some 6,800 cases of thyroid cancer were diagnosed among those who were under 18 in 1986, an incidence much higher than the rate among the average population.[780] The latest UN study on the subject found an increase in thyroid cancer cases in the same group over the period 1991–2015 of almost 20,000 cases, with incidence among females four times higher than among males.[781] Although thyroid cancer is treatable by surgery and medication with a resulting survival rate of 99 percent,[782] the physical and psychological toll of illness and treatment on children and their families is one of the real costs that evades death statistics.

The long-term transgenerational effects of continued exposure to radioactive elements are among the most hotly contested consequences of Chernobyl. A recent study of some 130 children born to parents involved in the Chernobyl cleanup found no transgenerational effects of exposure to radiation.[783] These findings are contradicted by many studies by scientists from the National Academies of Science of Ukraine and Belarus that demonstrate a rise in chromosomal disorders and congenital anomalies among children born to or aborted by women from contaminated areas in the former Soviet Union.[784]

The extent of transgenerational effects of radiation exposure might be obscured by the high rates of abortions among exposed women. The IAEA estimated that between 100,000 and 200,000 abortions were related to Chernobyl radiation concerns in the year following the accident in Western Europe alone.[785] While data are sparse for the former Soviet Union, the

778 - Alexey B. Nesterenko, Vassily B. Nesterenko and Alexey V. Yablokov, "Chapter II. Consequences of the Chernobyl Catastrophe for Public Health" in "Chernobyl Consequences of the Catastrophe for People and the Environment", *Annals of the New York Academy of Sciences*, Volume 1181, Issue 1, 30 November 2009. These widely different estimates of the Chernobyl radiation-related deaths stem from a disagreement about the linear no-threshold hypothesis of radiation impact, that is, whether the harmful effects of the radiation are proportional to the dozes receives, or whether below a certain threshold, low doses of radiation cease to be harmful.

779 - Ian Fairlie, "TORCH-2016 – An Independent Scientific Evaluation of the Health-Related Effects of the Chernobyl Nuclear Disaster", March 2016, op. cit.

780 - UNSCEAR, "Evaluation of Data on Thyroid Cancer in Regions Affected by the Chernobyl Accident – A White Paper To Guide the Scientific Committee's Future Programme of Work", United Nations Scientific Committee on the Effects of Atomic Radiation, 2018, see http://www.unscear.org/docs/publications/2017/Chernobyl_WP_2017.pdf, accessed 8 June 2021.

781 - Ibidem, v, 9. Although some of increase is attributed to the increased spontaneous rate of thyroid cancer due to the aging of the cohort, as well as to the improved diagnostic techniques, the fraction attributed to radiation exposure is estimated at 60 percent for those evacuated and 25 percent for non-evacuated. Ibidem, 12.

782 - The United Nations, "Chernobyl: The True Scale of the Accident", 6 September 2005, op. cit.

783 - Meredith Yeager, Mitchell J. Machiela et al., "Lack of transgenerational effects of ionizing radiation exposure from the Chernobyl accident", *Science*, Vol. 372, Issue 6543, 14 May 2021.

784 - G. Lazjuk, P. Verger et al., "The congenital anomalies registry in Belarus: a tool for assessing the public health impact of the Chernobyl accident", *Reproductive Toxicology*, Volume 17, Issue 6, November–December 2003, pp. 659–666; and O.F. Vozianov, V.G. Bebeshko and D.A. Vazyka, "Medychni Naslidky Avarii na Chornobyl's'kii Atomnii Elektrostantsii" ["Medical Consequences of the Accident at the Chernobyl Nuclear Power Plant"], National Research Center for Radiation Medicine of the National Academy of Medical Sciences of Ukraine, 2007.

785 - *The Journal of Nuclear Medicine*, "Lessons of Chernobyl: SNM Members Try to Contaminate World Threatened by Fallout", Part II, Vol. 28, No. 6, June 1987, p.6, see https://jnm.snmjournals.org/content/jnumed/28/6/933.full.pdf, accessed 10 June 2021.

incidence of Chernobyl-related abortions was likely much higher, contributing to the drastic collapse of birth rates between 1986 and 1992—nearly halving in the affected areas of Belarus—with long-term demographic effects.[786] Chernobyl's impact on reproductive health continues: a recently published study of exposed women who emigrated to Israel shows that they are more likely to be childless, have less children, undergo fertility treatment, and experience post-natal anemia than the general population.[787]

Chernobyl's consequences for public health, however, reach far beyond the direct effects of radiation exposure.[788] Psychological trauma caused by the disaster, resettlement, loss of community and livelihood, resulted in significantly higher rates of mental illness, including depression, anxiety, and substance abuse, among the population affected by Chernobyl than normal. Beyond socio-psychological trauma, there is evidence of direct neuropsychiatric effects of ionizing radiation on the brain, including cerebrovascular pathology and cognitive impairment.[789] In 2018, the Ukrainian government reported estimates that mental illness was about twice as prevalent and by some estimates suicide rates are as much as 20 times higher among the Chernobyl liquidators compared to the general population.[790] In Ukraine, 20 years after the Chernobyl disaster began, some 83 percent of the population affected by the accident had experienced some form of adverse health consequences; among the liquidators, the number is 92 percent.[791]

Economic costs of the accident for the countries of the former Soviet Union, particularly for Belarus and Ukraine, have been staggering. Fledgling nations struggling through a severe post-Soviet transitional crisis, Belarus and Ukraine allocated significant portions of their state budget to Chernobyl-related projects, benefits, and programs. Even so, they were unable to adequately address the public health and environmental crisis, compounding their negative consequences. In 1991, Chernobyl-related expenditures accounted for more than 22 percent of the Belarusian budget, a figure that gradually declined to about 6 percent in 2002.[792] Overall, Belarus spent some US$13 billion on the Chernobyl account between 1991 and 2003, a disproportionate financial burden for a nation of only 10 million.[793] Ukraine has been spending up to 15 percent of its budget in the Chernobyl-related programs in the 1990s, and up to

786 - Angelina I. Nyagy, "Health of Survivors in Ukraine in 25-Years Dynamics After the Chernobyl Catastrophe", Association 'Physicians of Chernobyl', as Presented at "The Chernobyl Catastrophe: Taking Stock of 25 Years of Ecological and Health Damages", Berlin, 4–10 April 2011; and Aleg Cherp, Angelina Nyagu et al., "The Human Consequences of the Chernobyl Nuclear Accident – A Strategy for Recovery", Report Commissioned by UNDP and UNICEF with the support of UN-OCHA and WHO, 6 February 2002, see https://www.iaea.org/sites/default/files/strategy_for_recovery.pdf, accessed 10 June 2021.

787 - Julie Cwikel, Ruslan Sergienko et al., "Reproductive Effects of Exposure to Low-Dose Ionizing Radiation: A Long-Term Follow-Up of Immigrant Women Exposed to the Chernobyl Accident", *Journal of Clinical Medicine,* 8 June 2020, see https://www.ncbi.nlm.nih.gov/pmc/articles/PMC7356322/, accessed 9 June 2021.

788 - The United Nations, "Chernobyl: The True Scale of the Accident", 6 September 2005, op. cit.

789 - K. Loganovsky, M. Bomko et al, "Mental Health and Neuropsychiatric Effects of the Chornobyl Accident – A 30 Year Aftermath and Fukushima Projections", in WHO and National Research Center for Radiation Medicine of the National Academy of Medical Sciences of Ukraine, "Health Effects of the Chornobyl Accident – 30 Years Aftermath", International Conference, 18–19 April 2016, p. 94, see https://nrcrm.gov.ua/downloads/abstracts_18_04_16.pdf, accessed 4 August 2021.

790 - Chornobyl Center, "What are the consequences of the Chornobyl accident?", 18 January 2018, see http://www.chornobyl.net/en/what-are-the-consequences-of-the-chornobyl-accident/, accessed 9 June 2021.

791 - National Research Center for Radiation Medicine of the National Academy of Medical Sciences of Ukraine, "Medychni Naslidky Avarii na Chornobyl's'kii Atomnii Elektrostantsii" ["Medical Consequences of the Accident at the Chernobyl Nuclear Power Plant"], 2007 op. cit., p.784.

792 - The Chernobyl Forum, "Chernobyl's Legacy: Health, Environmental and Socio-Economic Impacts and Recommendations to the Governments of Belarus, the Russian Federation and Ukraine", April 2006, p.33, op. cit.

793 - Ibidem.

7 percent in the 2000s.[794] From 1991 to 2015, Ukraine's expenditures on the Chernobyl account amounted to more than US$20 billion.[795]

These figures do not reflect indirect economic losses in Belarus, Russia, and Ukraine caused by the depression of economic activity in the contaminated areas, nation-wide effects on agriculture, forestry, and fishing, as well as the public health crisis. Ukraine estimated its economic losses—including heavy indirect losses (non-production in power engineering, manufacturing, agricultural, forest, water, and fishing industries, etc)—in the order of US$232 billion over the two and a half decades following the accident.[796] Countless heads of livestock and harvests of agricultural produce have been contaminated in the former Soviet Union and across Europe. For instance, immediately following the accident, the U.K. government imposed a ban on slaughter and movement of sheep, affecting some 9,700 farms and 4 million sheep, in Cumbria, Scotland, Northern Wales, and Northern Ireland.[797] The controls have been fully lifted only in 2012.[798] In southern Germany, wild game and mushrooms are still found contaminated with caesium-137 to several times the legal limits for sales.[799] The government of Saxony still requires all wild boar hunted for sale to be tested for caesium-137; in 2014, one in three boars was still found too radioactive to consume.[800]

Finally, there are irreversible cultural losses inflicted by the disaster. The Chernobyl site is situated in the Polissya, an isolated marshy region straddling northern Ukraine and southern Belarus. Polissya's relative remoteness, lack of urbanization and industrialization—save for the nuclear power plant—allowed for the preservation of archaic rural cultural practices and artifacts. Much of this cultural tradition has been lost as communities disintegrated and settlements were abandoned. A few dedicated ethnographers, like Rostyslav Omeliashko, launched expeditions to record the local dialects, oral traditions, and cultural practices from residents who remained in or returned to the CEZ and from those who had been resettled, as well as collect material relicts.[801] Due to their efforts, much been rescued from oblivion and preserved as museum pieces and ethnographic collections. Still, a unique bit of world cultural heritage has been wiped out by the Chernobyl explosions forever.

794 - Ibidem.

795 - Tetiana Yarmoshchuk, "Na likvidatsiiu 'Chornobylia' Ukraiina vtratyla tsilyi richnyi biudzhet" ["Ukraine spent its entire annual budget on Chernobyl"], *Radio Liberty*, 14 April 2016, see https://www.radiosvoboda.org/a/27673107.html, accessed 10 June 2021.

796 - Ministry of Ukraine for Emergencies, "Twenty-five Years after Chornobyl Accident: Safety for the Future", National Report of Ukraine, 2011, see http://www.chernobyl.info/Portals/0/Docs/ua-25-chornobyl-angl-c.pdf, accessed 9 June 2021.

797 - Steve Wearne, "The Removal of Post-Chernobyl Sheep Controls", UK Food Standards Agency, FSA 12/03/06, 20 March 2012, see https://www.food.gov.uk/sites/default/files/media/document/fsa120306.pdf, accessed 10 June 2021.

798 - *BBC News*, "Post-Chernobyl disaster sheep controls lifted on last UK farms", 1 June 2012, see https://www.bbc.com/news/uk-england-cumbria-18299228, accessed 10 June 2021.

799 - BfS, "Radioactive contamination of mushrooms and wild game", German Federal Office for Radiation Protection, Undated, see https://www.bfs.de/EN/topics/ion/environment/foodstuffs/mushrooms-game/mushrooms-game.html, accessed 14 June 2021.

800 - Ministry for Energy, Climate Protection, Environment and Agriculture of Saxony, "Radiocäsiumbelastung von Wildschweinfleisch" ["Radiocesium contamination of wild boar meat"], Undated, see http://www.wald.sachsen.de/radiocaesiumbelastung-von-wildschweinfleisch-4538.html, accessed 10 June 2021; and Rachel Nuwer, "Radioactive Boars Are Roaming Around Germany", *Smithsonian Magazine*, 2 September 2014, see https://www.smithsonianmag.com/smart-news/radioactive-boars-are-roaming-around-germany-180952586/, accessed 10 June 2021.

801 - Kate Brown, "A Historian in the Dead Zone", *The Chronicle of Higher Education*, 23 September 2005, see https://www.chronicle.com/article/a-historian-in-the-dead-zone/, accessed 29 May 2021.

NUCLEAR POWER AND CRIMINAL ENERGY

INTRODUCTION

Recent events shed light on ways in which criminality affects the nuclear industry. Three major corruption scandals involving American nuclear energy companies made headlines in 2020. In South Carolina, SCANA Corporation, its subsidiary South Carolina Electric & Gas and members of their senior management were prosecuted amid allegations of fraud in the failed VC Summer nuclear expansion project[802]. The other two cases involved two companies in Illinois and Ohio, Exelon's subsidiary Commonwealth Edison (ComEd) and FirstEnergy Solutions respectively, both of which were accused of bribing congressmen to pass pro-nuclear legislation and obtain state subsidies[803]. While ComEd paid a fine to settle with Illinois federal charges and SCANA pleaded guilty to fraud charges in South Carolina, investigations in Ohio are still ongoing.

Criminality in the nuclear energy sector, like in the corporate world at large, has taken the shape of corrupt practices such as bribery and fraud. Other notable large-scale corruption cases have taken place across all regions of the world, and this phenomenon can be traced back to the late 1980s, as exemplified with the Transnuklear Affair which involved several actors from the nuclear industry across Europe in a bribery and nuclear-waste trafficking scheme. Parliamentary Enquiry Commissions were established in Belgium, Germany[804], and in the European Parliament[805].

In addition to corruption, the involvement of organized crime groups as well as incidents, such as insider sabotage and theft, underscore other crime dimensions which affect the nuclear energy sector. Among other incidents which have taken place on nuclear sites: a Japanese Yakuza boss dispatched workers, including his own Yakuza subordinates, to nuclear power

802 - United States District Court of the District of South Carolina, "Jury Trial Demand—United States Securities and Exchange Commission v. Scana Corporation, Dominion Energy South Carolina Inc. (f/k/a South Carolina Electric & Gas Company), Kevin B. Marsh and Stephen A. Byrne", 27 February 2020, see https://www.sec.gov/litigation/complaints/2020/scana-complaint-022720.pdf, accessed 26 August 2021.

803 - Dan Gearino, "Illinois and Ohio Bribery Scandals Show the Perils of Mixing Utilities and Politics", *Inside Climate News*, 26 July 2020, see https://insideclimatenews.org/news/26072020/ohio-illinois-bribery-scandals-utilities-climate-change-commonwealth-edison-firstenergy-householder/; and Cassandra Jeffery and M. V. Ramana, "Big money, nuclear subsidies, and systemic corruption", *Bulletin of the Atomic Scientists*, 12 February 2021, see https://thebulletin.org/2021/02/big-money-nuclear-subsidies-and-systemic-corruption/, both accessed 7 June 2021.

804 - Deutscher Bundestag, "Kernenergie auf dem Prüfstand: Sichere Energiequelle oder nicht beherrschbares Risiko? Bericht des 2. Untersuchungsausschusses der 11. Wahlperiode des Deutschen Bundestages ('Transnuklear/Atomskandal')", Bd. 1 and 2, 1991.

805 - Gerhard Schmid, "Report drawn up on behalf of the Committee of Inquiry on the handling and transport of nuclear material – On the result of the Enquiry", European Parliament Working Documents, 24 June 1988; and Mycle Schneider, "Transnuklearaffäre—Über die Arbeit des Untersuchungsausschusses im EP", November 1988.

plant construction sites all over Japan from as early as 2007[806]; there have also been recent insider sabotage cases in Belgium[807] as well as cases of material theft in Russia[808].

Fraudulent and criminal activities in the nuclear industry entail significant potential and real consequences for the public. Corruption and associated rent-seeking behaviors can also affect safety and security within nuclear power plants[809]. Furthermore, bribery- and fraud-cases such as those in South Carolina, Illinois and Ohio increase the capital- and production-costs of nuclear energy, which either the rate- or the taxpayer pays for.[810] As Richard Tanter, Professor at the University of Melbourne, puts it, "[w]idespread corruption of the nuclear industry has profound social and political consequences resulting from the corrosion of public trust in companies, governments, and energy systems themselves".[811]

Following a literature review on criminality in the nuclear energy sector, this chapter elaborates upon a typology of prominent illegal practices in the nuclear industry, focusing on bribery of public and company officials, as well as fraud cases relating to counterfeit or fraudulent items.

The first part of the chapter focuses on cases that have been investigated and/or have come to trial between 2010 and 2020, either involving companies from or having taken place in the 2020 Top-8 nuclear power fleets (by operating capacity), the United States, France, China, Russia, South Korea, Canada, Ukraine, and Japan.

The second part of the chapter provides, without any specific timeframe, a cross-country comparison of events involving sabotage and organized crime on nuclear power plant sites in Japan, Russia, and the U.S.

In addition to its constrained geographical focus and timeframe, this chapter is limited in other ways. Firstly, the analyzed cases represent only a fraction of the events having occurred in the selected countries. Additionally, the second section examines cases of insider attacks, and threats targeting nuclear power plants specifically, thereby excluding all outsider attacks and all fuel chain facilities, from uranium processing to plutonium separation plants. While, as illustrated in the following literature review, nuclear terrorism and cyber-attacks represent an identified, increasing threat to the industry, they are not examined in this first analysis. Finally, considering that this review relies on open-source information and focuses primarily on confirmed cases, it offers only incomplete information and most likely constitutes an underestimation of the phenomenon.

806 - Jake Adelstein, "How the Yakuza and Japan's Nuclear Industry Learned to Love Each Other", *The Atlantic*, 24 May 2012, see https://www.theatlantic.com/international/archive/2012/05/how-yakuza-and-japans-nuclear-industry-learned-love-each-other/327691/, accessed 7 June 2021.

807 - Thomas Hegghammer and Andreas Hoelstad Daehli, "Insiders and Outsiders: a Survey of Terrorist Threats to Nuclear Facilities", in Matthew Bunn and Scott D. Sagan (eds.), "Insider Threats", 2017, *Cornell University Press*.

808 - Alex P. Schmid and Robert Wesley, "Possible Causes and Motives of Nuclear and Radiological Terrorism in the Light of Empirical Data on Smuggling Incidents of Nuclear Materials", in Jeff Victoroff (ed.), "Tangled Roots: Social and Psychological Factors in the Genesis of Terrorism", 2006, *IOS*.

809 - Mihály Fazekas, Zsolt Főző and István János Tóth, "The Corruption Risks of the Nuclear Power Plants: What Can We Expect in Case of Paks II?", Corruption Research Center Budapest, on behalf of Energiaklub Climate Police Institute and Applied Communications, October 2014, see https://energiaklub.hu/files/study/corruption_risks_paks2.pdf, accessed 26 June 2021.

810 - Cassandra Jeffery and M. V. Ramana, "Big money, nuclear subsidies, and systemic corruption", *Bulletin of the Atomic Scientists*, 12 February 2021, op. cit.; and Dan Gearino, "Illinois and Ohio Bribery Scandals Show the Perils of Mixing Utilities and Politics", *Inside Climate News*, 26 July 2020, op. cit.

811 - Richard Tanter, "After Fukushima: A Survey of Corruption in the Global Nuclear Power Industry", *Asian Perspective*, *Johns Hopkins University Press*, Vol. 37, No. 4, October–December 2013, see https://www.researchgate.net/publication/286345864_After_Fukushima_A_Survey_of_Corruption_in_the_Global_Nuclear_Power_Industry, accessed 29 August 2021.

LITERATURE REVIEW

Research on the topic of criminality in the nuclear energy sector has mainly focused on the threat of a terrorist attack on nuclear facilities. Experts have assessed possible scenarios of outsider and insider attacks perpetuated at various types of nuclear sites[812], especially those producing and/or storing weapon-grade materials[813]. Armed assaults, sabotage and plane-crash scenarios specifically targeting nuclear infrastructures have become a growing concern since 9/11 for experts and governments alike.[814] Similarly, academic research has looked into the threat of cyber-attacks targeting nuclear facilities (probability assessments and recommendations on how to counter the threat).[815] The U.S.-based organizations, the National Consortium for the Study of Terrorism and Responses to Terrorism (START) and the Nuclear Threat Initiative (NTI) have developed databases gathering verified information on 80 confirmed physical attacks on nuclear facilities between 1961 and 2014 and 23 cyberattacks between 1990 and 2016 targeting the nuclear energy sector.[816]

There has also been scholarly interest for the topic of nuclear trafficking with research relying upon the International Atomic Energy Agency (IAEA)'s Incident and Trafficking Database (ITDB) factsheets, the academic Database on Nuclear Smuggling, Theft and Orphan Radiation Sources (DTSO) and the Center for Nonproliferation Studies (CNS)' Global Incidents and Trafficking Database—the latter being the only publicly available database on the matter.

According to the latest IAEA ITDB factsheet, the database has recorded 3,686 confirmed incidents between 1993 and 31 December 2019, all reported by some of the currently 139 participating States; there were 290 incidents classified as "confirmed or likely act of trafficking or malicious use", 1,023 incidents for which a link with trafficking/malicious use cannot be established nor excluded, and 2,373 cases unrelated to trafficking/malicious use.[817]

Science writer Richard Stone has described the post-Cold War trafficking phenomenon as a "real and dangerous" issue in the Black Sea Region.[818] He and other scholars, including Louise Shelley, Robert Orttung, William Potter and Elena Sokova, pointed out that well-organized, transnational, criminal groups engage in nuclear and radioactive materials

812 - Thomas Hegghammer and Andreas Hoelstad Daehli, "Insiders and Outsiders: a Survey of Terrorist Threats to Nuclear Facilities," 2017, op. cit.

813 - Matthew Bunn and Dmitri Kovchegin, "Nuclear Security in: Can Progress be Sustained?", *Nonproliferation Review*, Vol. 24, No. 5-6, 2018, pp. 527-551.

814 - Eric Guéret, "Sécurité nucléaire : le grand mensonge", *Arte France*, 2015 ; and French National Assembly, "Rapport fait au nom de la Commission d'enquête sur la sûreté et la sécurité des installation nucléaires", Report prepared on behalf of the Commission of inquiry on nuclear safety and security, submitted 28 June 2018 (in French), see https://www.assemblee-nationale.fr/dyn/15/rapports/cenucl/l15b1122-ti_rapport-enquete, accessed 26 June 2021.

815 - Julian Rrushi and Roy Campbell, "Detecting Cyber Attacks On Nuclear Power Plants", University of Illinois, in International Conference on Critical Infrastructure Protection, "Critical Infrastructure Protection II", edited by Mauricio Papa and Sujeet Shenoi, *Springer US*, 2008; also Jong Woo Park and Seung Jun Lee, "Probabilistic safety assessment-based importance analysis of cyber-attacks on nuclear power plants", *Nuclear Engineering and Technology*, vol. 51, no. 1, February 2019, pp. 138–145.

816 - START, "Nuclear Facilities Attack Database (NuFAD)", National Consortium for the Study of Terrorism and Responses to Terrorism, Undated, see https://www.start.umd.edu/nuclear-facilities-attack-database-nufad; and NTI, "References for Cyber Incidents at Nuclear Facilities", Nuclear Threat Initiative, see https://www.nti.org/analysis/tools/table/133/, both accessed 7 June 2021.

817 - IAEA, "IAEA Incident and Trafficking Database (ITDB) – Incidents of nuclear and other radioactive material out of regulatory control", 2020 Fact Sheet, 2020 see https://www.iaea.org/sites/default/files/20/02/itdb-factsheet-2020.pdf, accessed 12 June 2021.

818 - Richard Stone, "Nuclear Trafficking: 'A Real and Dangerous Threat'", *Science*, vol. 292, Issue 5522, 1 June 2001, pp. 1632–1636.

trafficking.[819] Nonetheless, data collected by CNS since 2013 does not include theft incidents having taken place at nuclear power plants. Considering that only a small number of countries consistently report these incidents (i.e. Russia and former Soviet Republics do not), the evolution of this issue cannot be evaluated.

Finally, the topic of corruption in the nuclear industry has received limited attention. While this is the first time the WNISR is devoting an entire chapter to criminal activities in the nuclear industry, the WNISR has regularly mentioned major corruption cases in various places around the world. WNISR2020, for example, features "corrupt" 14 times in connection with corruption cases involving nine countries on four continents.[820]

Richard Tanter appears to be the only scholar having documented cases of corruption in this sector on a global scale; however, his analysis covers only a short period of time, that is 2012 to mid-2013.[821] Tanter has found that "major corruption incidents occurred in the nuclear power industry in every country currently seeking to export nuclear reactors: the United States, Canada, Japan, South Korea, Russia, France, and China".[822] These are also seven of the Top-8 nuclear power fleets.

Other journalists and experts have also investigated corruption in the nuclear industry at national levels in China[823], Japan[824], Russia[825], South Korea[826], and the U.S.[827]. Overall, this research identifies some specific factors facilitating corrupt practices in the nuclear industry: the special status of the nuclear industry in nuclear weapon countries and the tradition of restricted access to information,[828] exceptional corporate-governance rules undermining

819 - Louise Shelley and Robert Orttung, "Criminal acts: How organized crime is a nuclear smuggler's new best friend", *Bulletin of the Atomic Scientists*, vol. 62, no. 5, 2006, pp. 22–23, see https://journals.sagepub.com/doi/full/10.2968/062005007, accessed 31 August 2021; and William Potter and Elena Sokova, "Illicit nuclear trafficking in the NIS: What's new? What's true?", *The Nonproliferation Review*, vol. 9, no. 2, 2002, pp. 112–120.

820 - Bangladesh, Brazil, Canada, India, Japan, Mexico, South Korea, Slovakia, U.S.

821 - Richard Tanter, "After Fukushima: A Survey of Corruption in the Global Nuclear Power Industry", University of Melbourne, published in *Asian Perspective*, vol. 37, no. 4, October 2013, pp. 475–500; Richard Tanter, "Nuclear corruption 2012 to date", *Nautilus Peace and Security Weekly Report*, 4 July 2012, see https://nautilus.org/napsnet/napsnet-policy-forum/nuclear-corruption-2012-to-date/, accessed 22 June 2021.

822 - Richard Tanter, "After Fukushima: A Survey of Corruption in the Global Nuclear Power Industry", 2013, op. cit.

823 - Qiang Wang and Xi Chen, "Regulatory transparency—How China can learn from Japan's nuclear regulatory failures?", *Renewable and Sustainable Energy Reviews*, vol. 16, no. 6, 2012, pp. 3574–3578.

824 - Qiang Wang and Xi Chen, "Regulatory failures for nuclear safety–the bad example of Japan–implication for the rest of world", *Renewable and Sustainable Energy Reviews*, vol. 16, no. 5, June 2012, pp. 2610–2617.

825 - Andrey Ozharovsky, "Corruption: A new Russian Fukushima in the making?", Bellona, 27 September 2011, see https://bellona.org/news/russian-human-rights-issues/access-to-information/2011-09-corruption-a-new-russian-fukushima-in-the-making ; Kendra Ulrich, Jehki Harkonen and Brian Blomme, "Rosatom risks—Exposing the troubled history of Russia's state nuclear corporation", Greenpeace International, October 2014, see https://wayback.archive-it.org/9650/20200313133935/http://p3-raw.greenpeace.org/hungary/PageFiles/636986/rosatom_risks.pdf, both accessed 7 June 2021.

826 - Philip Andrews-Speed, "South Korea's nuclear power industry: recovering from scandal", *The Journal of World Energy Law & Business*, vol. 13, no. 1, March 2020, pp. 47–57; Ilchong Nam and Geoffrey Rothwell, "New Nuclear Power Industry Procurement Markets: International Experiences", Korea Development Institute, 15 December 2014, see https://www.kdi.re.kr/kdi_eng/publications/publication_view.jsp?pub_no=13874, accessed 31 August 2021.

827 - Cassandra Jeffery and M. V. Ramana, "Big money, nuclear subsidies, and systemic corruption", *Bulletin of the Atomic Scientists*, 12 February 2021, see https://thebulletin.org/2021/02/big-money-nuclear-subsidies-and-systemic-corruption/, accessed 7 June 2021.

828 - Kendra Ulrich, Jehki Harkonen and Brian Blomme, "Rosatom risks: Exposing the troubled history of Russia's state nuclear corporation", Greenpeace International, October 2014, see https://wayback.archive-it.org/9650/20200313133935/http://p3-raw.greenpeace.org/hungary/PageFiles/636986/rosatom_risks.pdf, accessed 12 June 2021.

accountability,[829] and the apparent lack of independence of regulatory authorities in many countries.[830]

The broader literature on energy policies and large projects also provides insights into other factors contributing to corrupt practices in the nuclear energy sector. One study finds bribery risks are reinforced because the oligopolistic nature of energy and infrastructure markets generates little to no competition between sellers which often creates "bilateral monopolistic" relationships between buyers and sellers.[831] Other assessments find that the long-lasting nature and the scale of these projects as well as the involvement of multiple actors, including several layers of subcontractors, further increases misuse potential.[832]

The same concerns seemingly apply to vendor and miscellaneous fraud, considering that the IAEA and the Organisation for Economic Co-operation and Development (OECD) also find that the "increased complexity and length of supply chains" are contributing factors to the presence of Counterfeit or Fraudulent Items (CFIs) on the nuclear energy market.[833] Nonetheless, the scale of this issue is hardly quantifiable. A 2016-IAEA report includes information on the experience of Canada, Slovenia, South Korea, the U.K. and the U.S. in dealing with CFIs; the 2019-edition contains an appendix with a non-exhaustive list of documents detailing cases which have involved the discovery of CFIs on the market and/or in nuclear power plants and affected at least seven countries since at least the 1990s. It also mentions that the World Association of Nuclear Operators (WANO) was made aware of 10 incidents involving fraudulent and counterfeited parts over the period 2012 to early 2016: "Eight of the ten CFI related event reports were from WANO Atlanta Centre[834] plants. WANO reported that it is likely that plants in other WANO regional centres have experienced similar issues with counterfeit parts that have not been reported."[835]

Some experts have expressed concerns about countries with widespread corruption issues.[836] In Transparency International's 2020 Corruption Perceptions Index—based upon 13 surveys and assessments from 12 independent institutions conducting research on governance and

829 - Ilchong Nam and Geoffrey Rothwell, "New Nuclear Power Industry Procurement Markets: International Experiences", KDI, December 2014, op. cit.; and Hyomin Kim, "Reconstructing the public in old and new governance: A Korean case of nuclear energy policy", *Public Understanding of Science*, April 2014.

830 - Richard Tanter, "After Fukushima: A Survey of Corruption in the Global Nuclear Power Industry", *Asian Perspective*, 2013, op. cit.; also Qiang Wang and Xi Chen, "Regulatory failures for nuclear safety–the bad example of Japan–implication for the rest of world", *Renewable and Sustainable Energy Reviews*, 2012, op. cit.

831 - Mihály Fazekas, Zsolt Főző and István János Tóth, "The Corruption Risks of the Nuclear Power Plants: What Can We Expect In Case of Paks II?", Corruption Research Center Budapest, on behalf of Energiaklub Climate Police Institute and Applied Communications, October 2014, https://energiaklub.hu/files/study/corruption_risks_paks2.pdf, accessed 26 June 2021.

832 - Neil Overy, "Nuclear energy in Africa", *New Frame*, 1 December 2020, see https://www.newframe.com/part-two-nuclear-energy-in-africa/; and Giorgio Locatelli, Giacomo Mariani et al., "Corruption in public projects and megaprojects: There is an elephant in the room!", *International Journal of Project Management*, vol. 35, no 3, April 2017, p. 252–268 see https://www.sciencedirect.com/science/article/pii/S0263786316301090, both accessed 31 August 2021.

833 - IAEA, "Managing Counterfeit and Fraudulent Items in the Nuclear Industry", *IAEA Nuclear Energy Series*, March 2019, no. NP-T-3.26, see https://www-pub.iaea.org/MTCD/Publications/PDF/P1817_web.pdf, accessed 31 August 2021.

834 - WANO Atlanta Centre is located in Atlanta, Georgia (U.S.) and provides services and assistance to WANO members in the United States, Mexico, Canada, South Africa, China, United Arab Emirates, and Romania; see WANO, "Atlanta Centre", World Association of Nuclear Operators, Undated, see https://www.wano.info/centres/atlanta-centre, accessed 1 July 2021.

835 - IAEA, "Managing Counterfeit and Fraudulent Items in the Nuclear Industry", March 2019, no. NP-T-3.26, op. cit.

836 - Trevor Findlay, "Nuclear Energy and Global Governance", Routledge, 2010; Laszlo Lovei and Alastair McKechnie, "The Costs of Corruption for the Poor—The Energy Sector", *Viewpoint*, World Bank, no. 207, 2000, see http://hdl.handle.net/10986/11437, accessed 26 June 2021; and Oleg Bukharin, "Upgrading security at nuclear power plants in the newly independent states", Princeton University, published by *The Nonproliferation Review*, vol. 4, no. 2, 1997, pp. 28–39.

business climate—18 or half of the 35 countries operating or constructing nuclear power plants on their territory rate under 50 out of 100.[837] In the Bribery Payers Index (BPI, last published in 2011), which surveys and rates the 28 world leading economies based on companies' perceived likelihood to resort to bribery when conducting business abroad, seven out of the ten worst rated countries operate or are building nuclear power plants on their territory.[838] These results are consistent with that of BPI 2008, which reads that eight of the ten worst rated[839] of 22 investigated leading economies were nuclear countries. The two worst-rated countries, both in BPI 2008 and 2011, are the 2020 Top 2nd and 4th nuclear power generating countries, China and Russia, the latter—coming in last—also currently being the leading reactor exporting country.

Overall, the literature and data on criminality in the nuclear industry is disparate. No existing study has examined it as a whole. Several articles, books, parliamentary investigations and documentaries have investigated the topics of cyberattacks, nuclear terrorism and nuclear trafficking; however, reliable data on sabotage and nuclear theft is not systematically available. While the topic of corruption has received more attention since the Fukushima accidents, it remains understudied even as bribery and fraud cases, such as those in South Carolina, Ohio and Illinois, break out. This chapter attempts to make a small and limited contribution to the literature, that of providing a broader picture of prominent forms of crimes in the nuclear energy sector, including sabotage, theft, and corrupt practices such as bribery and fraud.

TYPOLOGY OF CORRUPT PRACTICES

For this analysis, 13 cases of corrupt practices have been selected on the basis of the verifiable degree of culpability (i.e. having resulted in external/internal investigations and/or in criminal convictions) in publicly available data as involving representatives of the nuclear industry in the 2020 Top-8 nuclear power fleets (by operating capacity)—hereafter Top-8—between 2010 and 2020. This list is by no means exhaustive and focuses only on corrupt practices with a notable degree of severity (significant threats to the safety in nuclear power plants and/or to good public governance), ranging from systematic/large-scale certificate falsification to bribery of public officials.

The chapter proceeds with the analysis of common features in reviewed corrupt practices—e.g. modi operandi, motives, deficiencies in regulatory structures etc.—to select and categorize events, and in turn identify reliable patterns to understand criminality in the nuclear industry.

Fraud takes various forms; it is a holistic term.[840] The fraud subsection focuses on vendor involvement and miscellaneous cases, which have often taken the form of counterfeiting and falsification in the nuclear industry. Accordingly, while there have been cases of employee

837 - Transparency International, "Corruption Perceptions Index 2020", see https://www.transparency.org/en/cpi/2020, accessed 27 June 2021.

838 - Transparency International, "Bribe Payers Index 2011", see https://www.transparency.org/en/publications/bribe-payers-index-2011, accessed 27 June 2021.

839 - The remaining two economies were Hong Kong and Italy. The Hong Kong Nuclear Investment Company (HKNIC) owns a 25-percent share in the Daya Bay nuclear power plant that sells 80 percent of its output to Hong Kong. See HKNIC, "FAQ on Daya Bay", Undated, see https://www.hknuclear.com/DayaBay/FAQ/Pages/FAQ.aspx#q8, accessed 8 July 2021. Italy is a former nuclear country that phased out nuclear power after the Chernobyl accident.

840 - Maria Vassiljev and Lehte Alver, "Conception and Periodisation of Fraud Models: Theoretical Review", presented at the 5th International Conference on Accounting, Auditing, and Taxation (ICAAT 2016), *Atlantis Press*, December 2016, see https://www.atlantis-press.com/proceedings/icaat-16/25864767 accessed 7 June 2021.

embezzlement in the nuclear sector, these incidents are not covered in the bribery subsection unless they are specifically related to bribery.

Bribery

Nuclear Operators and Contractors

Numerous cases of nuclear utility companies, operators, and contractors in Top-8 countries involved in the nuclear procurement market and fuel chain have been documented to have resorted to bribery, primarily to acquire orders and contracts. Approximately half of the bribery schemes identified in publicly available data during this research can be categorized as company-to-company bribery.

- **International (Russia/U.S.), 2015**—Former President of U.S.-based Rosatom subsidiary TENAM Vadim Mikerin received a 4-year prison sentence for his participation in a US$2.1-million bribery scheme involving several American companies and Rosatom officials. Mikerin was the "fourth person who has been convicted or pleaded guilty in the conspiracy."[841] Between 2004 and 2014, he received kickbacks from companies such as Transport Logistics International—whose president was put on trial and convicted in 2019—in exchange for confidential information to win contracts with the Rosatom subsidiary.[842] Simultaneously, in 2009–2012, an FBI operation concluded that Mikerin attempted to obtain the property of a U.S. based company by "the wrongful use of force, violence, and fear, including fear of economic loss".[843]
- **International (Lithuania/U.S.), 2012**—U.S. company Data Systems & Solutions (DS&S) paid US$8.8 million to settle charges of bribing several Lithuania's Ignalina nuclear power plant officials, including its Director General, to secure long-term business contracts.844
- **International (China, South Korea, U.S.), 2012**—CEO and five executives of Control Component Inc. (CCI), an American control valve manufacturer, received up to 5-year prison sentences each, for making "approximately 236 corrupt payments to officers and employees of state-owned and private companies in thirty-six countries totalling approximately [U.S.]$6.85 million and earned approximately [US]$46.5 million in net profits from the sales related to those corrupt payments."[845] Korea Hydro and Nuclear Power (KHNP) and Jiangsu Nuclear Power Corporation (JNPC) in China were among the bribe recipients.

841 - Lynh Bui, "Md. man is convicted of bribing Russian official to secure business contracts", *The Washington Post*, 25 November 2019, see https://www.washingtonpost.com/local/public-safety/md-man-convicted-of-bribing-russian-official-to-secure-business-contracts/2019/11/25/3655d5bc-0d70-11ea-a49f-9066f51640f6_story.html, accessed 27 June 2021.

842 - Ibidem; also Stella Roque, "US Court Sentences Russian Nuclear Official in $2.1 Million Bribery Scheme", Organized Crime and Corruption Reporting Project, see https://www.occrp.org/en/daily/4719-us-court-sentences-russian-nuclear-official-in-2-1-million-bribery-scheme; and *RFE/RL*, "U.S. Deports Russian Man Convicted Of Nuclear Bribery Scheme", *RadioFreeEurope/RadioLiberty*, 19 May 2018, see https://www.rferl.org/a/u-s-deports-mikerin-russian-convicted-nuclear-bribery-scheme/29236937.html; both accessed 27 June 2021.

843 - United States District Court of Maryland, "Affidavit by Special Agent David Gadren, Office of Inspector General, United States Department of Energy", Signed 24 July 2014, as part of the case "United States of America v. Vadim Mikerin", Case 8:13-cr-00529-TDC, Filed 30 November 2014, see https://fcpa.stanford.edu/fcpac/documents/4000/003144.pdf, accessed 26 June 2021.

844 - Richard Tanter, "Nuclear corruption 2012 to date", *Nautilus Peace and Security Weekly Reports*, 4 July 2012, op. cit.

845 - Southern Division of the U.S. District Court for the Central District of California, "Statement of Facts", attached to "United States of America v. Control Components, Inc.—Plea Agreement" July 2009, see https://jenner.com/system/assets/assets/4224/original/United_States_v._Control_Components.pdf?1319828638, accessed 26 August 2021.

While the DS&S and CCI cases can be categorized as incidents involving companies on the supply side using bribery to secure long-term and lucrative contracts, the TENAM case illustrates the reversed scenario, which is that of a supplier requesting bribes from customers. Considering that TENAM is the only Russian uranium supplier in the U.S., this case shows how in some instances, suppliers can take advantage of the paucity of actors on the procurement market and resort to unlawful practices to make profit. Furthermore, this case also exemplifies possible consequences of the regulations governing Rosatom's procurements. Rosatom is exempted from complying with the purchase and procurement standards established by Russian Federal Law no. 94 because of its special role as a military and research complex. Rosatom and its subsidiaries' procurement activities are not subjected to external control, and Rosatom's internal set of purchase standards rules are weaker than those set up by federal law. Monitoring studies found irregularities, including in Rosatom's methods for placing orders.[846]

Accountability issues affect the nuclear industry in other Top-8 countries, including China, South Korea[847] and Ukraine[848]. For instance, the lack of transparency and scrutiny is constitutive of a bribery scandal which found its way into court in China in 2010 and involved China National Nuclear Corporation (CNNC) general manager Kang Rixin—de facto the head of the Chinese civil and military nuclear establishments—who was subsequently condemned to life in prison for embezzlement of CNY_{2009}1.8 billion ($US\$_{2020}$317 million) and corruption.[849]

Public Officials

Several recent scandals involved other Top-8 nuclear corporations and/or their executives bribing and being bribed by public officials (see KEPCO case hereunder). These bribes are offered usually with the aim to obtain/arrange contracts locally and internationally. As in Illinois and Ohio, a 2014-case disclosed in Japan involved bribes to politicians with the aim of obtaining favorable nuclear legislation over an 18-year long period between 1972 and 1990.[850]

→ **International (Ukraine/Czech Republic), Energoatom/Skoda, October 2020**—A Swiss court sentenced Mykola Martynenko, a former Ukrainian member of parliament and chair of the energy committee, to a 28-month prison term for aggravated money laundering through Swiss banks. He had received multi-million-dollar kickbacks from Czech firm

846 - Ecodefense! and Transparency International, "Анализ эффективности использования денежных средств при осуществлении деятельности по размещению заказов для нужд Государственной корпорации по атомной энергии «Росатом»" ["Analysis of the Effectiveness of Monetary Funds for the Implementation of Placement Orders for the Requirements of Rosatom (the State Corporation for Atomic Energy)"], 2010 (in Russian), see https://www.boell.de/sites/default/files/assets/boell.de/images/download_de/rosatom_final.pdf, accessed 7 June 2021.

847 - Ilchong Nam and Geoffrey Rothwell, "New Nuclear Power Industry Procurement Markets: International Experiences", KDI, December 2014, op. cit.; Hyomin Kim, "Reconstructing the public in old and new governance: A Korean case of nuclear energy policy", *Public Understanding of Science*, April 2014.

848 - Tatiana Kasperski, "Nuclear power in Ukraine: Crisis or path to energy independence?", *Bulletin of the Atomic Scientists*, 1 July 2015, see https://thebulletin.org/2015/07/nuclear-power-in-ukraine-crisis-or-path-to-energy-independence/, accessed 31 August 2021.

849 - Qiang Wang and Xi Chen, "Regulatory transparency—How China can learn from Japan's nuclear regulatory failures?", *Renewable and Sustainable Energy Reviews*, 2012, vol. 16, no. 6, pp. 3574–3578; and Brice Predoletti, "Un haut responsable du nucléaire chinois est soupçonné de corruption", *Le Monde*, 11 August 2009 (in French), see https://www.lemonde.fr/asie-pacifique/article/2009/08/11/un-haut-responsable-du-nucleaire-chinois-est-soupconne-de-corruption_1227513_3216.html, accessed 1 July 2021.

850 - Eric Johnston, "A closer look at Kansai Electric and its gift-giving scandal", *The Japan Times*, 29 March 2020, see https://www.japantimes.co.jp/news/2020/03/29/business/kansai-electric-gift-giving-scandal/, accessed 22 June 2021.

Skoda JS in exchange for facilitating the acquisition of contracts with Ukrainian state enterprise Energoatom.[851]

- **Japan, KEPCO, September 2019**—A Kansai Electric Power Co. (KEPCO) internal investigation revealed that the utility's President and 19 other employees received cash and gifts worth US$3 million from former Deputy Mayor Eiji Moriyama who aimed to encourage KEPCO to work with local suppliers he had ties with.[852] Moriyama's influence as a broker between KEPCO and Takahama businesses can be traced back to 1987.[853]
- **International (Canada/Libya), SNC-Lavalin, October 2014**—SNC-Lavalin Vice-President Riadh Ben Aissa admitted before Switzerland's federal-crime court to have bribed Saadi Gaddafi, son of former Libyan leader Muammar Gaddafi, in exchange for successfully helping SNC-Lavalin to obtain several contracts in Libya.[854] SNC-Lavalin is one of the largest engineering, procurement and construction companies in the world with long-time involvement in nuclear projects in Canada and various other countries.

The SNC-Lavalin case exemplifies a well-documented motive for bribery of public officials by multinationals: they usually aim to adopt "business practices of the host country" to gain contracts. During investigations, Ben Aissa described the ways in which structural deficiencies in the Libyan state made it difficult to conduct business "alone": "You need a protector".[855] This practice was also displayed in a scandal relating to the Bataan nuclear plant in the Philippines that was never completed.[856]

Since investigations of the Uramin scandal begun in 2010, similar allegations have been made against AREVA and various independent investigations have found it highly plausible that AREVA bribed public officials in Namibia, Central African Republic, and South Africa with the hope to secure other contracts in the region—allegedly with the help of French politician Patrick Balkany[857], who has been accused of receiving kickbacks for his role as an intermediary in Central African Republic.[858]

The three cases mentioned above show that political figures can play the role of intermediaries and use their influence in favor of companies involved in the procurement market in exchange for personal and/or political gain. In other instances, the problem of public officials' "special interests" vis-à-vis the nuclear industry also translates into revolving doors.

Concerns about the revolving-doors phenomenon's possible impact over governments and regulatory agencies' impartiality— an issue which is well-documented in the financial

851 - Michael Shields and Natalia Zinets, "Swiss court upholds ex-Ukraine MP's money-laundering conviction", *Reuters*, 26 October 2020, see https://www.reuters.com/article/uk-swiss-ukraine-idUKKBN27B1B7, accessed 7 June 2021.

852 - Junko Fujita, "Scandal-hit head of Japan's Kansai Electric has no plans to resign", *Reuters*, 2 October 2019, see https://www.reuters.com/article/us-kansai-electric-scandal-idUSKBN1WH0FM, accessed 7 June 2021.

853 - Eric Johnston, "A closer look at Kansai Electric and its gift-giving scandal", *The Japan Times*, 29 March 2020, op. cit.

854 - Richard L. Cassin, "Swiss court accepts guilty plea from former SNC-Lavalin exec", *The FCPA Blog*, 2 October 2014, see https://fcpablog.com/2014/10/02/swiss-court-accepts-guilty-plea-from-former-snc-lavalin-exec/, accessed 7 June 2021.

855 - Attorney General of Switzerland, "Acte d'accusation en procédure simplifiée", Procedure: SV.13.0414-THO, August 2014 (in French), see https://cdn.nawaat.org/wp-content/uploads/Acte_Accusation_riadh_Ben_Aissa_ALSTOM.pdf, accessed 1 July 2021.

856 - William Beaver, "Nuclear nightmares in the Philippines", *Journal of Business Ethics*, vol. 13, April 1994, pp. 271–279.

857 - Patrick Balkany has been sentenced to a five-year prison term in 2020 for other crimes.

858 - Pascal Henry, "Pièce à conviction—Affaire Areva Uramin 3 milliards en fumée", *France 3*, 2014; and Marc Eichinger and Thierry Gadault, "L'homme qui en savait beaucoup trop: révélations d'un agent au cœur des secrets d'état", *Massot Edition*, 2020.

sector[859]—have also been raised in seven out of the Top-8 countries' nuclear industries: China, France, Japan, Russia, South Korea, Ukraine, and the U.S.[860]

As an example, former Director General of the Finnish nuclear regulator STUK, Jukka Laaksonen, became a high-ranking Rosatom executive a few months after he had praised—while still with STUK—the design and construction of the Leningrad-2 plant. Only one month after his statement, a several-hundred-ton reinforcement cage of the containment building dropped and created serious damage on the concrete frame.[861]

Grand Collusion Schemes, Counterfeiting, Fraud

Grand Collusion Schemes

Top-8 stakeholders in the procurement market, including operators, manufacturers, and testing companies have collaborated in large-scale fraud and counterfeiting schemes. Two "grand-collusion" cases illustrate how, even in the absence of a bribery scheme, factors such as the paucity of market actors, the organizational structure of nuclear operating companies and weaknesses in regulatory mechanisms can facilitate fraud.[862]

→ **France, April 2015**—The French Nuclear Safety Authority (ASN) revealed that the bottom and lid manufactured at AREVA's Creusot Forge[863] for the Flamanville EPR pressure vessel displayed "very serious" defects.[864] In 2016, AREVA informed ASN about "irregularities in the manufacturing checks" at Creusot Forge, including "inconsistencies, modifications or omissions in the production files, concerning manufacturing parameters or test results" for about 400 components fabricated since 1965.[865] EDF subsequently identified 2,982 "anomalies" in documentation related to parts integrated into 58 French reactors[866] (see Figure 39).

859 - Charles Ferguson, "Inside Job: the Financiers Who Pulled Off the Heist of the Century", One World, 2014.

860 - Mathias Hunter, Alex Polfliet, Patrick Cummins-Tripodi et al., "Revolving Doors and the Fossil Fuel Industry: Time to tackle conflicts of interest in climate policy-making", May 2018, The Greens/EFA Group in the European Parliament, see https://www.greens-efa.eu/files/assets/docs/report_of_revolving_doors_digital_-min.pdf, accessed 7 June 2021; also Qiang Wang and Xi Chen, "Regulatory failures for nuclear safety–the bad example of Japan–implication for the rest of world", *Renewable and Sustainable Energy Reviews*, 2012, op cit.; and Michael Dreiling and Nakamura Tomoyasu, "A Nuclear Complex? A Network Visualization of Japan's Nuclear Industry and Regulatory Elite, 2006 to 2012", *Socius*, January 2018, vol. 4, pp. 1-4; also Tatiana Kasperski, "Nuclear power in Ukraine: Crisis or path to energy independence?", *Bulletin of the Atomic Scientists*, 2015, op. cit.; and Qiang Wang and Xi Chen, "Regulatory transparency—How China can learn from Japan's nuclear regulatory failures?", *Renewable and Sustainable Energy Reviews*, 2012, op. cit.

861 - Kendra Ulrich, Jehki Harkonen and Brian Blomme, "Rosatom risks: Exposing the troubled history of Russia's state nuclear corporation", Greenpeace International, October 2014, op. cit.

862 - Ilchong Nam and Geoffrey Rothwell, "New Nuclear Power Industry Procurement Markets: International Experiences", KDI, December 2014, op. cit.

863 - AREVA went technically bankrupt and was broken up by the French government in 2017. AREVA NP that concentrated all manufacturing activities was allocated the new (old) Framatome. AREVA NC that covered transport, reprocessing and MOX manufacturing was relabeled Orano (the old COGEMA).

864 - Ludovic Dupin, "Le cri d'alarme de l'ASN sur le nucléaire français", *Usine Nouvelle*, 20 January 2016 (in French), see http://www.usinenouvelle.com/article/le-cri-d-alarme-de-l-asn-sur-le-nucleaire-francais.N374729, accessed 12 June 2021.

865 - ASN, "AREVA has informed ASN of irregularities concerning components manufactured in its Creusot Forge plant", Information Notice, 4 May 2016, see http://www.french-nuclear-safety.fr/Information/News-releases/Irregularities-concerning-components-manufactured-in-its-Creusot-Forge-plant, accessed 7 June 2021.

866 - EDF, "Dossiers de fabrication", Undated (in French), see https://www.edf.fr/groupe-edf/nos-energies/nucleaire/segregation-carbone-et-dossiers-de-fabrication-creusot-forge/dossiers-de-fabrication, accessed 7 June 2021.

- **South Korea, November 2012**—Korea Hydro & Nuclear Power (KHNP) reported fraudulent documents on equipment qualification in 60 procurement contracts involving 7,682 items. A subsequent investigation led to the disclosure of the so-called JS Cable scandal, a similar fraud scheme, which involved KHNP procurement managers, Korea Electric Power Corporation (KEPCO) Engineering & Construction Company engineers charged with verification, executives from the Saehan testing company and from the JS Cable manufacturing company.[867]

In both cases, the paucity of viable options contributed to AREVA, EDF and KEPCO working with unreliable manufacturers. In 2005, the ASN notified AREVA about discrepancies at Creusot Forge and left them with a choice: "Your supplier has big problems, either replace it or buy it!".[868] AREVA chose the buy-up option and subsequently struggled to implement relevant changes at Creusot Forge. It took until late 2020 to restart forging large pieces. Similarly, JS Cable, a company which was unfamiliar with the manufacturing of cables designed for nuclear power plants, was selected as a supplier by KEPCO in accordance with Korean industrial policies promoting domestic vendors.[869]

These scandals also underscore structural problems with governance and regulations. In the JS Cable case, incentive mechanisms for collusion were enabled by KEPCO's governance structure. KHNP executives were able to pressure KEPCO Engineering & Construction engineers into fabricating fake testing reports, which subsequently incited Saehan and then JS Cable to participate in the fraud scheme.[870] The scale of collusion displayed in both cases also underlines regulatory mechanism weaknesses. It is particularly salient in the Creusot Forge scandal, considering that the manufacturing company continued to supply nuclear power plants with faulty components or irregular documentation for more than ten years after ASN, AREVA and EDF discovered discrepancies.[871]

867 - Ilchong Nam and Geoffrey Rothwell, "New Nuclear Power Industry Procurement Markets: International Experiences", KDI, 2014, op. cit.

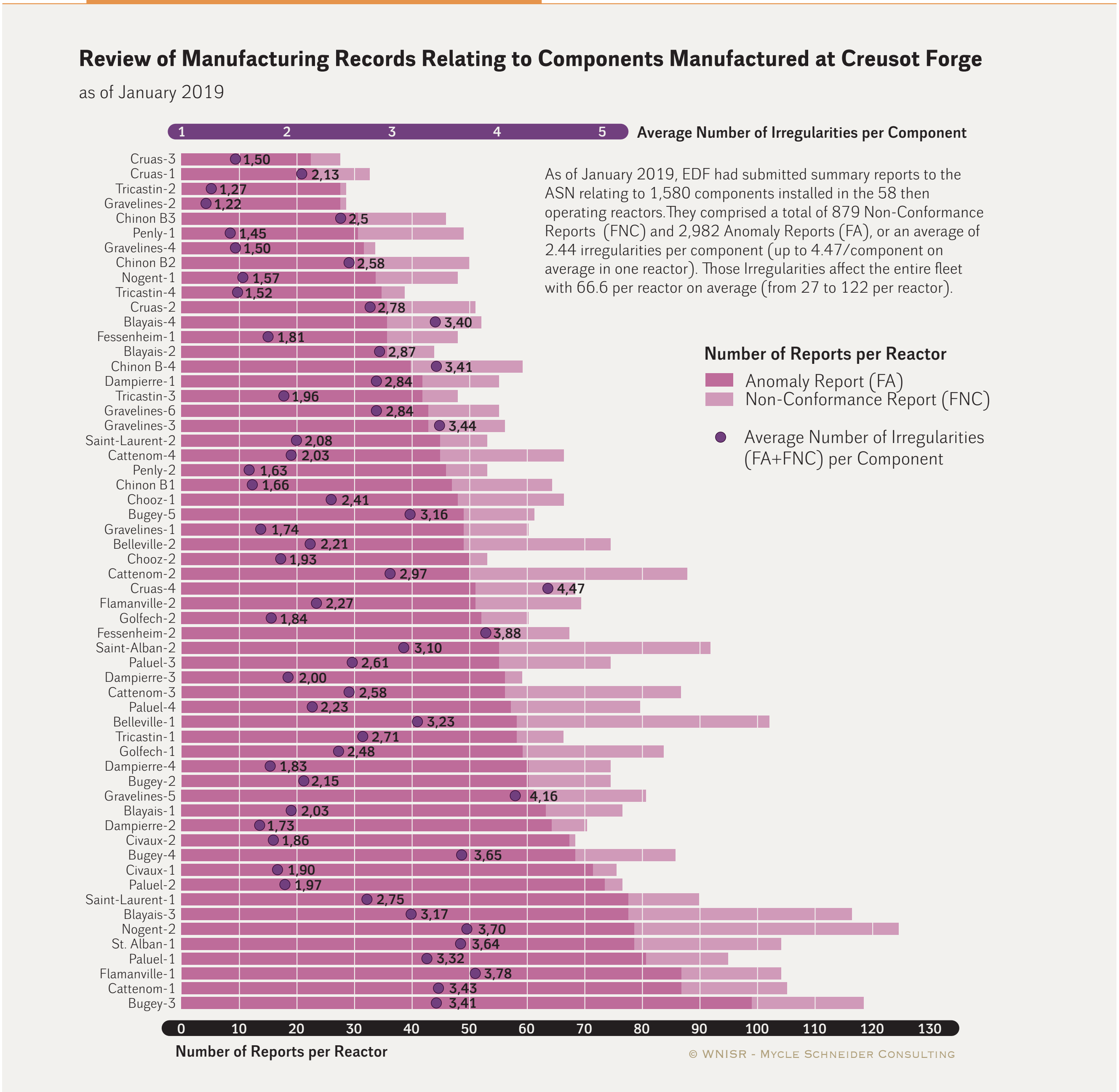
868 - Sylvain Tronchet, "Cuve de l'EPR de Flamanville : l'incroyable légèreté d'Areva et EDF", *France Inter*, 31 March 2017 (in French), see https://www.franceinter.fr/sciences/cuve-de-l-epr-de-flamanville-l-incroyable-legerete-d-areva-et-edf, accessed 12 June 2021.

869 - Ilchong Nam and Geoffrey Rothwell, "New Nuclear Power Industry Procurement Markets: International Experiences", KDI, 2014, op. cit.

870 - Ilchong Nam and Geoffrey Rothwell, "New Nuclear Power Industry Procurement Markets: International Experiences", KDI, op. cit.

871 - *France Inter*, "Cuve de l'EPR de Flamanville : l'incroyable légèreté d'Areva et EDF", 31 March 2017 (in French), op. cit.

Figure 39 · Irregularities at the French Creusot Forge



Source: EDF, "Dossiers de fabrication", 2019

Notes:

Non-Conformance Report (**FNC**): a deviation is found which relates to one of the *manufacturer's own standards*.

Anomaly Report (**FA**): a component fails to comply with a *contractually binding or statutory requirement*.[872]

This figure does not cover the "Formal Deviation" category, when a deviation relates to contractually binding requirements that do not have any technical impact and which are obsolete. The number of Formal Deviations by reactor varies between 0 and 100 (25 on average).

872 - Definitions according to EDF France, "Creusot Forge manufacturing records", 14 September 2017, see https://www.edf.fr/en/edf/creusot-forge-manufacturing-records, accessed 27 July 2021.

Company-level Fraud

Nuclear power plants have also been supplied with counterfeit and fraudulent components without operator consent or knowledge, which has become a growing concern for nuclear operators.[873] Among a variety of cases (see IAEA-2019 report), some incidents have taken place when suppliers adopted a rent-seeking behavior and/or had a deficient appreciation of safety culture.

- **International (Canada/China/South Korea), February 2015**—Ontario Power Generation (OPG) was informed that hundreds of valve assemblies and parts supplied to every Canadian nuclear power plant did not meet nuclear material certification. Investigations disclosed that the valve supplier's steel sub-supplier had not carried out external testing for all components as well as misrepresented other test results to meet Canadian standards for nuclear components.[874] The sub-supplier also delivered components with misrepresented results to nuclear operators in other Top-8 countries (e.g. China and South Korea).
- **Russia, May 2012**—Former deputy head of the Research Institute for Complex Testing of Optoelectronic Devices and Systems (NIIKI OEP)'s testing department, Alexander Murach, was found guilty of selling counterfeit equipment used for gauging nuclear turbine vibrations to nuclear operators. Murach had created his own company, Informtech, which provided the counterfeited equipment's fake certificates.[875]

While sharing similarities, these cases underline two features in vendor fraud identified by the IAEA and WANO. The Informtech example illustrates a case of rent-seeking behavior with potentially serious consequences, considering the implications for evidently unviable turbine vibration detection equipment. The Canadian case exemplifies what the IAEA and WANO identified as "a lack of safety culture"[876]. Evidence suggests that the steel supplier produced material meeting British commercial (non-nuclear) standards and decided to lie about the tests which they ran.[877] This case resonates with the Sellafield MOX scandal, which also involved a British company having supplied fuel pellets to Korean power plants with falsified documentation: a U.K. Health and Safety Executive (HSE) report suggests that Sellafield employees came to normalize such fraudulent practice due to a lack of proper awareness training and supervision.[878]

873 - IAEA, "Managing Counterfeit and Fraudulent Items in the Nuclear Industry", March 2019, no. NP-T-3.26, op. cit.

874 - Ibidem.

875 - Richard Tanter, "After Fukushima: A Survey of Corruption in the Global Nuclear Power Industry", *Asian Perspective*, 2013, vol. 37, no. 4, pp. 475–500.

876 - IAEA, "Managing Counterfeit and Fraudulent Items in the Nuclear Industry", March 2019, no. NP-T-3.26, op. cit, pp. 55–56.

877 - CNSC, "Public meeting", Canadian Nuclear Safety Commission, Meeting held 17 June 2015 (in French and English), see http://www.ccsn.gc.ca/eng/the-commission/pdf/2015-06-17-Meeting-eDocs4788732-e.pdf, accessed 26 June 2021; also CNSC, "Public meeting", Meeting held 7 April 2016, see http://www.nuclearsafety.gc.ca/eng/the-commission/pdf/2016-04-07%20-%20Meeting%20Corrected.pdf, accessed 25 August 2021; and IAEA, "Managing Counterfeit and Fraudulent Items in the Nuclear Industry", March 2019, no. NP-T-3.26, op. cit.

878 - The Nuclear Installations Inspectorate, "An Investigation into the Falsification of Pellet Diameter Data in the MOX Demonstration Facility at the BNFL Sellafield Site and the Effect of this on the Safety of MOX Fuel in Use", U.K. Health and Safety Executive, 18 February 2000, see http://www.wise-paris.org/english/reports/000221HSEMOXFalsification.pdf, accessed 7 June 2021.

CASE STUDIES: SABOTAGE AND ORGANIZED CRIME IN JAPAN, RUSSIA, AND THE U.S.

Data on organized crime and sabotage at nuclear power plants is difficult to access. Most detailed and sensitive information has been collected and gathered in official and scholarly databases, such as the ITDB and the DTSO, both of which are not open source. For instance, elements such as the identity of perpetrators, the circumstances and frequency of incidents are generally unknown/concealed to the public. This is exemplified in a consequential case of sabotage which led to the 6-months-shutdown of a reactor at the Belgian Doel nuclear power plant in 2014. While on-site investigations have been undertaken up until June 2020, the identity of the insider perpetrator(s) has never been discovered.[879]

Accordingly, without any specific timeframe, this section selects and analyzes 10 insider threat cases which have been the most publicly documented (literature, START database). It focuses specifically on events involving criminal practices which compromised security and/or safety having occurred at nuclear power plants in Japan, Russia, and the U.S.

Sabotage

Insider sabotage has occurred on several occasions at U.S. nuclear power plants. While no similar events have been reported in Japan and Russia, there have been, like in the U.S., sabotage plans and alleged sabotage attempts by outsiders at Japanese and Russian nuclear power plants.[880] The following sabotage cases at U.S. nuclear power plants involved disgruntled employees.

- **St. Lucie Nuclear Power Plant, U.S., August 1996**—Employees glued backup switches in a high security area during a labor strike over their working conditions. The month before, it had been discovered that padlocks and doors had also been glued.[881]
- **Surry Nuclear Power Station, U.S., 27 April 1979**—Former employees William Kuykendall and James Merrill poured sodium hydroxide caustic soda on fuel rods at the plant, causing over US$800,000 worth of damage[882]. During their trial, they claimed that their objective was to draw attention to persistent safety issues at the plant.[883]

Although these cases occurred decades ago, they underline the centrality of insider threats in nuclear security, as well as likely shortcomings with the "four-eyes principle" (requiring at least a two-person presence) which has been implemented in many countries including the U.S. since then.

879 - Maxime Vande Weber, "Des perquisitions ont lieu à la centrale nucléaire de Doel", *L'Echo*, 24 June 2020 (in French), see https://www.lecho.be/entreprises/energie/des-perquisitions-ont-lieu-a-la-centrale-nucleaire-de-doel/10235169.html, accessed 12 June 2021.

880 - START, "Nuclear Facilities Attack Database (NuFAD)", National Consortium for the Study of Terrorism and Responses to Terrorism, see https://www.start.umd.edu/nuclear-facilities-attack-database-nufad; and NTI, "Less Well Known Cases of Nuclear Terrorism and Nuclear Diversion in Russia", Nuclear Threat Initiative, 20 August 1997, see https://www.nti.org/analysis/articles/less-well-known-cases-nuclear-terrorism-and-nuclear-diversion-russia/, both accessed 7 June 2021.

881 - *Tampa Bay Times*, "Glue found in switches at nuclear power plant", 15 August 1996, see https://www.tampabay.com/archive/1996/08/15/glue-found-in-switches-at-nuclear-power-plant/, accessed 7 June 2021.

882 - START, "Nuclear Facilities Attack Database (NuFAD)", op. cit.

883 - *Sarasota Herald Tribune*, "Nuclear Workers Convicted of Sabotage", 17 October 1979, see https://news.google.com/newspapers?id=DJwcAAAAIBAJ&sjid=i2cEAAAAIBAJ&hl=fr&pg=4150%2C279441, accessed 7 June 2021.

While there seem to be no reported cases of insider sabotage in Japan, there have been several cases of insiders mistakenly and deliberately gaining access to sensitive areas at the Kashiwazaki-Kariwa and Ohi nuclear power plants in 2015, 2018 and 2020.[884] Independent experts have underlined Japan's idiosyncratic nuclear security culture deficiencies, explaining that "it always seemed as if in Japan there was a very basic missing ingredient. And that was the imagination of a threat".[885] In 2015, Japan's National Regulation Authority (NRA) established a plan of action to improve upon security at Japanese nuclear power plants, including a "Code of Conduct on Nuclear Security Culture". The abovementioned incidents underline these measures' limited impact and the feasibility of an insider attack.[886]

Several reports have established a link between financial hardship, loss of social prestige of nuclear professions following the disintegration of the Soviet Union and material theft. A 2014-Russian-NGO-study on Leningrad power plant employees' working-conditions reported low salaries, unhygienic accommodations, and the confiscation of foreign workers' passports by managers.[887] In 2004, former Leningrad-plant employee Sergei Karitonov published a report claiming that individuals, most likely employees, had stolen switches from a safety system that can trigger an automatic reactor shutdown. The theft of valves was also reported in the press.[888]

Organized Crime and Nuclear Trafficking

Criminal network infiltration in nuclear power plants is a well-documented problem in Japan. Examples include:

- **Fukushima Nuclear Power Plant, Japan, October 2014**—Yuuki Sagawa, a member of the Matsuba Kai mob was arrested in 2014 for brokering unlicensed workers to Fukushima cleanup operations.
- **May 2012**—Makoto Owada, high-ranking member of Sumiyoshi-kai, the second largest Yakuza group in the country, was arrested for the same crime.[889]

The Center for Nonproliferation Studies (CNS) database 2013–2017 analysis finds that 68 percent of the discovered nuclear and radioactive materials trafficking incidents worldwide have occurred in countries of the Former Soviet Union.

884 - Osamu Tsukimori, "Tepco lapse a wake-up call for Japan's nuclear security protocols, expert says", *The Japan Times*, 15 April 2021, see https://www.japantimes.co.jp/news/2021/04/15/national/nra-niigata-tepco-nuclear-security/; and *The Japan Times*, "Another security breach at Tepco nuclear plant uncovered", 9 May 2021, see https://www.japantimes.co.jp/news/2021/05/09/national/tepco-nuclear-power-plant-security-breach/, both accessed 7 June 2021.

885 - Osamu Tsukimori, "Tepco lapse a wake-up call for Japan's nuclear security protocols, expert says", *The Japan Times*, April 2021, op. cit.

886 - Matthew Bunn, Nicholas Roth and William H. Tobey, "Revitalizing Nuclear Security in an Era of Uncertainty", Project on Managing the Atom, Belfer Center for Science and International Affairs, Harvard Kennedy School, January 2019, see https://scholar.harvard.edu/files/matthew_bunn/files/bunn_revitalizing_nuclear_security_in_an_era_of_uncertainty_2019.pdf, accessed 7 June 2021.

887 - Kendra Ulrich, Jehki Harkonen and Brian Blomme, "Rosatom risks: Exposing the troubled history of Russia's state nuclear corporation", Greenpeace, October 2014, op. cit.

888 - *NEI*, "Serious concerns over Leningrad", 20 October 2004, see https://www.neimagazine.com/news/newsserious-concerns-over-leningrad/, accessed 26 June 2021.

889 - *NHK*, "Gen patsu sagyoin haken de Matsubakaikei boryokudanin taiho" [Arrest of Mob Member Affiliated with Matsuba kai for Sending Workers to Nuclear Power Work], as published on 弁財天/Benzaiten.org, 6 October 2014 (in Japanese), see http://benzaiten.dyndns.org/roller/ugya/entry/matsubakai-2014; and Jake Adelstein, "How the Yakuza and Japan's Nuclear Industry Learned to Love Each Other", *The Atlantic*, 24 May 2012, see https://www.theatlantic.com/international/archive/2012/05/how-yakuza-and-japans-nuclear-industry-learned-love-each-other/327691/, accessed 7 June 2021.

This is of course no proof that similar incidents have not occurred in other regions involving a range of other nuclear facilities, but from available data it appears that nuclear power plants are not primarily involved in nuclear and radioactive materials trafficking.

On the other hand, the mentioned Japanese mafia cases present evidence of a systemic issue which aligns with Japanese nuclear operators' apparently deficient security culture. In his statement to the police, Owada admitted he had sent Yakuza members to work on several nuclear-plant construction-sites since 2007. Other sources suggest that the Yakuza supply workers to nuclear plants since the 1990s.[890] Furthermore, an executive from a Yakuza Kudo-Kai front company was arrested in January 2012 for contributing to the making of illegal work contracts with the Ohi nuclear power plant.[891] Considering that the extortion and blackmail of nuclear power plant officials is a longstanding practice among Japanese mobs,[892] and that at least two suspected sabotage cases occurred at Fukushima since the beginning of the post-3/11 clean-up, mafia-member infiltration as decontamination workers appears particularly worrisome.[893]

CONCLUSION

In February 2021, the *Bulletin of the Atomic Scientists* headlined a piece "Big money, nuclear subsidies, and systemic corruption".[894] The multiplication of cases of fraud and corruption in recent years—WNISR2020 mentions the term "corrupt" or "corruption" 14 times throughout the report—keeps observers wondering whether the nuclear industry is indeed confronted with a systemic phenomenon of criminal behavior.

The public views nuclear power plants and other nuclear facilities as being under particularly strict safety and security control. However, the nuclear sector is subject to some of the same irregularities and criminal activities as other large infrastructure projects. Huge contract size and multiple layers of subcontractors make the sector attractive for people with malicious intentions. The presence of nuclear and other radioactive materials leads to particular safety and security implications.

In Transparency International's 2020 Corruption Perceptions Index, half of the 35 countries operating or constructing nuclear power plants on their territory rate under 50 out of 100. In the Bribery Payers Index (last published in 2011), which rates 28 world leading economies based on companies' perceived likelihood to resort to bribery when conducting business abroad, seven out of the ten worst rated countries operate or are building nuclear power plants on their territory. The two countries at the bottom of the ranking are China and Russia, respectively

890 - Jake Adelstein, "How the Yakuza and Japan's Nuclear Industry Learned to Love Each Other", *The Atlantic*, 24 May 2012, op. cit.

891 - Jake Adelstein, "First Arrest Made Linking Yakuza with Fukushima Nuclear Clean-Up Crews.", *The Atlantic*, 22 May 2012, see https://www.theatlantic.com/international/archive/2012/05/first-arrest-made-linking-yakuza-fukushima-nuclear-clean-crews/327820/, accessed 7 June 2021.

892 - Mark J. Ramseyer, "Nuclear Power and the Mob: Extortion in Japan", *Journal of Empirical Legal Studies*, vol. 13, no. 3, 2016, pp. 487–515; and Jake Adelstein, "How the Yakuza and Japan's Nuclear Industry Learned to Love Each Other", *The Atlantic*, 24 May 2012, op. cit.

893 - Ethan Huff, "Intentional sabotage believed to have disrupted decontamination at Fukushima plant", *Natural News*, 23 April 2014, see https://www.naturalnews.com/045109_Fukushima_sabotage_radiation_decontamination.html, accessed 7 June 2021.

894 - Cassandra Jeffery and M. V. Ramana, "Big money, nuclear subsidies, and systemic corruption", *Bulletin of the Atomic Scientists,* op. cit.

the second and fourth largest nuclear power generating countries, with Russia, the worst-rated, also representing the largest current nuclear power plant exporter.

According to the IAEA, "The infiltration into the global supply chain of CFIs [Counterfeit or Fraudulent Items] is a growing concern worldwide."[895] Nonetheless, the phenomenon is difficult or impossible to quantify. For example, over the period 2012 to early 2016, WANO was made aware of ten fraudulent and counterfeited-parts incidents, eight of which had been reported to the Atlanta Centre, the liaison office for just seven nuclear countries.

Comprehensive data on issues such as theft, trafficking and sabotage is difficult to access and generally publicly unavailable. Thus, evaluating the scale of these criminal activities is particularly challenging. The publicly accessible START worldwide database, for example, contains 80 cases of attacks on nuclear facilities between 1961 and 2014. Yet, Anthony Honnellio and Stan Rydell of the U.S. Environmental Protection Agency, claimed that, up until 2005, there had already been 120 confirmed sabotage attempts in American nuclear power plants alone.[896]

The ITDB database, which is not available for the public, has recorded 3,696 confirmed incidents between 1995 and 31 December 2019, 290 out of which were "confirmed or likely act[s] of trafficking or malicious use". In most known cases, research and development sites or other sectors manipulating radioactive materials have been the source of smuggled substances. Nuclear power plants or fuel chain facilities have not been primarily involved in nuclear and radioactive materials trafficking.

In the past decade, there has been growing evidence of criminality in the nuclear industry. Similar to other sectors of large infrastructure investments, this has included cases of bribery and corruption, counterfeit and fraud in manufacturing and quality control. Most public discussion about these matters has focused on governance and image; but the potential safety and security implications have been little explored. In addition, there is also the threat of insider sabotage and terrorist attacks, but information remains scarce in the public domain.

895 - IAEA, "Managing Counterfeit and Fraudulent Items in the Nuclear Industry", March 2019, No. NP-T-3.26, op. cit.

896 - Anthony L. Honnellion and Stan Rydell, "Sabotage vulnerability of nuclear power plants", U.S. Environmental Protection Agency, *International Journal of Nuclear Governance, Economy and Ecology*, Vol. 1, No 3, 2007, pp. 312–321.

DECOMMISSIONING STATUS REPORT 2021

INTRODUCTION

Decommissioning nuclear power plants is an important element of the nuclear power system. The defueling, deconstruction, and dismantling—summarized by the term decommissioning—are the final steps in the life cycle of a nuclear power plant (excluding waste management and disposal). The process is technically complex and poses major challenges in terms of long-term planning, execution, and financing. Decommissioning was rarely considered in the reactor design, and the costs for decommissioning at the end of the lifetime of a reactor were usually discounted away, and thus, subsequently, largely ignored. However, as an increasing number of nuclear facilities either reach the end of their operational lifetimes or are already closed, the challenges of reactor decommissioning are coming to the fore, and also attract increasing public and policy attention.

Elements of National Decommissioning Policies

Decommissioning plays an increasing role in nuclear politics, both in timing and production process, and the financing thereof. When analyzing decommissioning policies, one needs to distinguish between the process itself (in the sense of the actual implementation), and the financing of decommissioning. The technological process can be divided into three main stages, which are briefly described hereunder (for more details, see WNISR2018).

- The **warm-up stage** comprises the post-operational stage, the dismantling of systems that are not needed for the decommissioning process. Also, the dismantling of higher contaminated system parts begins. An indicator for the progress of this stage is the defueling of the reactor as it is crucial for further undertakings: defueling means removing the spent fuel from the reactor core *and* the spent fuel pools.
- The **hot-zone stage** comprises the dismantling activities in the hot zone, i.e. dismantling of highly contaminated or activated parts, e.g. the reactor pressure vessel (RPV) and its internals (RVI), the biological shield.
- The **ease-off stage** comprises removal of operating systems as well as decontamination of the buildings. This stage ends ideally with the demolition of the buildings and the release of the reactor site as a greenfield for unrestricted use but the release as a brownfield is allowed in some countries, which means that the buildings can also be further used, for nuclear or other purposes.

With respect to financing, four main approaches are observable: Public budget, external segregated fund, internal non-segregated fund, and internal segregated fund (for more details, see WNISR2018).

GLOBAL OVERVIEW

Decommissioning Worldwide

As of 1 July 2021, worldwide, there are 196 closed reactors totaling 90.4 GW of capacity. Since WNISR2020, seven additional reactors (5.5 GW) have officially been closed: two each in the U.S. and the U.K., and one each in Russia, Sweden, and Taiwan. Of the closed units, nearly 60 percent are located in Europe (93 in Western Europe and 24 in Central and Eastern Europe), followed by nearly a quarter of closed units in North America (46) and one sixth in Asia (33). Almost four in five or 154 reactors used three technologies: Pressurized Water Reactors or PWRs (31 percent or 61 units), Boiling Water Reactors or BWRs (27 percent or 53 units), and Gas-Cooled Reactors or GCRs (20 percent or 40 units). Of the latter, the majority (29 units) are in the U.K. Table 12 provides an overview of the closed reactors worldwide.

Table 12 – Overview of Reactor Decommissioning Worldwide (as of July 2021)

Country	Closed Reactors	Warm-up	Hot-zone	Ease-off	LTE	Completed	Share of Completed
USA	40	9	0	4	13	14	35%
UK	32	0	0	0	32	0	0%
Germany	30	8	8	8	1	5	17%
Japan	27	26	0	0	0	1	4%
France	14	4	2	0	8	0	0%
Russia	9	0	0	0	9	0	0%
Sweden	7	3	4	0	0	0	0%
Canada	6	1	0	0	5	0	0%
Bulgaria	4	4	0	0	0	0	0%
Italy	4	4	0	0	0	0	0%
Ukraine	4	0	0	0	3	0	0%
Slovakia	3	2	1	0	0	0	0%
Spain	3	1	0	1	1	0	0%
Taiwan	3	3	0	0	0	0	0%
Lithuania	2	2	0	0	0	0	0%
South Korea	2	2	0	0	0	0	0%
Switzerland	1	1	0	0	0	0	0%
Armenia	1	1	0	0	0	0	0%
Belgium	1	0	0	1	0	0	0%
India	1	1	0	0	0	0	0%
Kazakhstan	1	0	0	0	1	0	0%
Netherlands	1	0	0	0	1	0	0%
Total	**196**	**72**	**15**	**14**	**74**	**20**	**10%**

Sources: Various, compiled by WNISR, 2021

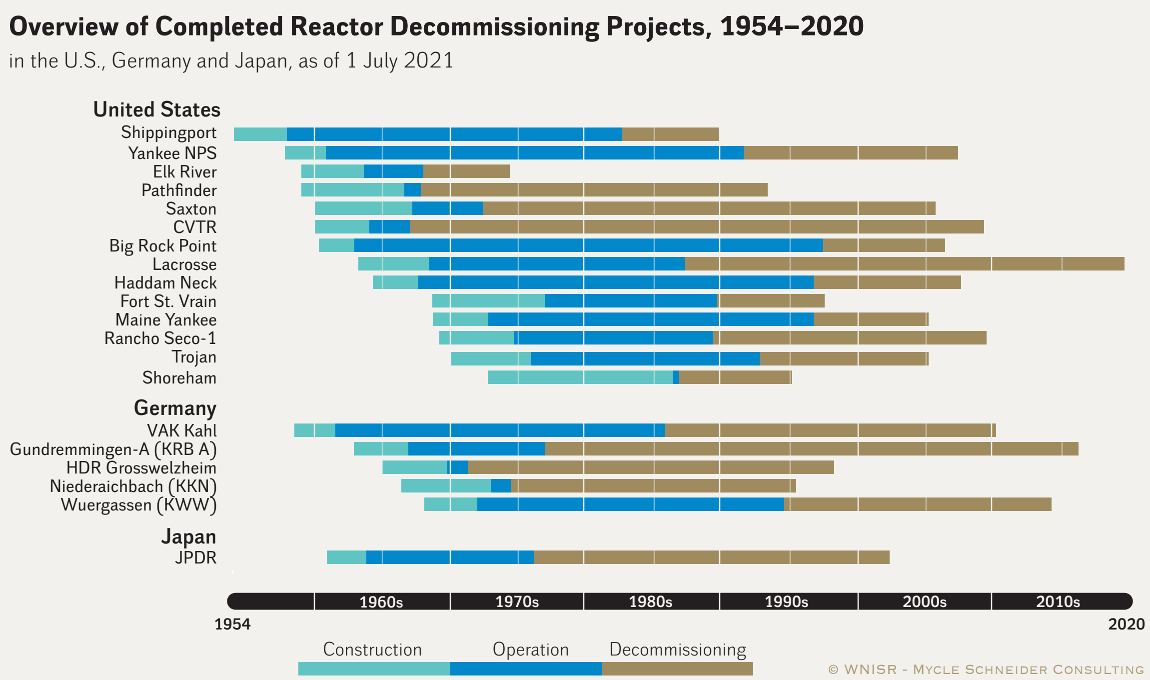
Looking ahead, the implementation numbers will increase significantly: Assuming a 40-year average lifetime, a further 180 reactors will close by 2030 (reactors connected to the grid between 1981 and 1990); and an additional 132 will be closed by 2060; this does not even account for the 99 reactors which started operating before 1981, an additional 26 reactors in Long-term Outage (LTO) and the 53 reactors under construction as of mid-2021.

Overview of Reactors with Completed Decommissioning

Since WNISR2020, no reactor finished the technical decommissioning process. The latest completed reactor was the La Crosse station in the USA, where, in November 2019, EnergySolutions announced the completion of the "physical work".[897] Final site survey and license reduction to the independent spent fuel installation were planned for 2020.[898] But, as of March 2021, the site had still not been released from regulatory control.[899] The 48-MW La Crosse plant was decommissioned 37 years after its closure.

Of the 20 decommissioned reactors, only 10 have been returned to greenfield sites. The average duration of the decommissioning process, independent of the chosen strategy, is around 20 years, with a very high variance: the minimum of six years for the 22-MW Elk River plant, and the maximum of 42 years for the 17-MW CVTR (Carolinas-Virginia Tube Reactor), both in the U.S., both very small.

Figure 40 · Overview of Completed Reactor Decommissioning Projects, 1954–2020



Sources: Various, compiled by WNISR, 2021

897 - *NEI*, "Physical work completed for decommissioning of US La Crosse NPP", 14 November 2019, see https://www.neimagazine.com/news/newsphysical-work-completed-for-decommissioning-of-us-la-crosse-npp-7508092, accessed 7 July 2020.

898 - NRC, "La Crosse Boiling Water Reactor", 19 November 2019, see https://www.nrc.gov/info-finder/decommissioning/power-reactor/lacrosse-boiling-water-reactor.html, accessed 7 July 2020.

899 - NRC, "La Crosse Boiling Water Reactor", Updated 25 March 2021, see https://www.nrc.gov/info-finder/decommissioning/power-reactor/lacrosse-boiling-water-reactor.html, accessed 21 June 2021.

The only countries to have completed the technical decommissioning process are the United States (14), Germany (5), and Japan (1). Some of the U.S. reactors are amongst the most rapidly decommissioned. In Germany, the HDR (Heißdampfreaktor, a superheated steam reactor) Großwelzheim was on the grid for one year only, but decommissioning lasted well over 20 years. Gundremmingen-A and Würgassen have de facto completed the technical decommissioning process but, legally, cannot be released from regulatory control as the buildings are used for interim storage of wastes or conditioning work for operational units (in the case of Gundremmingen).[900] In Japan, the only reactor decommissioned was a small research reactor, whereas none of the commercial reactors has yet been decommissioned.[901] Figure 40 provides the timelines of the 20 reactors that have completed the decommissioning process.

Overview of Reactors with Ongoing Decommissioning in 11 Selected Countries

As of the first quarter of 2021, 176 units are globally awaiting or in various stages of decommissioning, seven more than in the first half of 2020. WNISR2021 provides an update of in-depth reviews of developments in eleven major countries published in WNISR2018 and WNISR2019. The country case-studies suggest that both duration and costs have been systematically largely underestimated. In nearly all cases, the ongoing decommissioning projects encounter delays as well as cost increases.

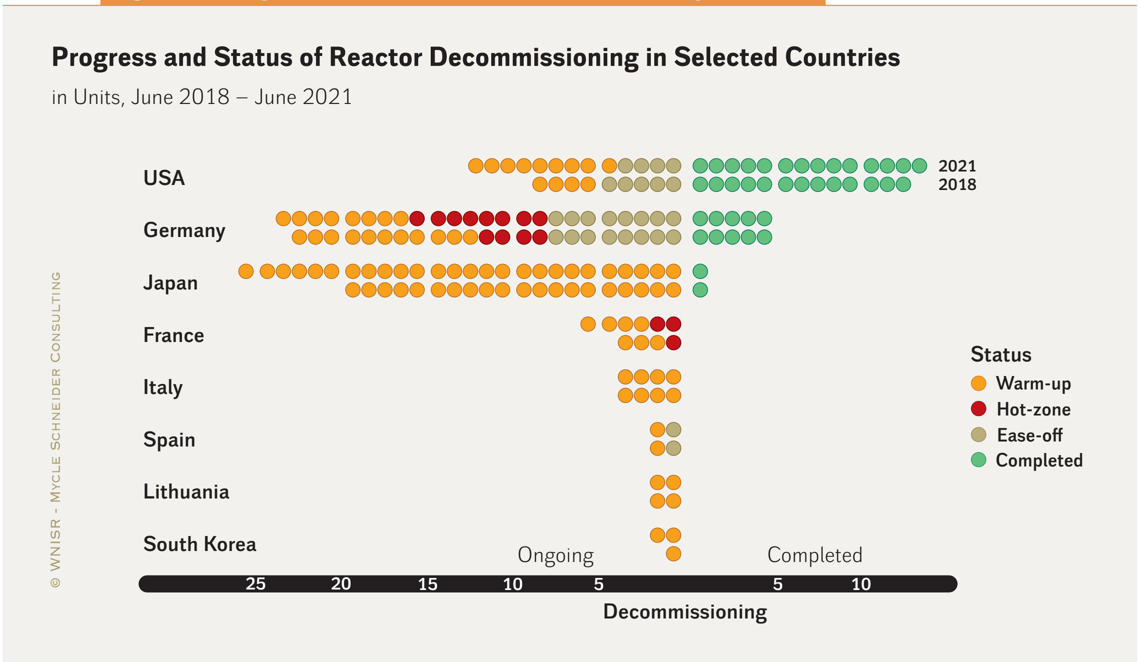
This section provides a review of developments since WNISR2020, while the following section contains more details on the case studies. There are 169 closed reactors in the selected 11 countries[902]; this represents around 86 percent of all closed reactors, 149 of which are in various stages of decommissioning with 20 fully decommissioned. Currently 57 are in the warm-up stage, only 10 reactors are in the "hot-zone -stage", and 13 are in the ease-off stage. None of the early nuclear states—U.K., France, Russia, and Canada—have fully decommissioned a single reactor yet. Russia has put all its closed reactors into Long-Term Enclosure (LTE), postponing decommissioning into the future. WNISR2021 counts a total of 69 reactors in LTE in these 11 countries, 40 percent of all closed units. The U.K. opted for the same decommissioning strategy but changed its strategy in 2021, after the NDA concluded that a site-specific strategy for each site is better suited for reflecting the nature and context of the facility or site in question. Decommissioning of a Magnox reactor will now begin at the Trawsfynydd site in Wales.

900 - Ines Bredberg, Johann Hutter et al., "Statusbericht zur Kernenergienutzung in der Bundesrepublik Deutschland 2019", Division for Nuclear Safety and Supervision in Nuclear Disposal, German Federal Office for the Safety of Nuclear Waste Management, 21 September 2020 (in German), see https://doris.bfs.de/jspui/handle/urn:nbn:de:0221-2020092123025, accessed 19 August 2021.

901 - Marc Schmittem, "Nuclear Decommissioning in Japan – Opportunities for European Companies", EU-Japan Centre for Industrial Cooperation, March 2016, see https://www.eu-japan.eu/sites/default/files/publications/docs/2016-03-nuclear-decommissioning-japan-schmittem-min_0.pdf, accessed 23 April 2018.

902 - Canada, France, Germany, Italy, Japan, Lithuania, Russia, South Korea, Spain, U.K. and U.S.

Figure 41 · Progress and Status of Reactor Decommissioning, 2018–2021



Sources: Various, compiled by WNISR, 2021

Figure 41 reflects the little progress that the global decommissioning industry is making. Between July 2020 and June 2021, little progress can be reported for most of the reactors undergoing decommissioning. In Canada, Douglas Point entered the warm-up stage after being in enclosure for more than 30 years. This represents the first decommissioning start in Canada as well as the first decommissioning start of a CANDU reactor worldwide. In the U.S., Indian Point-3 entered into the warm-up stage. The U.S. has also a large number of reactors in LTE too, with Duane Arnold-1, this number increased to 13 reactors in LTE in 2021 (see the following Case Studies for details).

Brief Overview of Reactors with Ongoing Decommissioning

This section contains a brief overview of the decommissioning process of 26 reactors in another eleven countries which are not analyzed in-depth in the following case studies.

With the closure of Ringhals-1 in December 2020, **Sweden** has now seven reactors undergoing decommissioning. Ringhals-1 and Ringhals-2 are in the warm-up stage. Decommissioning of the first Swedish nuclear reactor Ågesta, which was closed in 1974, only started in 2020 and is thus also in the warm-up stage. Dismantling of the reactor will be carried out by Westinghouse.[903] The two Barsebäck units as well as the two Oskarshamn units are in the hot-zone stage. Dismantling of the reactor vessel internals was completed for the four units in 2019[904] by Westinghouse at the Barsebäck units[905] and by GE Hitachi Nuclear Energy at the

903 - *WNN*, "Westinghouse to dismantle Ågesta reactor", 21 December 2020, see https://world-nuclear-news.org/Articles/Westinghouse-to-dismantle-Agesta-reactor, accessed 1 July 2021.

904 - Kristina Gillin, "Sweden prepares for a decade of nuclear decommissioning", *NS Energy*, 27 February 2020, see https://www.nsenergybusiness.com/news/nuclear-decommissioning-sweden/, accessed 1 July 2021.

905 - *WNN*, "Swedish dismantling work for Westinghouse", 2 November 2015, see https://www.world-nuclear-news.org/WR-Swedish-dismantling-work-for-Westinghouse-0211154.html, accessed 1 July 2021.

Oskarshamn site[906]. The dismantling of the reactor pressure vessels of the four units was awarded to an Uniper and Nukem Technologies consortium, which expects to complete the works by 2024.[907]

In **Bulgaria** (Kozloduy 1–4) and **Slovakia** (Bohunice-1 and -2) six PWRs are being decommissioned as well as one heavy water reactor (Bohunice A1). The decommissioning of the six PWRs, as it is the case with the Soviet reactors in Lithuania, are co-funded by the European Union. Bulgaria, Lithuania and Slovakia agreed to shut down the reactors at Kozloduy, Ignalina (which is covered more in depth later, see Country Case Studies – Lithuania), and Bohunice respectively, when they joined the European Union. The Kozloduy plants are in the warm-up-stage and expected to be decommissioned by 2030.[908] Decommissioning at the Bohunice site is the most advanced decommissioning project going on in the three countries. Here, Unit 1 entered, in 2020, the hot-zone-stage with the removal and transport of the reactor pressure vessel to the pool of the wet fragmentation workplace.[909] Completion date of decommissioning the two units is set to 2025[910] and would constitute the first completed decommissioning of a Soviet (or Russian) PWR. Decommissioning of the Bohunice A-1 reactor, which was closed in 1977 due to an accident, officially started in 1999[911] and seems to be slowly progressing.[912] The four closed reactors in the **Ukraine** are the four units of the Chernobyl station. For Units 1–3 preparation works to put the three reactors in LTE started in 2015.[913]

In **Belgium**, the only reactor undergoing decommissioning is the reactor BR-3 (10 MW), which was closed in 1987 and is in the ease-off stage and expected to complete decommissioning to a greenfield site by 2023.[914] The decommissioning of the seven Doel and Tihange units, which are planned to close by 2025, will cost at least €18 billion [US$21.4 billion] according to the operator Engie Electrabel.[915] In the **Netherlands**, the 55 MW Dodewaard reactor, which was

906 - *WNN*, "Dismantling of Oskarshamn reactor internals completed", 19 December 2019, see https://world-nuclear-news.org/Articles/Dismantling-of-Oskarshamn-reactor-internals-comple, accessed 1 July 2021.

907 - Nukem Technologies, "Dismantling of 4 Reactor Pressure Vessels at Oskarshamn NPP and Barsebäck NPP", Undated, see https://www.nukemtechnologies.de/en/projects/se/Dismantling of 4 Reactor Pressure Vessels at Oskarshamn NPP and Barsebäck NPP, accessed 1 July 2021.

908 - European Commission, "Report from the Commission to the European Parliament and the Council on the implementation of the work under the nuclear decommissioning assistance programme to Bulgaria, Slovakia and Lithuania in 2020 and previous years", 18 May 2021, see https://op.europa.eu/en/publication-detail/-/publication/d5aefc6c-b7c4-11eb-8aca-01aa75ed71a1/language-en, accessed 19 August 2021.

909 - *NEI*, "Pressure vessel removal at Bohunice", 12 August 2020, see https://www.neimagazine.com/features/featurepressure-vessel-removal-at-bohunice-8079422/, accessed 1 July 2021.

910 - European Commission, "Report from the Commission to the European Parliament and the Council on the Implementation of the Work under the Nuclear Decommissioning Assistance Programme to Bulgaria, Slovakia and Lithuania in 2020 and Previous Years", 2021, op. cit.

911 - javys, "A1 NPP Decommissioning", Undated, see https://www.javys.sk/en/activities-of-the-company/a1-npp-decommissioning, accessed 2 July 2021.

912 - Slovak Republic, "National Report of the Slovak Republic—Compiled in Terms of the Joint Convention on the Safety of Spent Fuel Management and on the Safety of Radwaste Management", National report of Slovakia for the 6th Review Meeting, IAEA, August 2017, see https://www.iaea.org/sites/default/files/national_report_of_slovakia_for_the_6th_review_meeting_-_english.pdf, accessed 19 August 2021.

913 - *WNN*, "Chernobyl 1-3 enter decommissioning phase", 13 April 2015, see https://world-nuclear-news.org/Articles/Chernobyl-1-3-enter-decommissioning-phase, accessed 1 July 2021.

914 - Belgian Nuclear Research Centre, "Belgian Reactor 3 - BR3", SCK CEN, Undated, see https://science.sckcen.be/en/Facilities/BR3, accessed 1 July 2021.

915 - Andreas Kockartz, "Der Rückbau der belgischen Kernkraftwerke kostet mindestens 18 Mia. €", *vrt NWS*, 30 June 2021 (in German), see https://www.vrt.be/vrtnws/de/2021/06/30/der-rueckbau-der-belgischen-kernkraftwerke-kostet-mindestens-18/, accessed 1 July 2021.

closed in 1997, was put into LTE in 2007 for 40 years.[916] In **Switzerland**, Mühleberg, which was closed in 2019, constitutes the first reactor to enter decommissioning. The operator BKW Energie expects decommissioning to last 15 years.[917]

In **Taiwan**, the two reactors at the Chinshan site got their decommissioning license in 2019[918] and decommissioning to a greenfield site is expected to last 25 years.[919] In **Armenia**, a Nukem-led consortium consisting also of EWN was awarded a contract in 2014 to set up a decommissioning plan for the closed reactor of the Metsamor site. There is however no clear indication if the plan is finished or actual dismantling works have started. For Rajasthan-1 in **India**—placed in LTO status since 2004 and (since 2014) considered by WNISR as closed as of this date—no official information is available as to whether actual dismantling work has started. However, there has been a media report in March 2021 stating that "fuel has been removed".[920]

Decommissioning of the sodium-cooled fast reactor Aktau in **Kazakhstan** is progressing very slowly due to its complexity. From 1999 until 2016 with the financial support of the U.S. government, nuclear fuel was removed and, works on the sodium in the primary circuit were carried out.[921] The decommissioning strategy is to put the reactor into LTE for 50 years. Financing decommissioning is also a challenge. Total costs were estimated to be around KZT125 billion (US$330 million); of which only roughly one percent of the estimate has been collected in Kazakhstani Wealth Fund Samruk- Kazyna. The remaining funding will be paid by the local residents through the electricity tariff.[922]

COUNTRY CASE STUDIES

The following section describes a number of case studies by order of significance in recent decommissioning activities.

916 - Wolfgang Irrek, Lutz Jarczynski and Lars Kirchner, "Comparison Among Different Decommissioning Fund Methodologies for Nuclear Installations—Country Report The Netherlands", Wuppertal Institute, On Behalf of the European Commission Directorate-General Energy and Transport, 31 October 2006.

917 - *WNN*, "Mühleberg plant enters permanent decommissioning stage", 18 September 2020, see https://www.world-nuclear-news.org/Articles/Muhleberg-plant-enters-permanent-decommissioning-s, accessed 1 July 2021.

918 - Atomic Energy Council, "Words from the Chairman", 1 June 2020, see https://www.aec.gov.tw/english/About-AEC/Words-from-the-Chairman-17.html, accessed 1 July 2021.

919 - Timothy Ferry, "Nuclear Decommissioning Stuck in Limbo", AmCham Taiwan, *Taiwan Business TOPICS*, 6 February 2020, see https://topics.amcham.com.tw/2020/02/nuclear-decommissioning-in-limbo/, accessed 1 July 2021.

920 - Fiftytwo, "Fissile", 5 March 2021, see https://fiftytwo.in/story/fissile/, accessed 22 August 2021.

921 - *NEI*, "Local residents pay for decommissioning of Kazakhstan's BN-350 reactor", 27 February 2020, see https://www.neimagazine.com/news/newslocal-residents-pay-for-decommissioning-of-kazakhstans-bn-350-reactor-7796914, accessed 2 July 2021.

922 - Ibidem.

Focus Country: Germany

With the closure of Philppsburg-2 in Bavaria on 31 Germany has (with the U.K.) the second largest fleet of closed reactors (30) worldwide as well as the second highest number of decommissioned units (5) in the world. WNISR2021 therefore looks in detail into the decommissioning sector in Germany.

Completed Decommissioning Projects

Germany closed its first reactor already in 1971: the prototype reactor **HDR Großwelzheim** in Bavaria, a Boiling Water Reactor operated with superheated steam. The reactor was already closed after around 1.5 years. The reason for the closure was the discovery of defective fuel elements which would not have allowed continued operation at full load. Although the decommissioning license was granted in 1983, the reactor was used for experiments on reactor safety from 1974 until 1992.[923] In 1993, the decommissioning licensee KIT (Karlsruher Institut für Technologie) began with the dismantling of the unit and decommissioning was completed in 1998 with the restoration of the site to the greenfield state. There is no indication on the decommissioning cost.

The second reactor that finished decommissioning was **Niederaichbach**, a heavy water-moderated pressure-tube reactor in Bavaria, which entered power operation in 1973, but was closed only a year later. The power plant only operated 18 days with full load.[924] Although, the floor slabs of the reactor building remained in the ground, the reactor is considered as a "greenfield site".[925] Decommissioning costs amounted to around DM269 million (around €$_{2021}$184 million or US$$_{2021}$166 million) and was thus more expensive than construction (DM232 million).[926] Far more than 90 percent of the decommissioning costs were borne by the federal government, with the rest covered by Siemens AG.[927]

The first and only light water reactor which was released from regulatory control is the prototype boiling water reactor **VAK Kahl**. The reactor was closed in 1985 after 24 years of operation. This also constitutes the first decommissioning project by German utilities, as the reactor was majority-owned by RWE (75 percent). Dismantling began immediately after its closure and the site was released as a greenfield site in 2010. Total costs were given as

923 - Stefan Thierfeldt and Frank Schartmann, "Stilllegung und Rückbau kerntechnischer Anlagen—Erfahrungen und Perspektiven", 3rd Edition, Brenk Systemplanung, Report Commissioned by the German Federal Ministry of Education and Research, November 2009 (in German), see https://www.ptka.kit.edu/ptka-alt/downloads/ptka-wte-e/WTE-E-Entsorgungsforschung-Broschuere_Stilllegung-und-Rueckbau_BRENK.pdf, accessed 22 August 2021.

924 - Ines Bredberg, Johann Hutter et al., "Statusbericht zur Kernenergienutzung in der Bundesrepublik Deutschland 2019", German Federal Office for the Safety of Nuclear Waste Management, 21 September 2020, op. cit.

925 - Ibidem.

926 - Luis Valencia and Erwin Prechtl, "Die Demontage und Beseitigung des Kernkraftwerkes Niederaichbach (KKN) bis zur 'Grünen Wiese'—Abschlußbericht", Scientific Report FZKA 6070, Karlsruhe Institute of Technology, April 1998 (in German), see https://publikationen.bibliothek.kit.edu/270043126/3813667, accessed 22 August 2021.

927 - Federal Government of Germany, "Antwort der Bundesregierung—Erfahrungen aus dem Abriß des KKW Niederaichbach (KKN) für die Entsorgung stillgelegter Kernkraftwerke", Drucksache 13/721, German Bundestag, 9 March 1995 (in German), see https://dserver.bundestag.de/btd/13/007/1300721.pdf, accessed 22 August 2021.

€150 million in 2010 (~US$$_{2010}$14,366/kW). Decommissioning took longer and was more costly than construction, according to RWE.[928]

Two commercial reactors finished the technical decommissioning process. **Gundremmingen-A** closed in 1977 after 10 years of operation after an emergency cooling system malfunctioned and flooded the containment building.[929] Decommissioning was started in 1983 and concluded in 2016.[930] The latest cost estimate for decommissioning of Gundremmingen-A was around €2.2 billion (US$2.4 billion) or €9,000/kW (US$9,690/kW).

Würgassen was shut down in 1994, after 23 years of operation, when cracks on the reactor's core jacket were found during a scheduled inspection.[931] Decommissioning started in 1997 and was concluded in 2014. The latest cost estimate for Würgassen was around €1 billion (US$1.1 billion) or €1,500/kW (US$1,615/kW). Both sites, Würgassen and Gundremmingen, cannot be released from regulatory control as the buildings are used for further decommissioning works or interim storage of wastes.[932] Also for these two reactors both decommissioning costs and duration exceed construction costs and duration.

Table 13 – Decommissioned Reactors in Germany (as of May 2021)

Reactor	Capacity in MW	Reactor type	Decommissioning licensee	Closure in	Operating time	Released from regulatory control
HDR Großwelzheim	25	BWR[(a)]	KIT	1971	1.5 year	1998
Niederaichbach	100	HWGCR	KIT	1974	1.5 year (18.3 days full load)	1998
Gundremmingen-A	237	BWR	75% RWE, 25% E.ON	1977	10 years	not yet
VAK Kahl	15	BWR	80% RWE, 20% Bayernwerk AG	1985	24 years	2010
Würgassen	640	PWR	E.ON	1994	23 years	not yet
Total	1 017					

Sources: Various, compiled by WNISR, 2021

Note: (a) - Superheated steam reactor.

Table 13 provides an overview of the completed decommissioning projects in Germany. Although five reactors have been decommissioned, this represents only around 1 GW of capacity. In the cases of Gundremmingen A, HDR Großwelzheim, and Niederaichbach, decommissioning lasted three to four times as long as construction and operation combined. Where decommissioning costs are available, they exceed construction costs. Final costs are only available for the two prototype reactors. For the two commercial reactors only the latest

928 - Katja Riedel, "Anfang und Ende des ersten deutschen Meilers", *Focus Online*, 14 March 2016 (in German), see https://www.focus.de/wissen/klima/tid-22667/versuchsatomkraftwerk-kahl-anfang-und-ende-des-ersten-deutschen-meilers_aid_637434.html, accessed 3 July 2020.

929 - Thomas Overton, "Malware at German Nuke Plant Leads to Shutdown", *POWER Mag*, 27 April 2016, see https://www.powermag.com/malware-at-german-nuke-plant-leads-to-shutdown/, accessed 20 August 2021.

930 - Ines Bredberg, Johann Hutter et al., "Statusbericht zur Kernenergienutzung in der Bundesrepublik Deutschland 2016", German Federal Office for the Safety of Nuclear Waste Management, August 2017 (in German), see https://doris.bfs.de/jspui/bitstream/urn:nbn:de:0221-2017070714281/3/Statusbericht_2016_BfE-KE-01-17.pdf.

931 - Ines Bredberg, Johann Hutter et al., "Statusbericht zur Kernenergienutzung in der Bundesrepublik Deutschland 2019", German Federal Office for the Safety of Nuclear Waste Management, 21 September 2020, op. cit.

932 - Jan Paul Seidel and Ben Wealer, "Rückbau von Kernkraftwerken in Deutschland. Analyse von Organisationsmodellen, Status Quo des Rückbaus, Marktbeobachtung und internationale Erfahrungen", TU Berlin, 2015.

estimates are known. In addition, they have not yet been released from regulatory control and are not yet in a "greenfield" state, so costs are not final. Although these two reactors are considered commercial, their net power capacity is relatively low. Concerning decommissioning experience of the incumbent German utilities, only a majority-owned RWE reactor has been fully decommissioned. Energie Baden-Württemberg AG (EnBW), PreussenElektra (E.ON), and Vattenfall have not yet released a reactor from regulatory control.

Decommissioning Monitoring

Currently, decommissioning work is ongoing at 24 units.

- Eight reactors are in the warm-up stage: Biblis-A and -B (both defueled), Grafenrheinfeld (defueled), Gundremmingen-B, Isar-1 (defueled), Krümmel (defueled), Lingen (defueled), and Philippsburg-2;
- Eight reactors are in the hot-zone-stage: AVR Jülich, Brunsbüttel, KNK II, Mülheim-Kärlich, Neckarwestheim-1, Obrigheim, Philippsburg-1, and Unterweser;
- Eight reactors are in the ease-off-zone stage: Greifswald Units 1–5, MZFR, Rheinsberg, and Stade.

The thorium prototype reactor THTR-300 is the only reactor in LTE in the country.

With the defueling of **Isar-1** in November 2020,[933] all eight reactors closed in the aftermath of the Fukushima events in March 2011 are now defueled. **Grafenrheinfeld** was defueled too in December 2020.[934] The still operational **Gundremmingen-C** reactor in Bavaria got its decommissioning license granted. The reactor will be shut down on 31 December 2021 (at the latest). In April and July 2020, respectively, the Hessian Ministry of the Environment issued the second dismantling permit for Unit A and B of the **Biblis NPP**.[935] This permit includes the dismantling of the reactor pressure vessel and the biological shield, which was initially scheduled to be carried out in 2020–2024. As there is currently no information that the works in the hot-zone have started, WNISR counts both reactors as in the "warm-up" stage. RWE plans to complete the decommissioning process by 2032. In July 2020, the first underwater dismantling work on the internals of the reactor pressure vessel at the **Brunsbüttel** nuclear power plant has been successfully completed.[936]

Decommissioning of **Stade** (640 MW) was thought to be achieved by 2014, but ongoing difficulties due to unexpected contamination keeps delaying the project. PreussenElektra now expects to conclude decommissioning by 2026, while initial cost

933 - Harald Mitterer, "Rückbau: Das Atomkraftwerk Isar 1 ist frei von Brennelementen", *BR24*, 12 November 2020 (in German), see https://www.br.de/nachrichten/bayern/rueckbau-das-atomkraftwerk-isar-1-ist-frei-von-brennelementen,SG8tT8r, accessed 28 June 2021.

934 - Andreas Wilkens, "Atomkraft: AKW Grafenrheinfeld hat keine Brennelemente mehr", *Heise*, 16 December 2020 (in German), see https://www.heise.de/news/Atomkraft-AKW-Grafenrheinfeld-hat-keine-Brennelemente-mehr-4991465.html, accessed 28 June 2021.

935 - Hessian Ministry of the Environment, Climate Protection, Agriculture and Consumer Protection, "Umweltministerium erteilt zweite Abbaugenehmigung für Block B", Press Release, 15 July 2020 (in German), see https://www.hessen.de/presse/pressemitteilung/umweltministerium-erteilt-zweite-abbaugenehmigung-fuer-block-b-0, accessed 28 June 2020.

936 - Vattenfall, "Rückbau Kernkraftwerk Brunsbüttel – Dampftrockner erfolgreich zerlegt", 23 July 2020 (in German), see https://group.vattenfall.com/de/newsroom/blog/2020/rueckbau-kernkraftwerk-brunsbuettel, accessed 28 June 2021.

estimates of around €500 million (US$2021594 million) are now expected to double to over €1 billion (US$20211.2 billion).[937]

Table 14 shows the development in the decommissioning process since 2015 (see WNISR2018 for more details on decommissioning in Germany).

Table 14 – Status of Reactor Decommissioning in Germany (as of May 2021)

Closed Reactor Status in Germany	2015	May 2018	May 2019	May 2020	May 2021
"Warm-up-stage"	10	11	11	8	8
of which defueled	*0*	*3*	*6*	*4*	*6*
"Hot-zone-stage"	3	4	4	8	8
"Ease-off-stage"	9	8	8	8	8
LTE	2	1	1	1	1
Completed	4	5	5	5	5
of which released from regulatory control	*3*	*3*	*3*	*3*	*3*
Total Closed Reactors	**28**	**29**	**29**	**30**	**30**

Sources: Various, compiled by WNISR, 2021

Concentrated decommissioning market in the hot-zone

Germany is currently exploring large-scale decommissioning, and, with the exception of the former GDR reactors, it is currently carried out (and financed) by the utilities themselves. The legacy fleet of the former GDR is being decommissioned by Entsorgungswerk für Nuklearanlagen (EWN), a public company under control of the German Federal Ministry of Finances. EWN was initially set up solely for the decommissioning of the GDR legacy fleet but has been since then involved in the majority of the German decommissioning projects.[938] Experiences from past and ongoing decommissioning projects show that specialized companies are needed for the works in the "hot-zone stage", where the reactor pressure vessel (RPV) and the reactor vessel internals (RVI) are dismantled. There were concerns that, as the industry for nuclear decommissioning and waste management services required in this stage involved only a few globally operating firms, this would constitute a bottleneck.[939]

RWE tendered most of its hot-zone works to a consortium consisting of Orano GmbH, a German subsidiary of French Orano, and German EWN. The consortium is responsible for the dismantling of the reactor vessel internals at three RWE reactors (Biblis-A/B, Mülheim-Kärlich) and the dismantling of the reactor pressure vessel at Mülheim-Kärlich,[940] while the segmentation of the vessel was tendered to the U.S. company Atkins. In 2017, Vattenfall tendered the dismantling of the reactor vessel internals of the Brunsbüttel and Krümmel plants to the Orano/EWN consortium.

937 - Jörg Dammann, "Rückbau des AKW Stade dauert zwei Jahre länger", *Kreiszeitung Wochenblatt*, 6 December 2020 (in German), see https://www.kreiszeitung-wochenblatt.de/stade/c-wirtschaft/rueckbau-des-akw-stade-dauert-zwei-jahre-laenger_a186108, accessed 28 June 2021.

938 - Tim Scherwath, Ben Wealer and Roman Mendelevitch, "Nuclear decommissioning after the German Nuclear Phase-Out an integrated view on new regulations and nuclear logistics", *Energy Policy*, 2020.

939 - Ibidem.

940 - Orano will take over the dismantling of the internals, while EWN is responsible for the dismantling of the reactor pressure vessel as well as the conditioning of the wastes.

EnBW awarded a contract for the dismantling of the RPV and RVI of its first reactor to enter decommissioning Obrigheim to EWN. Dismantling of the RPV and RVI of Philippsburg-1 is carried out by a Westinghouse-led consortium with Nukem Technologies and GNS. Dismantling of the RVI at the Philippsburg-2 and Neckarwestheim-2 stations will also be carried out by the Orano/EWN consortia.[941]

In January 2018, PreussenElektra awarded the dismantling of the RVI of six of its reactors to ZerKon—a consortium consisting of three companies: the German utilities-owned waste management company GNS, Westinghouse Electric Sweden, and Westinghouse Electric Germany. In early 2020, dismantling of the reactor internals was started at the Unterweser station. In December 2019, PreussenElektra had subcontracted the reactor vessel segmentation to the GNS group.[942] In May 2021, Preussen Elektra again awarded a single large decommissioning contract. This time the dismantling of 16 steam generators at the Unterweser, Grafenrheinfeld, Grohnde and Brokdorf stations was awarded to EDF-subsidiary Cyclife and its subcontractor Framatome, another EDF subsidiary. The dismantling of the first steam generator at Unterweser is scheduled for the second quarter of 2023.[943]

Although a bottleneck cannot yet be observed with the majority of the reactors just entering the hot-zone stage (in the coming years), there is a high concentration of companies undertaking the work in the hot-zone. Two companies stand out: the German federally-owned company EWN and French Orano. Both companies created a consortium and won the tenders for the dismantling of the vessel internals of the German reactor fleet, except for PreussenElektra. The latter contracted a Westinghouse consortium for these works.

United States

The U.S. has not only the largest fleet of operating (93) and closed reactors (40), but also the highest number of decommissioned units (14) in the world, representing about two thirds of the total.

In the U.S., so far, 40 reactors (19.2 GW) have been closed. By 2050, at least 100 reactors are likely to be undergoing decommissioning in the country. Of the 40 reactors (20 PWR, 14 BWR, 2 HTGR, 1 FBR, 1 PHWR, 2 others),[944] 14 units or 5 GW have been decommissioned (see Table 15). Currently, 13 units are in LTE and decommissioning work is ongoing at 13 units:

- nine reactors are in the warm-up stage: Crystal River-3, Fort Calhoun-1, Indian Point-2, and -3, Oyster Creek, Pilgrim-1, San Onofre-2 and -3, and Vermont Yankee and;
- four reactors are in the ease-off stage: Humboldt Bay, San Onofre-1, Zion-1 and -2.

941 - Orano, "Dismantling: Orano's global strengths", Undated, see https://www.orano.group/en/unpacking-nuclear/dismantling-orano-s-global-strengths, accessed 5 July 2021.

942 - PreussenElektra, "Kernkraftwerk Unterweser: Zerlegearbeiten im Reaktordruckbehälter haben begonnen", Press Release, 6 February 2020 (in German), see https://www.preussenelektra.de/de/unser-unternehmen/newsroom/pressemitteilungen/2020/KKUZerlegearbeitenimRDBhabenbegonnen.html, accessed 11 May 2020.

943 - Artjom Maksimenko, "Preussen Elektra erteilt Rückbauaufträge für Kernkraftwerke", *energate messenger*, 12 May 2021 (in German), see https://www.energate-messenger.de/news/212122/preussen-elektra-erteilt-rueckbauauftraege-fuer-kernkraftwerke, accessed 5 July 2021.

944 - PWR: Pressurized Water Reactor; BWR: Boiling Water Reactor; HTGR: High-Temperature Gas-Cooled Reactor; FBR: Fast Breeder Reactor; PHWR: Pressurized Heavy-Water Reactor.

Since WNISR2020, two more reactors were closed. Indian Point-3, the last reactor of the Indian Point Station, just 30 km from New York City, was closed in April 2021 after 45 years of operation. Duane Arnold-1, the only nuclear reactor in Iowa, was initially planned to close in October 2020, but the reactor already ceased operation in August, after it scrammed, when a land-based hurricane severely damaged its cooling towers.[945] The operator NexTera Energy Resources plans to transfer the spent fuel into dry storage within the next three years and opts for the LTE strategy (also labeled SAFSTOR).[946] The current site-specific cost estimate for the license termination expenses is of US$747 million (~US$1,240/kW), US$150 million of which are still missing (as of 2020).[947] Including interim spent fuel storage, and non-radiological site restoration activities, the total site-specific cost estimate amounts to $US\$_{2020}$1.05 billion.[948]

Since WNISR2018, the number of reactors in the warm-up stage has more than doubled to nine reactors in 2021, although no reactor is presently in the hot-zone. Except for the recently closed Indian Point units and the Pilgrim station, six reactors in the warm-up stage are now defueled. In August 2020 the last spent fuel from San Onofre-2 and -3 was transferred into dry storage canisters.[949] San Onofre was initially scheduled to be defueled by 2019. In May 2021, Oyster Creek was defueled by Holtec International which took ownership of the plant in mid-2019, in what it claimed was a "world record time" of 32 months.[950] Table 15 shows the decommissioning process in the U.S.

Table 15 – Status of Reactor Decommissioning in the U.S. (as of May 2021)

Closed Reactor Status in the United States	May 2018	May 2019	May 2020	May 2021
"Warm-up-stage"	4	6	8	9
of which defueled	*1*	*1*	*3*	*6*
"Hot-zone-stage"	0	0	0	0
"Ease-off-stage"	5	5	4	4
Long Term Enclosure (LTE)	12[(a)]	12[(a)]	12[(a)]	13[(a)]
Completed	13	13	14	14
of which released from regulatory control	*6*	*6*	*6*	*6*
Total Closed Reactors	**34**	**36**	**38**	**40**

Sources: Various, compiled by WNISR, 2021

Notes: (a) – of which three reactors are in "Entombment": DOE-reactors Piqua (Ohio), Bonus (Puerto Rico), Hallam (Nebraska).

945 - WNISR, "Storm Damage Prompts Early Closure of Duane Arnold Nuclear Reactor in the U.S.", 26 August 2020, see https://www.worldnuclearreport.org/Storm-Damage-Prompts-Early-Closure-of-Duane-Arnold-Nuclear-Reactor-in-the-U-S.html, accessed 25 May 2021.

946 - NextEra Energy, "Duane Arnold Energy Center—Decommissioning Process", Undated, see https://www.nexteraenergyresources.com/what-we-do/nuclear/duane-arnold/decommissioning.html; and U.S.NRC, "Duane Arnold Energy Center", Updated 24 March 2021, see https://www.nrc.gov/info-finder/reactors/duan.html, both accessed 23 August 2021.

947 - Sierra Club Iowa Chapter, "Duane Arnold Nuclear Power Plant Decommissioning", as of 2020, see https://www.sierraclub.org/iowa/duane-arnold-nuclear-power-plant-decommissioning, accessed 6 July 2021.

948 - NextEra Energy "Duane Arnold Energy Center, 2021 Annual Decommissioning and Spent Fuel Management Funding Status Report", Filed with the U.S.NRC, 31 March 2021, see https://www.nrc.gov/docs/ML2109/ML21090A232.pdf, accessed 23 August 2021.

949 - Rod Walton, "Nuclear fuel canisters all stored at decommissioned San Onofre nuclear station in California", *Power Engineering*, 8 October 2020, see https://www.power-eng.com/nuclear/waste-management-decommissioning/nuclear-fuel-canister-all-stored-at-decommission-san-onofre-nuclear-station-in-california/ - gref, accessed 6 July 2021.

950 - *WNN*, "Oyster Creek defuelled in record time", 24 May 2021, see https://www.world-nuclear-news.org/Articles/Oyster-Creek-defuelled-in-record-time, accessed 6 July 2021.

Decommissioning in the U.S. is characterized by two major trends identified in WNISR2018: removal as a whole of large components, like the reactor pressure vessel, and disposing of it without prior dismantling (see WNISR2018 for more details) and selling the license to a decommissioning contractor (see WNISR2019 for more details on this process). The former is also one reason for the short decommissioning periods in the U.S. The San Onofre decommissioning project also opts for this strategy. In summer 2020, EnergySolutions, together with AECOM the general decommissioning contractor, transported the reactor pressure vessel of San Onofre-1 to its disposal facility in Utah.[951]

The new organizational model of selling the license to a decommissioning contractor consists of transferring the decommissioning license from the operator to a decommissioning contractor, mostly a waste management company with the goal to reap efficiency gains through the co-management of the decommissioning process by a company owning disposal facilities or providing casks or spent fuel storage installations. Of the 13 reactors currently in the warm-up and ease-off stage, as well as recently completed La Crosse, only Humboldt Bay and Duane Arnold were not transferred to a decommissioning licensee or contracted to one of the following three companies: Energy Solutions, Accelerated Decommissioning Partners (NorthStar/Orano joint venture), and Holtec International (with SNC-Lavalin) and Holtec subsidiaries (see WNISR2020 for a detailed analysis).

Holtec and Entergy agreed on the transfer of the three Indian Point reactors (Unit 1 is in LTE) to Holtec International, as owner, and Holtec Decommissioning International, as decommissioning operator. Holtec has proposed decommissioning and demolishing the three units by year-end 2033, at a projected cost of US$2.3 billion.[952] The Decommissioning Trust Fund for the Indian Point Station contains US$2.4 billion.[953] Following the license transfer application some of New York's congressional lawmakers called on the NRC to hold a public hearing before approving a license transfer. However, the NRC went ahead and approved the transfer in November 2020 without any prior hearing. In January 2021, the NRC denied any requests for hearings, which was followed by the filing of a lawsuit by the New York state Attorney General on behalf of the state against the NRC in February 2021. Apart from the rejection of any public hearings, the lawsuit was also motivated by financial concerns, mainly on the question whether Holtec's decommissioning plans will ensure adequate funding for decommissioning and spent fuel management, for which Holtec also intends to use the funds. The lawsuit challenges the NRC's decision to allow Holtec to use more than US$630 million of the plant's dedicated decommissioning trust funds for spent fuel management costs.[954] As Holtec would supply the casks and spent fuel management, the US$630 million of the decommissioning funds would go directly to the company itself. In April 2021, the state withdrew the lawsuit after some arrangements were made between

951 - Rob Nikolewski, "Old reactor vessel from San Onofre nuclear plant heads to Utah", *The San Diego Union-Tribune*, 27 May 2020, see https://www.sandiegouniontribune.com/business/energy-green/story/2020-05-27/old-reactor-vessel-from-san-onofre-heads-to-utah, accessed 7 June 2021.

952 - Darrell Proctor, "Indian Point Unit 2 Will Shut Down April 30", *POWER Mag*, 27 April 2020, see https://www.powermag.com/indian-point-unit-2-will-shut-down-april-30/, accessed 6 July 2021.

953 - American Nuclear Society, "N.Y. drops its objections to sale of Indian Point in deal with Holtec", *Nuclear News*, 19 April 2021, see https://www.ans.org/news/article-2820/ny-drops-its-objections-to-sale-of-indian-point-in-deal-with-holtec/, accessed 23 August 2021.

954 - Allison Dunne, "NYS AG Sues NRC Over Indian Point Decomissioning Matters", *WAMC Northeast Public Radio*, 25 January 2021, see https://www.wamc.org/post/nys-ag-sues-nrc-over-indian-point-decomissioning-matters, accessed 6 July 2021.

Entergy, Holtec, New York State, and the involved environmental organizations. The parties agreed, amongst other issues, that Holtec maintains a minimum balance of US$400 million in the decommissioning trust fund for 10 years following the sale of the plant, and a minimum balance of US$360 million in the funds at partial site release from the NRC for costs related to waste management, and radiological cleanup of the site. Holtec has also agreed to return to the fund 50 percent of the money recovered from the DOE for spent fuel management.[955] The transfer of ownership of the Indian Point nuclear power plant was completed in May 2021.[956]

In June 2019, the owner of Crystal River-3, Duke Energy, announced that it plans to sell the operating license for Crystal River-3, which is currently in LTE, to the NorthStar and Orano joint-venture Accelerated Decommissioning Partners (ADP). The US$540-million-deal would foresee decommissioning the station by 2027, around 50 years earlier than anticipated and US$260 million cheaper.[957] In April 2020, the NRC approved the transfer. Under this agreement, Duke Energy will remain the owner of the reactor and retain ownership and control of the decommissioning fund, while ADP will become the NRC licensee responsible for decommissioning the station. In October 2020, Duke Energy and ADP successfully completed the transaction, after the Florida Public Service Commission's approval in August 2020. ADP became the licensed operator responsible for decommissioning. In addition, the company is now the owner of the dry cask storage system, including the spent fuel.[958]

The infamous second unit of Three Mile Island (TMI) is owned by GPU Nuclear, a subsidiary of FirstEnergy (which filed for bankruptcy in 2018). EnergySolutions negotiated with GPU Nuclear on purchasing TMI-2, currently in LTE, and to complete its decommissioning. The contract between EnergySolutions and the FirstEnergy subsidiary was signed in October 2019 and the decommissioning responsibility will be transferred to EnergySolutions subsidiary TMI-2 Solutions LLC. To perform the decommissioning work at TMI-2, EnergySolutions and New Jersey-based construction company Jingoli formed a joint venture, called ES/Jingoli Decommissioning LLC.[959] In January 2021, the NRC agreed to the license transfer to EnergySolutions. Financial concerns remain, as the trust fund contains around US$900 million, while decommissioning costs are estimated to be around US$1.32 billion, leaving a US$400 million shortfall. EnergySolutions aims to cut decommissioning time by 15 years—and release the site from regulatory control in 2037 instead of 2053—as well as reducing decommissioning expenses to US$1.06 billion.[960]

955 - American Nuclear Society, "N.Y. drops its objections to sale of Indian Point in deal with Holtec", *Nuclear Newswire*, 19 April 2021, see https://www.ans.org/news/article-2820/ny-drops-its-objections-to-sale-of-indian-point-in-deal-with-holtec/, accessed 6 July 2021.

956 - *WNN*, "Indian Point sale completed as decommissioning under way", 1 June 2021, see https://world-nuclear-news.org/Articles/Indian-Point-sale-completed-as-decommissioning-und, accessed 6 July 2021.

957 - *Nuclear Energy Insider*, "Crystal River to be decommissioned 50 years early", Reuters, 5 June 2019, see https://analysis.nuclearenergyinsider.com/crystal-river-be-decommissioned-50-years-early, accessed 11 May 2020.

958 - Duke Energy, "Crystal River Nuclear Plant", n.d., see https://www.duke-energy.com/Our-Company/About-Us/Power-Plants/Crystal-River, accessed 6 July 2021.

959 - *WNN*, "EnergySolutions adds TMI-2 to decommissioning projects", 16 October 2019, see https://www.world-nuclear-news.org/Articles/EnergySolutions-takes-on-TMI-2-for-decommissioning, accessed 11 May 2020.

960 - John Stang, "Companies Aim to Cut Cost, Timeline for Three Mile Island Reactor Decommissioning", *ExchangeMonitor*, 31 January 2020, see https://www.exchangemonitor.com/companies-aim-cut-cost-timeline-three-mile-island-reactor-decommissioning/, accessed 7 June 2021.

Canada

In Canada, no commercial reactor has been decommissioned so far. As of mid-2021, six reactors or 2.1 GW have been closed. Except for Gentilly-1, a Heavy-Water Moderated Boiling Light-Water Cooled Reactor (HWBLWR), all reactors are CANDU reactors (CANadian Deuterium Uranium). Gentilly-1 plus the demonstration reactor in Rolphton and the Douglas Point station are now licensed as waste facilities.[961] All three reactors are owned by Atomic Energy of Canada Limited (AECL), while Canadian Nuclear Laboratories (CNL) is the operator and license holder. Except for Gentilly-1, where full decommissioning plans have not yet been developed, AECL plans to move forward with decommissioning. In March 2021, the Canadian Nuclear Safety Commission (CNSC) granted a license amendment to the Douglas Point Waste Facility to enter active decommissioning.[962] The decommissioning process is expected to be concluded with the complete removal of the facility by 2070. Spent fuel was transferred in 1987 to the on-site dry storage facility.[963] WNISR2021 counts the Douglas Point reactor as in the warm-up-stage. For the Rolphton reactor, CNL is proposing to demolish the above-ground structures but to entomb the reactor. The remaining reactor components and installations inside the underground concrete foundation structure would be filled with grout, capped with concrete and covered with an engineered barrier and monitored for a minimum of 100 years.[964] In December 2020, CNL resubmitted a revised environmental impact statement for the entombment strategy, which did not pass a completeness check.[965]

The decommissioning start of the Douglas Point reactor constitutes the first decommissioning project for Canada and the worldwide first for a CANDU reactor. With only one reactor just entering the warm-up-stage, while the others are in LTE, there is no cost data for CANDU reactors in Canada or elsewhere (see WNISR2018 for more details on the decommissioning process and funding system in Canada).

Japan

As of mid-June 2021, 27 reactors or 17.1 GW were permanently disconnected from the grid in Japan. Japan, one of the early adopters of nuclear power, has not completed decommissioning of a single commercial reactor. The only completed decommissioning project involves the small 12-MW research reactor Japan Power Demonstration Reactor (JPDR), which was released as a greenfield site in 2002.

Since WNISR2020, there was no tangible process in decommissioning in Japan.

961 - CNSC, "Nuclear Power Plants - Decommissioning activities", 28 October 2016, see https://www.cnsc-ccsn.gc.ca/eng/reactors/power-plants/index.cfm#DA, accessed 2 May 2018.

962 - CNSC, "Commission grants licence amendment to Canadian Nuclear Laboratories to enter active decommissioning for Douglas Point Waste Facility", News Release, 15 March 2021, see https://www.canada.ca/en/nuclear-safety-commission/news/2021/03/commission-grants-licence-amendment-to-canadian-nuclear-laboratories-to-enter-active-decommissioning-for-douglas-point-waste-facility.html, accessed 26 May 2021.

963 - Canadian Nuclear Laboratories, "Decommissioning the Douglas Point facility", 3 February 2020, see https://pub-kincardine.escribemeetings.com/filestream.ashx?DocumentId=3382, accessed 5 July 2021.

964 - AECL, "Environmental Stewardship—Nuclear Power Demonstration Reactor", n.d., see https://www.aecl.ca/environmental-stewardship/nuclear-power-demonstration/, accessed 5 July 2021.

965 - CNL, "NPD – Latest EIS update", 29 March 2021, see https://www.cnl.ca/success_stories/latest-eis-update-2/, accessed 5 July 2021.

In 2020, Kyushu Electric Power filed the decommissioning license for the Genkai-2 reactor with the Japan Nuclear Regulation Authority (NRA). Defueling is expected to occur from 2026 to 2040. Kyushu Electric Power also asked approval for a change to its ongoing decommissioning plan for Genkai-1, which would push back the completion target-date from 2043 to 2054 for both units. According to the operator, the reason for this, is that the slowdown of Unit 1 would allow the decommissioning process to catch up with Unit 2, so that decommissioning works at both units can be carried out simultaneously.[966]

In April 2021, Japan Nuclear Regulation Authority (NRA) approved of the decommissioning plans for the four reactors of the Fukushima Daiini station. Decommissioning plans were submitted by TEPCO in May 2020. Currently, around 10,000 fuel assemblies are still stored in the cooling pools of the four reactors. TEPCO estimates that defueling will take 22 years. The overall decommissioning process is expected to be completed by 2064 and is currently estimated to cost more than US$2.5 billion excluding fuel disposal.[967] In October 2020, the NRA also approved the decommissioning license for Ikata-2. Defueling of the reactor is scheduled to be carried out during the preparatory stage lasting ten years. Overall decommissioning should take about 40 years.[968]

The general regulation in Japan stipulates that the licensed operator of a nuclear power plant is responsible for decommissioning. Historically, electric utilities had to establish tangible fixed assets for decommissioning during the period of operation through surcharges on the retail price of electricity and based on the output of a plant.[969] The Fukushima disaster in 2011, however, caused the shutdown of all operating plants by 2014 and thus a halt to the allocation of funds resulting in a shortage of decommissioning capital. In accordance with a Ministerial Ordinance in 2013[970], total asset retirement costs related to decommissioning are henceforth allocated by the straight-line method over the period of operation and LTE. As a response to 3/11, the surcharges were decoupled from the electricity output of a given reactor. To cover the financial shortage, many operators chose to postpone decommissioning in order to collect more money. The standard decommissioning scenario in Japan now includes a period of LTE of up to fifteen years before the plant enters the hot-zone-stage, while the overall decommissioning process is estimated to last between 25 and 40 years.[971]

In 2015, the Power Generation Cost Analysis Working Group of the Ministry for Economy Trade and Industry (METI) estimated an average of ¥71.6 billion (US$600 million) per

966 - *Asian Power*, "Kyushu Electric Power to decommission Genkai-2 Nuclear Power Plant", 2020, see https://asian-power.com/power-utility/news/kyushu-electric-power-decommission-genkai-2-nuclear-power-plant, accessed 6 July 2021.

967 - *NEI*, "Japan's NRA approves decommissioning plan for Fukushima Daiini", 29 April 2021, see https://www.neimagazine.com/news/newsjapans-nra-approves-decommissioning-plan-for-fukushima-daiini-8708800, accessed 6 July 2021.

968 - *WNN*, "Regulator approves Ikata 2 decommissioning plan", 7 October 2020, see https://www.world-nuclear-news.org/Articles/Regulator-approves-Ikata-2-decommissioning-plan, accessed 6 July 2021.

969 - Chubu Electric Power Company, "Quarterly Financial Report for the Nine Months Period Ended December 31, 2013", 31 January 2014.

970 - METI, "Ordinance No. 52", 30 September 2013.

971 - Jochen Latz, Katsuhiro Sato et al., "Decommissioning and dismantling Japan's nuclear power plants", McKinsey & Company, 8 September 2020, see https://www.mckinsey.com/industries/electric-power-and-natural-gas/our-insights/decommissioning-and-dismantling-japans-nuclear-power-plants, accessed 8 September 2020.

reactor.[972] An assessment reported by the Institute of Energy Economics of Japan (IEEJ) expects decommissioning costs at an average of ¥68 billion (US$560 million) per reactor.[973]

Another issue for the decommissioning process in Japan is that under ministerial guidelines, companies are permitted to temporarily divert decommissioning funds for other business purposes and thus risking that the funds are not available when needed. This has come to light in November 2017, with Japan Atomic Power Co using its decommissioning fund to cover costs of building the Tsuruga nuclear power station Units 3 and 4, which were later abandoned[974] (see WNISR2018, WNISR2019 for more details).

South Korea

South Korea is running a large nuclear program, including 24 operating reactors and four units under construction. As of mid-2021, two commercial reactors had been closed: South Korea's oldest unit Kori-1, a 576 MW PWR, and Wolsong-1, a 661 MW Pressurized Heavy-Water Reactor (PHWR). Wolsong-1 ceased generating power in May 2017 but was officially closed only in December 2019.[975]

Since WNISR2020, there was no tangible progress in decommissioning in South Korea. A final and detailed decommissioning plan for Kori-1 was submitted by Korea Hydro and Nuclear Power (KHNP) to the Nuclear Safety and Security Commission (NSSC) in May 2021.[976] Decommissioning is estimated to start in mid-2022 and last until December 2032.[977] According to the new plan, the decommissioning cost estimate increased from around $US\$_{2017}$570 million or $US\$_{2017}$990/kW[978] to around $US\$_{2021}$719 million ($KRW_{2020}$812.9 billion)[979].

In the next decades, South Korea is expected to build up its own decommissioning industry. In early 2020, South Korea announced plans to launch the construction of an institute that will develop decommissioning technologies, which is part of Government plans to access a global decommissioning market. Two establishments are planned: one focusing on LWRs and the other one on PHWRs[980] (see WNISR2019 for details on the decommissioning process in South Korea).

972 - Based on a calculation estimate for a sample plant, then for the other reactors multiplied with the generation output; the costs include an enclosure period of ten years. Power Generation Cost Analysis Working Group, "Report on Analysis of Generation Costs, Etc. for Subcommittee on Long-term Energy Supply-Demand Outlook", METI, May 2015, see https://www.meti.go.jp/english/press/2015/pdf/0716_01b.pdf, accessed 23 August 2021.

973 - Yuhji Matsuo, Kei Shimogori and Atsuhiko Suzuki, "Major Issues Regarding Nuclear Power Generation Costs Assessment in Japan", *IEEJ Energy Journal, Vol. 10, No. 2, January 2015, see* https://eneken.ieej.or.jp/data/6474.pdf, accessed 23 August 2021.

974 - Sasai Tsuneo, "Japan Atomic Power in dire straits after diverting funds", *The Asahi Shimbun*, 17 November 2017.

975 - KHNP, "Nuclear Power Operation - Plant Status", 31 December 2018, see http://cms.khnp.co.kr/eng/content/529/main.do?mnCd=EN03020101, accessed 27 March 2019.

976 - *WNN*, "KHNP applies to dismantle Kori 1", 14 May 2021, see https://world-nuclear-news.org/Articles/KHNP-applies-to-dismantle-Kori-1, accessed 8 July 2021.

977 - Jane Chung, "South Korea to complete dismantling of oldest nuclear reactor by 2032", *Reuters*, 19 June 2017, see https://www.reuters.com/article/us-southkorea-nuclear-idUSKBN19A02R, accessed 26 June 2019.

978 - Ibidem.

979 - Jung Min-hee, "Decommissioning Plan Released for Kori Nuclear Power Plant Unit 1", *Business Korea*, 30 June 2020, see http://www.businesskorea.co.kr/news/articleView.html?idxno=48258, accessed 5 July 2021.

980 - David Dalton, "Seoul To Build Institute For Nuclear Decommissioning", *NucNet*, 22 April 2020, see https://www.nucnet.org/news/seoul-to-build-institute-for-nuclear-decommissioning-4-3-2020, accessed 11 May 2020.

France

In February 2020, France closed Unit 1 of the Fessenheim station, followed by Unit 2 in June 2020. These represent the first large PWRs to enter decommissioning in France. The closed French reactor fleet now includes 14 reactors (8 GCR, 1 HWGCR, 2 FBR, 3 PWR) or 5.6 GW.[981] French regulation states that decommissioning has to begin immediately after reactor closure, but depending on the type of reactor, this could mean many years up to several decades.

Currently, decommissioning work is ongoing at 14 units:

- Four reactors are in the warm-up stage: Brennilis, Phénix, Fessenheim-1, and Fessenheim-2;
- two reactors are in the hot-zone: Superphénix, and Chooz-A;
- eight reactors are in LTE: Bugey-1, Chinon A-1, A-2, A-3, St Laurent A-1, A-2, G-2 and G-3 at Marcoule.

There was no tangible progress in decommissioning since 2019. The completion of the decommissioning of the HWR EL-4 on the Brennilis was postponed again by two years, with the earliest possible completion in 2040. The plant should be in the hot-zone between 2022 and 2035.[982]

With 56 PWRs, French utility EDF operates the most standardized fleet in the world. Until the Fessenheim station was closed, the only closed PWR was Chooz-A, where decommissioning is expected to be completed by 2025.[983] For Fessenheim, EDF foresees a post-operational stage of five years. The reactors have been defueled. All spent fuel has been moved to the spent fuel pool, which is in a separate building.[984] In the next few years, spent fuel will be removed from the pools and sent to the nuclear fuel reprocessing plant of La Hague. During the post-operational phase, non-nuclear installations will be dismantled too. After this stage, the partial dismantling of the reactor will begin in 2025, during which all the buildings—except for the reactor building—will be dismantled. During this period, the reactor will be isolated and under surveillance.[985] The dismantling of the nuclear island will be carried out in the final stage and last around five years; decommissioning of Fessenheim is thus scheduled to take around 20 years. EDF has undertaken to reclassify the site by 2041 and keep it "for industrial use", which has yet to be defined.[986]

981 - In addition, there is the military reactor G-1 on the Marcoule site, closed in 1968 and under decommissioning ever since.

982 - IRSN, "Les démantèlements d'installations nucléaires en France – Les démantèlements en cours chez EDF, Areva et au CEA", 2020 (in French), see https://www.irsn.fr/FR/connaissances/Installations_nucleaires/demantelement/demantelement-France-centrales-installations-nucleaires-EDF-recherche-militaire/Pages/2-centrales-installations-nucleaires-en-cours-France.aspx, accessed 5 July 2021.

983 - Bertrand Martelet, "EDF's Expertise and Position in Nuclear Decommissioning", presented at the World Nuclear Decommissioning & Waste Management Congress, September 2016.

984 - Ministry of the Environment, Climate Protection and the Energy Sector of Baden-Württemberg, "Fessenheim (Frankreich)", 4 December 2020 (in German), see https://um.baden-wuerttemberg.de/en/umwelt-natur/kernenergie-und-strahlenschutz/kerntechnische-anlagen/grenznahe-kernkraftwerke/fessenheim-frankreich/, accessed 5 July 2021.

985 - Adélaïde Tenaglia, "Fessenheim: comment démantèle-t-on une centrale nucléaire?", *Le Parisien*, 19 February 2020 (in French), see http://www.leparisien.fr/economie/fessenheim-comment-demantele-t-on-une-centrale-nucleaire-19-02-2020-8262930.php, accessed 11 May 2020.

986 - Adrien Dentz, "Le complexe et coûteux démantèlement de la centrale nucléaire de Fessenheim", *Le Monde*, 20 February 2020 (in French), see https://www.lemonde.fr/economie/article/2020/02/20/le-complexe-et-couteux-demantelement-de-la-centrale-nucleaire-de-fessenheim_6030185_3234.html, accessed 11 May 2020.

For the entire PWR fleet, in 2015, EDF expected total costs of around €75 billion (US$$_{2015}$82 billion) but only €23 billion (US$26 billion) are covered by earmarked investments. In a recent report on the technical and financial feasibility of the decommissioning process, the French National Assembly alleged that EDF shows excessive optimism.[987] The report concluded that decommissioning and clean-up will take more time, that the technical feasibility is not fully assured, and that the process will likely cost overall much more than EDF anticipates. Table 16 shows the current status of reactor decommissioning in France (See WNISR2018 for details).

Table 16 – Status of Reactor Decommissioning in France (as of May 2021)

Closed Reactor Status in France	May 2018	May 2019	May 2020	May 2021
"Warm-up-stage"	3	3	4	4
of which defueled	2	2	1	1
"Hot-zone-stage"	1	1	2	2
"Ease-off-stage"	0	0	0	0
LTE	8	8	8	8
Completed	0	0	0	0
of which released from regulatory control	0	0	0	0
Total Closed Reactors	**12**	**12**	**14**	**14**

Sources: Various, compiled by WNISR, 2021.

Lithuania

In Lithuania, two RBMK Chernobyl-type reactors with 1185 MW each were closed in 2004 and 2009 respectively as a requirement for Lithuania to join the European Union. The two reactor cores are defueled and in May 2021, the last spent fuel assemblies were removed from the pool of Unit 1 and transported to the interim dry storage facility. The complete removal of the spent fuel from Unit 2 is estimated to be achieved in October 2022.[988] The decommissioning end-date has, since 2011, been postponed by a further nine years to 2038. It is planned to decommission Ignalina to "brownfield" status.[989]

The EU covers more than half of the decommissioning costs of Ignalina. EU-support budgeted until 2020 has totaled €1.8 billion (US$2 billion).[990] In 2021, the EU approved additional funding of €552 million (US$647 million) for the period 2021–2027.[991] Between 2010 and 2015,

987 - Mission d'information relative à la faisabilité technique et financière du démantèlement des installations nucléaires de base, "Rapport d'Information déposé en application de l'article 145 du règlement par la mission d'Information relative à la faisabilité technique et financière du démantèlement des installations nucléaires de base", N°4428, Commission du Développement Durable et de l'Aménagement du Territoire, French National Assembly, 1 February 2017 (in French), see http://www.assemblee-nationale.fr/14/pdf/rap-info/i4428.pdf, accessed 18 August 2018.

988 - State Enterprise Ignalina Nuclear Power Plant, "No spent nuclear fuel left in the Unit 1 of Ignalina NPP", Press Release, 1 May 2021, see https://www.iae.lt/en/news/press-releases/no-spent-nuclear-fuel-left-in-the-unit-1-of-ignalina-npp/700, accessed 6 July 2021.

989 - European Court of Auditors, "EU Nuclear Decommissioning Assistance Programmes in Lithuania, Bulgaria and Slovakia: Some Progress Made Since 2011, But Critical Changes Ahead", Special Report, No.22, 2016, see http://www.eca.europa.eu/Lists/ECADocuments/SR16_22/SR_NUCLEAR_DECOMMISSIONING_EN.pdf, accessed 20 June 2019.

990 - Ibidem.

991 - OJEU, "Council Regulation (EU) 2021/101 of 25 January 2021 establishing the nuclear decommissioning assistance programme of the Ignalina nuclear power plant in Lithuania and repealing Regulation (EU) No 1369/2013", Document 32021R0101, 1 February 2021, see https://eur-lex.europa.eu/eli/reg/2021/101/oj, accessed 24 August 2021.

costs increased by 67 percent to an estimated total of €3.4 billion (US$3.8 billion). If high-level waste management and spent fuel disposal were included, the total costs were estimated at close to €6 billion (US$6.8 billion) and the financing gap would more than double to reach €4.2 billion (US$4.7 billion).[992] In addition, Lithuania faces a lack of qualified engineers for decommissioning, as this is the first RBMK decommissioning project worldwide; qualified international experts are also missing. (See WNISR2019 for details on the decommissioning in Lithuania).

Italy

Following a referendum on the use of nuclear power in November 1987, triggered by the Chernobyl accident in April 1986, Italy agreed to no longer generate nuclear electricity. The PWR Enrico Fermi (Trino) produced its last kilowatt-hours in March 1987, the GCR Latina and the BWR Caorso in 1986 and the BWR Garigliano in 1978.[993] In 2017, Italy estimated the cost to decommission the four reactors and the associated waste management at €7.2 billion (US$$_{2017}$8.1 billion)[994], which has more than tripled since the closure of the reactors. The state-owned company Sogin (Società Gestione Impianti Nucleari SpA), which was established during the privatization process of Enel, is responsible for decommissioning,.

Since WNISR2020, not much has happened with respect to decommissioning. All four closed reactors are in the warm-up stage and have been defueled. Sogin expects to complete decommissioning of the PWR Enrico Fermi (Trino) to a brownfield site by 2029[995], the BWR Garigliano by 2026[996], and the BWR Caorso by 2031.[997] In 1999, Sogin took over ownership of the only GCR in Italy, the Latina plant—defueled in the early 1990s—and expects decommissioning up to the Brownfield Stage, with waste storage units onsite, to be completed by 2027, and to cost €313 million (US$369 million).[998]. Wastes are currently stored on-site, but the GCR Latina depends more than any other reactor on the opening of a national repository as the dismantling of the reactor will produce around 2,000 tons of highly radioactive graphite.

The missing waste disposal infrastructure not only hinders the complete decommissioning of the reactors, Italy also has to rely on other countries for waste management treatment. For instance, spent fuel of the LWRs was sent to France for reprocessing, and spent fuel of the Magnox reactor Latina to the U.K. Former operational wastes are sent to Slovakia for

992 - European Court of Auditors, "EU Nuclear Decommissioning Assistance Programmes in Lithuania, Bulgaria and Slovakia: Some Progress Made Since 2011, But Critical Changes Ahead", 2016, op. cit.

993 - WNISR considers the day of the last electricity generation as the closure date.

994 - David Dalton, "Italy's €7.2 Billion Decommissioning Cost Estimate Is Robust And Thorough, Says IAEA", *NucNet*, 21 September 2017, see https://www.nucnet.org/all-the-news/2017/09/21/italy-s-7-2-billion-decommissioning-cost-estimate-is-robust-and-thorough-says-iaea, accessed 24 August 2021.

995 - Sogin, "Trino Nuclear Power Plant", Undated, see https://www.sogin.it/en/closureoftheitaliannuclearcycle/italian-nuclear-sites/trinonuclearpowerplant/Pagine/default.aspx, accessed 24 August 2021.

996 - Sogin, "Garigliano nuclear power plant", Undated, see https://www.sogin.it/en/closureoftheitaliannuclearcycle/italian-nuclear-sites/gariglianonuclearpowerplant/Pagine/default.aspx, accessed 24 August 2021.

997 - Sogin, "Caorso nuclear power plant", Undated, see https://www.sogin.it/en/closureoftheitaliannuclearcycle/italian-nuclear-sites/caorsonuclearpowerplant/Pagine/default.aspx, accessed 24 August 2021.

998 - *WNN*, "Italy approves dismantling of Latina plant", 2 June 2020, see https://world-nuclear-news.org/Articles/Dismantling-of-Italys-Latina-plant-to-begin, accessed 6 July 2020; also Sogin, "Latina nuclear power plant", Undated, see https://www.sogin.it/en/closureoftheitaliannuclearcycle/italian-nuclear-sites/latinanuclearpowerplant/Pagine/default.aspx, accessed 29 August 2021.

incineration and conditioning[999], while metal waste from decommissioning (of the Garigliano reactor) are sent to EDF Cyclife's subsidiary Cyclife Sweden AB in Sweden for treatment.1000 (See WNISR2019 and WNISR2020 for details on the decommissioning process in Italy.)

United Kingdom

Since 1977, 32 reactors or 6.7 GW were closed in the U.K., consisting mainly of small, first generation Gas-Cooled Reactors (GCRs), of the Magnox design (26 reactors). Decommissioning of this legacy fleet is the responsibility of the public body Nuclear Decommissioning Authority (NDA). Some site decommissioning and remediation work has been undertaken at most sites.

All Magnox sites are defueled and reprocessing of the Magnox fuel is estimated to be completed by the end of 2021. Retrieval of the fuels from the legacy ponds (and silos) is still ongoing. Reprocessing is not an option here, as much of this fuel is—due to its heavy degradation—not suitable for reprocessing. This fuel is planned to be transferred into dry storage. Magnox Ltd. has built all of its interim intermediate-level waste storage facilities and has implemented conditioning capability at selected sites.

The NDA's initial strategy for the Magnox reactors was to seal and store the biological shield, the pressure vessel, the external pressure circuit, and steam generators, while the actual dismantling of the reactors would begin only 85 years after the initial closure.[1001] With the latest strategy publication, which is effective since March 2021, the NDA concluded that a "blanket strategy" of deferred decommissioning across the Magnox fleet is not appropriate and a site-specific strategy for each Magnox site will now be introduced, reflecting the nature and context of the facility or site in question.[1002] The idea is that site-specific strategies[1003] will result in a rolling program for the decommissioning of the Magnox fleet, allowing to share and implement lessons learned, and developing and implementing new technologies. The graphite wastes contained in the reactor cores is a significant consideration when developing site-specific strategies for reactor decommissioning. The Trawsfynydd site in Wales has been chosen as a lead site for Magnox reactor decommissioning, primarily due to the extensive degradation of the external structure since the station was closed thirty years ago (in 1991). Substantial amounts of work would be required to make it safe for LTE.[1004]

In the past, the NDA sites were managed through private-sector consortia (see WNISR2018 and WNISR2019 for more details). This so-called Parent Body Organization (PBO) Model was

999 - *WNN*, "Next phase of Italian nuclear waste shipments to Slovakia begins", 30 January 2020, see https://www.world-nuclear-news.org/Articles/Second-phase-of-shipments-of-Italian-waste-to-Slov, accessed 5 July 2021.

1000 - Cyclife, "Cyclife's Swedish facility has started to receive SOGIN Garigliano NPP's dismantling waste for treatment", EDF Group, 17 September 2020, see https://www.cyclife-edf.com/en/edf/cyclife-s-swedish-facility-to-start-the-treatment-of-sogin-garigliano-npp-s-dismantling-waste, accessed 5 July 2021.

1001 - NDA, "Strategy – Effective from April 2016", 1 April 2016, see https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/518669/Nuclear_Decommissioning_Authority_Strategy_effective_from_April_2016.pdf, accessed 26 August 2021.

1002 - NDA, "Strategy – Effective from March 2021", Corporate Report, 18 March 2021, see https://www.gov.uk/government/publications/nuclear-decommissioning-authority-strategy-effective-from-march-2021, accessed 26 August 2021.

1003 - The strategy and plans for Harwell and Winfrith were not subject to review and remain unchanged.

1004 - NDA, "Nuclear Decommissioning Authority Strategy effective from March 2021", op. cit.

first abandoned in 2016 for the Sellafield complex, where a detailed NDA review concluded that the PBO model was less suited for the complex, technical uncertainties at the Sellafield site.[1005] Then in July 2018, the NDA announced that Magnox Ltd will also become a subsidiary of the NDA.[1006] In a 2018-report, the House of Commons' Public Accounts Committee stated the NDA failed in both the procurement and management of the Magnox contract (one of the highest value and most important contracts awarded by the Government), e.g. the procurement process was overly complex, the contract was awarded to the wrong bidder, the settlement of legal claims reached nearly £100 million [US136_{2021}$ million] to a losing consortium, and the scale of the work was drastically under-estimated.[1007] In 2021, the NDA announced that Dounreay Site Restoration Limited (DSRL) and Low Level Waste Repository Limited (LLWR Limited) will also become wholly-owned subsidiaries in 2021.[1008] These changes will mark the end of the NDA's PBO model with all Site Licence Companies being wholly-owned NDA subsidiaries. (See WNISR2018 for details on the decommissioning process in the U.K.).

Spain

Spain has a national policy for decommissioning its reactors, specified by the official periodically updated "General Radioactive Waste Plan".[1009] In this plan, all decommissioning and waste management activities are developed by the state-owned company Enresa (Empresa Nacional de Residuos Radiactivos S.A.). While the LTE strategy is applied for the GCR Vandellos-1, all LWRs are bound to be immediately dismantled to greenfield. Spain describes decommissioning and waste management as an essential public service and assigns these tasks by law to Enresa.[1010]

As of mid-2021, Spain has three closed reactors with a combined capacity of just over 1 GW. There was no tangible progress in decommissioning since WNISR2020. José Cabrera-1, a 241-MW Westinghouse PWR (1-Loop), which was closed in 2006 is still in the "ease-off stage" and behind schedule, as it was expected to be completed in 2020. Vandellos-1, a 480-MW GCR designed and supplied by the French state agency CEA, and was closed in 1990. Although some limited decommissioning work was carried out, WNISR considers the reactor as in LTE, as the main decommissioning will be carried out after an enclosure period of 25 years. In March 2020, Enresa has submitted an application for the transfer of ownership and decommissioning-start for the GE BWR at Santa Maria de Garoña to the Ministry for Ecological Transition and Demographic Challenge (MITECO), which Enresa expects for 2022.[1011] In March 2021,

1005 - NDA, "Explained: the new model for managing Sellafield", Corporate Report, Updated 1 April 2016, see https://www.gov.uk/government/publications/new-model-for-managing-sellafield/explained-the-new-model-for-managing-sellafield, accessed 16 May 2017.

1006 - NDA and Magnox Ltd, "Magnox Limited to become a Nuclear Decommissioning Authority subsidiary", Press Release, 2 July 2018, see https://www.gov.uk/government/news/magnox-limited-to-become-a-nuclear-decommissioning-authority-subsidiary, accessed 26 August 2021.

1007 - Public Accounts Committee, "The Nuclear Decommissioning Authority's Magnox contract", House of Commons, 27 February 2018, see https://publications.parliament.uk/pa/cm201719/cmselect/cmpubacc/461/46103.htm#_idTextAnchor000, accessed 26 August 2021.

1008 - NDA, "Strategy – Effective from March 2021", March 2021, op. cit.

1009 - Enresa, "General Radioactive Waste Plan", Updated June 2006, see https://www.enresa.es/eng/index/about-enresa/general-radioactive-waste-plan, accessed 26 August 2021.

1010 - By Article 38 bis of Law 25/1964 of the Nuclear Energy Act.

1011 - *WNN*, "Decommissioning application submitted for Garoña", 26 May 2020, see https://www.world-nuclear-news.org/Articles/Decommissioning-application-submitted-for-Garona, accessed 26 May 2020.

the Subdirectorate General for Nuclear Energy announced its decommissioning plan: the first phase, which includes the dismantling of the interior of the turbine building in order to use it as a waste management facility, is expected to take 18 months, then the second phase of decommissioning work (hot-zone, ease-off) will be the subject of another authorization, including a corresponding environmental impact assessment.[1012] The reactor is currently in the warm-up stage. (See WNISR2019 for details on the decommissioning process in Spain).

Russia

As of mid-2021, Russia has nine closed reactors with a combined capacity of 3 GW consisting of two different reactor types: six first-generation Light-Water Gas-cooled Reactors (LWGR) among them two Chernobyl-type reactors RBMK, and three Soviet-style PWRs. In Russia, there was no tangible progress in reactor decommissioning in 2019–2021. With the latest closure of Leningrad-2, a pilot and demonstration engineering center for decommissioning was created at the site to test and probe decommissioning technologies. This constitutes the second engineering center in the country, with the first being at the Novovoronezh site.[1013] As long as there is no clear evidence of decommissioning progress, WNISR considers the Russian reactors as in LTE, based on long anticipated decommissioning duration of 50 years and unclear decommissioning strategies (see WNISR2019 for details on decommissioning in Russia).

According to Rosatom, as of the end of 2017, 38 billion rubles ($US\$_{2017}$659 million) were accumulated in the "special reserve funds".[1014] To put the amount into perspective, this is not even covering the estimated decommissioning costs for the four Leningrad reactors alone. In addition, if the numbers from Lithuania's Ignalina site are taken as reference, the decommissioning of the four Leningrad RBMKs will cost more likely around €7 billion (US$8.3 billion).[1015] It seems that, in addition to technological challenges with dismantling, Russia has not set aside appropriate funding for decommissioning and has been heavily underestimating costs. It is unclear how Russia will handle this challenge in the future. One short-term option would be the long-term enclosure of closed reactors, while other units still generate income. A much riskier strategy that Russia has apparently adopted consists in the building of new reactors dedicated to generate income to replace ageing, life-extended units,[1016] pushing the financing challenge further into the future.

1012 - *NEI*, "Spain announces plans for dismantling Garona NPP", 18 March 2021, see https://www.neimagazine.com/news/newsspain-announces-plans-for-dismantling-garona-npp-8609381, accessed 5 July 2021.

1013 - *WNN*, "Russia establishes RBMK decommissioning technology centre", 23 July 2020, see https://www.world-nuclear-news.org/Articles/Russia-establishes-RBMK-decommissioning-technology, accessed 6 July 2021.

1014 - *NIW*, "Back-End: Rosatom Grapples With Challenges of RBMK Dismantling", 25 January 2019.

1015 - Ibidem.

1016 - Oskar Njaa, Nils Bøhmer and Charles Digges, "Russian Nuclear Power 2018", Bellona, 28 August 2018, see https://bellona.org/publication/25568, accessed 26 August 2021.

CONCLUSION ON REACTOR DECOMMISSIONING

Reactor decommissioning is an important element of the nuclear power system, but its technical and financial challenges are still largely underestimated. The size of the decommissioning activities is increasing rapidly, though: assuming a 40-year average lifetime, a further 180 reactors would close by 2030 (reactors connected to the grid between 1981 and 1990); and an additional 132 will be closed by 2060; this does not even account for the 99 reactors which started operating before 1981, an additional 26 reactors in Long-Term Outage (LTO) and the 53 reactors under construction as of mid-2021.

Around 60 percent of the 196 reactors already closed are located in Europe (93 in Western Europe and 24 in Central & Eastern Europe), followed by North America (46 reactors), and Asia (33 reactors). As of mid-2021, 176 units are globally awaiting or in various stages of decommissioning, seven more than in the first half of 2020. Since WNISR2020, seven additional reactors (5.5 GW) have officially been closed: two each in the U.S. and the U.K., and one each in Russia, Sweden and Taiwan.

Since WNISR2020 no reactor completed decommissioning. Worldwide, a total of 20 reactors with a combined capacity of around 6.4 GW have completed the technical decommissioning process. This represents only 6.7 percent of the total 90.4 GW withdrawn from the grid.

The average worldwide duration of the decommissioning process, independent of the chosen strategy, has been around 20 years, with a very high variance: the minimum of six years for the 22-MW Elk River plant, and the maximum of 42 years for the 17-MW CVTR (Carolinas-Virginia Tube Reactor), both small reactors, both in the U.S. Many of the decommissioned reactors are rather small, averaging a nominal capacity of 300 MW compared to the average capacity of 427 MW of the remaining 176 reactors undergoing or awaiting decommissioning, the historic experience of the decommissioning duration cannot be taken as exemplary for all upcoming decommissioning projects.

The country case-studies' updates suggest that both duration and costs have been systematically and significantly underestimated. In nearly all the cases, the ongoing decommissioning projects encounter delays as well as cost increases. The review of the developments since WNISR2020 reflects the little progress that can be reported for most of the reactors undergoing decommissioning.

The U.S. is still the most advanced country and has with 14 completed projects by far the most decommissioned reactors, representing around three quarters of the world total.

Germany is the second-most advanced country with five completed projects, although this represents only around 1 GW of capacity. In three of five cases decommissioning lasted three to four times as long as construction and operation combined. Where decommissioning costs are available, they exceed construction costs.

Expanding the view from the 11 case studies to the global decommissioning industry shows that international decommissioning progress is even lower with only 10 percent completed. More than a third of the reactors (74) are in long-term enclosure (LTE).

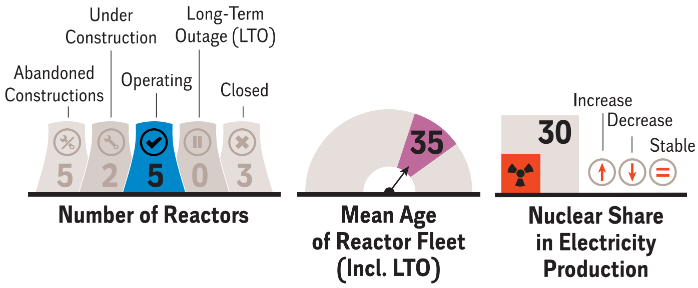
Globally, only one more reactor in the ease-off stage could be identified, the 10 MW BR-3 reactor in Belgium, which is expected to complete decommissioning to a greenfield site by 2023.

Looking at the hot-zone stage, only five more reactors could be identified where the nuclear island is currently being dismantled: the two Barsebäck units as well as the two Oskarshamn units in Sweden, and on at the Bohunice site in Slovakia where decommissioning is the most advanced.

Table 12 gives an overview of reactor decommissioning worldwide. Only five countries having experience in concluding hot-zone decommissioning works shows the great obstacles and challenges that the majority of countries operating nuclear power plants will have to overcome in the near future. Worldwide decommissioning is only just beginning and has progressed very slowly to date.

POTENTIAL NEWCOMER COUNTRIES

These "quick view" indicators will be used in the country sections throughout the report.



ASIA

Bangladesh

The idea of building nuclear reactors at Rooppur goes back to even before Bangladesh became an independent country, to a 1963 plan by the Pakistan Atomic Energy Commission (PAEC) to build one reactor in West Pakistan and one in East Pakistan.[1017]

In December 2015, an agreement was reportedly signed between the Bangladesh Atomic Energy Commission (BAEC) and Rosatom for 2.4 GW of capacity, with work expected to begin in 2016 and operation to start in 2022 and 2023.[1018] Construction on Rooppur-1 and -2 began in November 2017 and July 2018, respectively.[1019] Current schedules suggest that commercial operation for Unit 1 is expected in 2023 and Unit 2 in 2024.[1020] Russia's Novovoronezh II is the reference plant for the project. In November 2020, the pressure vessel for Unit 1 was shipped to the site and in January 2021, the internals of the reactor core were delivered.[1021]

According to the nuclear deal, Russia would provide 90 percent of the funds on credit at an interest rate of Libor plus 1.75 percent. Bangladesh will have to pay back the loan in 28 years with 10-year grace period. In late May 2016, negotiations were concluded over the US$12.65 billion project, with Russia making available US$11.385 billion.[1022] The government of Bangladesh has

1017 - IAEA, "Country Nuclear Power Profiles — Bangladesh", Updated 2016, see https://cnpp.iaea.org/countryprofiles/Bangladesh/Bangladesh.htm, accessed 1 May 2021.

1018 - *WNN*, "Bangladesh, Russia ink $12.65 billion Rooppur plant deal", 29 December 2015, see http://www.world-nuclear-news.org/NN-Bangladesh-Russia-ink-12.65-billion-Rooppur-plant-deal-29121501.html, accessed 1 May 2021.

1019 - Rosatom, "First concrete poured at the constructed Rooppur NPP site (Bangladesh)", 30 November 2017, see http://www.rusatom-overseas.com/media/news/first-concrete-poured-at-the-site-constructed-npp-rooppur-bangladesh.html, accessed 4 August 2020; and Rosatom, "Main construction of the 2nd Unit of Rooppur NPP begins with the ' First Concrete' ceremony", Press Release, 14 July 2018, see http://rosatom.ru/en/press-centre/news/main-construction-of-the-2nd-unit-of-rooppur-npp-begins-with-the-first-concrete-ceremony/, accessed 15 July 2018.

1020 - Ahmed Humayun Kabir Topu, "40pc of Rooppur Nuke Power Plant project completed", *The Daily Star*, 26 July 2021, see https://www.thedailystar.net/news/bangladesh/news/40pc-rooppur-nuke-power-plant-project-completed-2137021, accessed 31 July 2021.

1021 - *NEI*, "Russia ships reactor internals for Rooppur 1", 21 January 2021, see https://www.neimagazine.com/news/newsrussia-ships-reactor-internals-for-rooppur-1-8466401/, accessed 1 May 2021.

1022 - *NEI*, "Russia initials credit agreement with Bangladesh for Rooppur NPP", 30 May 2016, see http://www.neimagazine.com/news/newsrussia-initials-credit-agreement-with-bangladesh-for-rooppur-npp-4907672/, accessed 1 May 2021.

exempted all taxes and duties which include regulatory duty, advanced VAT import duty, VAT and supplementary duty on all imported goods, parts and machinery.[1023]

In January 2019, the Government of Bangladesh signed a nuclear support contract with Russia for the supply of fuel during the operational life of the reactor,[1024] with all used fuel to be sent back to Russia for reprocessing.[1025] In May 2020, a US$287.49 million agreement was signed between the Nuclear Security and Physical Protection System Cell (NSPC) of the Bangladesh Army and JSC Eleron, a Russian company, for the supply of physical protection systems at the plant.[1026]

Journalists and social activists have voiced concerns about various aspects of the project, including the impact on water use, the lack of preparedness of emergency planning, and possible terrorist acts against the facility.[1027] Others have pointed to the unsuitability of the site, with concerns over flooding, earthquakes and shifting alluvial soil, plus water shortages and high water temperatures that could affect cooling.[1028] Critics of the project also claimed that Bangladesh lacks the skilled labor and adequate regulators to oversee the operation of the nuclear power plant.[1029] Bangladesh clearly wants help from other countries, which might explain why it appointed India's Global Centre for Nuclear Energy Partnership (GCNEP) in 2017 to oversee the development and operation of the Rooppur nuclear facilities. Bangladesh has also contracted with Indian company Larsen & Toubro to build the transmission lines to carry electricity from Rooppur, with most of the funding for this coming from the Exim Bank of India, but this might result in the project getting behind schedule because of delays in receiving the approval for the financing.[1030]

The project's economics have been widely questioned. Earlier in 2017, a retired nuclear engineer who had been involved in advising the Bangladesh Atomic Energy Commission (BAEC), argued in one of the leading English-language newspapers in Bangladesh that the country was "paying a heavy price" for BAEC not having "undertaken a large-scale programme of recruitment, and training of engineers"; he also charged that Bangladesh was buying reactors at the "unreasonable and unacceptable" price of US$5,500/kW because its "negotiators didn't have the expertise to properly scrutinize the quoted price".[1031] There have been reports about

1023 - Khondaker Golam Moazzem, "The Power and Energy Sector of Bangladesh: Challenges of Moving beyond the Transition Stage", Center for Policy Dialogue, March 2019, see https://cpd.org.bd/wp-content/uploads/2019/03/The-Power-and-Energy-Sector-of-Bangladesh.pdf, accessed 1 May 2021.

1024 - *Energy Bangla*, "Nuclear Fuel Supply Deal signed with Russia for RNPP", 31 January 2019, see http://energybangla.com/nuclear-fuel-supply-deal-signed-with-russia-for-rnpp/, accessed 1 May 2021.

1025 - WNA, "Nuclear Power in Bangladesh", January 2021, op. cit.

1026 - *The Financial Express*, "Rooppur nuke plant: $287.49m deal signed for physical protection system", 29 May 2020, see https://thefinancialexpress.com.bd/national/rooppur-nuke-plant-28749m-deal-signed-for-physical-protection-system-1590767660, accessed 1 May 2021.

1027 - Petr Topychkanov, "Why the Bangladeshi public has concerns over the Rooppur nuclear project", *Russia Beyond*, 27 February 2017, see https://www.rbth.com/blogs/south_asian_outlook/2017/02/27/why-the-bangladeshi-public-has-concerns-over-the-rooppur-nuclear-project_709866, accessed 1 May 2021.

1028 - Rakesh Sharma, "Is Bangladesh Ready for Nuclear?", *NIW*, 22 December 2017.

1029 - *NIW*, "Bangladesh", 1 December 2017.

1030 - *Dhaka Tribune*, "Delays in Rooppur power transmission project likely", 23 October 2020, see https://www.dhakatribune.com/bangladesh/nation/2020/10/23/delays-in-rooppur-power-transmission-project-likely; and Eyamin Sajid, "India's L&T to build transmission lines for Rooppur plant", *The Business Standard*, see https://www.tbsnews.net/bangladesh/indias-lt-build-transmission-lines-rooppur-plant-194038, both accessed 21 August 2021.

1031 - Abdul Matin, "The economics of the Rooppur Nuclear Power Plant", *The Daily Star*, 2 March 2017, see http://www.thedailystar.net/op-ed/economics/the-economics-the-rooppur-nuclear-power-plant-1369345, accessed 17 May 2017.

corruption in the construction of the nuclear plant, although these allegations largely revolve around materials for housing of plant workers and their families.[1032]

Nuclear power is projected in the Bangladesh Revised Power Sector Master Plan to account for about 4 percent of electricity generation in 2030. However, according to a report published by the Atlantic Council even this small contribution is not necessary, and "Bangladesh can move towards a more sustainable, lower carbon future by limiting coal development, installing efficient natural gas, expanding renewables, and improving end-use energy efficiency".[1033]

The Bangladesh renewable energy strategy had envisaged that by 2020 they would provide 10 percent of power but achieved just 3 percent with a modest installed capacity of 700 MW—the original target is likely to be met only by 2025. With land shortages increased consideration is given to the use of rooftop or floating solar. The cost of rooftop solar is thought to be in the range of US$¢3–4/kWh.[1034]

Suspended or Cancelled Programs

Indonesia

Indonesia is ranked sixteenth in terms of GDP and in 2020 was the only one of three countries in the Top 20[1035] the others being Australia and Saudi Arabia, that have not deployed nuclear power. However, in 1997 a Nuclear Energy Law was adopted that gave guidance on construction, operation, and decommissioning. After various attempts, in December 2015, the government pulled the plug on all nuclear plans, even for the longer-term future.

However, in July 2020, the U.S.-based nuclear company Thorcon International and Indonesia's Defense Ministry signed an MOU to study developing a thorium molten salt reactor (TMSR) for either power generation or marine vehicle propulsion.[1036] Indonesia is thought to have considerable thorium reserves and researchers are looking at the extraction of uranium and thorium from unconventional sources, particularly monazite, which is often co-located with the country's tin ore mining. Indonesia is the world's largest tin producer.[1037]

The latest revision of the new- and renewable-energy policy mix mentions that nuclear will be only considered should the renewable energy target to produce 23 percent of power by 2025

1032 - *The Daily Star*, "Corruption in Rooppur Nuclear Power Plant: HC seeks to know steps", 2 July 2019, see https://www.thedailystar.net/city/corruption-in-rooppur-power-plant-hc-seeks-know-steps-1765591, accessed 28 May 2020.

1033 - Robert F. Ichord, "Transforming the Power Sector in Developing Countries: Geopolitics, poverty, and climate change in Bangladesh", Atlantic Council, January 2020, see https://www.atlanticcouncil.org/in-depth-research-reports/issue-brief/transforming-the-power-sector-in-developing-countries-geopolitics-poverty-and-climate-change-in-bangladesh/, accessed 1 May 2021.

1034 - Vandana Gombar, "Bangladesh Set to Cross 1-Gigawatt Renewables Mark: Q&A", BloombergNEF, 9 November 2020, see https://about.bnef.com/blog/bangladesh-set-to-cross-1-gigawatt-renewables-mark-qa/, accessed 1 May 2021.

1035 - World Development Indicators Database, "Gross Domestic Product 2020", World Bank, 1 July 2021, see https://databank.worldbank.org/data/download/GDP.pdf, accessed 19 August 2021.

1036 - *NEI*, "Indonesia signs MOU on molten salt reactor", 31 July 2021, see https://www.neimagazine.com/news/newsindonesia-signs-mou-on-molten-salt-reactor-8055819/, accessed 1 May 2021.

1037 - Sung-Mi Kim, "Indonesia's Nuclear Dream, Revived?", *The Diplomat*, 31 December 2021, see https://thediplomat.com/2020/12/indonesias-nuclear-dream-revived/, accessed 1 May 2021.

not be achieved,[1038] which may be indeed tough to meet, considering the 12-percent level in 2020.[1039]

Kazakhstan

Kazakhstan operated a small fast breeder reactor, the BN350 at Aktau, between 1972–1998 and is one of three countries in the world to have abandoned commercial nuclear power, the others being Italy and Lithuania. But in contrast to the other countries Kazakhstan has considerable uranium reserves and Kazatomprom is the world's largest producer. Kazakhstan has had discussions with countries and reactor suppliers. In April 2019, during a meeting between President Putin of Russia and Kazakhstan's President Qasym-Zhomart Toqaev, it was suggested that Russia help in the construction of a nuclear power plant at Ulken in the southeastern Almaty Province. Soon after this, Deputy Kazakh Energy Minister Magzum Mirzagaliev said there was no "concrete decision" to construct a nuclear power plant in Kazakhstan.[1040] Meanwhile the country is investing in renewable energy and in 2019, twenty-one renewable projects attracted US$613 million in investments and Central Asia's largest solar power plant, the 100-MW-Saran solar project, built by German developers, began operating the same year.[1041]

Thailand

In June 2007, in Thailand the cabinet set up the Nuclear Power Program Development Office under the National Energy Policy Council and appointed an Infrastructure Establishment Committee, the Nuclear Power Utility subcommittee of which is supervising the electricity utility (Electricity Generating Authority of Thailand or EGAT) in assessing the options for nuclear power. Since then, various policy options and companies have been considered, and in April 2017, China and Thailand signed a nuclear co-operation agreement. At that occasion, China General Nuclear Power Group (CGN) stated that "China is very willing to provide Thailand with the most advanced, most economical and safest nuclear power technology, as well as equipment, management experience and quality service."[1042] However, since then, there seems to have been no progress in developing nuclear power in Thailand.

1038 - Norton Rose Fulbright, "Renewable energy snapshot: Indonesia", April 2019, see https://www.nortonrosefulbright.com/en/knowledge/publications/0552a1f0/renewable-energy-snapshot-indonesia, accessed 1 May 2021.

1039 - McKinsey & Company, "Ten ways to boost Indonesia's energy sector", December 2020, see https://www.mckinsey.com/industries/oil-and-gas/our-insights/ten-ways-to-boost-indonesias-energy-sector-in-a-postpandemic-world#, accessed 1 May 2021.

1040 - Bruce Pannier, "Putin Offers Russian Help To Build Kazakh Nuclear Plant", *RadioFreeEurope/RadioLiberty*, 6 April 2019, see https://www.rferl.org/a/kazakhstan-putin-offers-russian-nuclear-plant-help/29865177.html, accessed 1 May 2021.

1041 - Vlagyiszlav Makszimov and, "Kazakhstan approves new green projects in a bid to cut fossil fuels in half by 2050", *The Astana Times*, as published by *Euractiv*, 25 May 2020, see https://www.euractiv.com/section/central-asia/news/kazakhstan-approves-new-green-projects-in-a-bid-to-cut-fossil-fuels-in-half-by-2050/, accessed 1 May 2021.

1042 - *WNN*, "China, Thailand agree to nuclear energy cooperation", 5 April 2017, see https://www.world-nuclear-news.org/NP-China-Thailand-agree-to-nuclear-energy-cooperation-0504174.html, accessed 1 May 2021.

Uzbekistan

Uzbekistan has announced its intention to develop nuclear power, with the help of Russia. In an April 2019 interview with *Nuclear Engineering International* (*NEI*), Jurabek Mirzamakhmudov, director general of Uzatom, announced site analysis work over the following 18 months at three locations. Mirzamakhmudov says that they have chosen the VVER-1200 reactor design, which would be financed through an engineering, procurement and construction agreement via a soft loan from Russia. The reactors would provide power for domestic consumption, but some of it could also be exported to neighboring countries such as Afghanistan.[1043] It was later stated that the intention was to choose a site, and have it licensed by September 2020,[1044] which did not happen. A ten-year plan for electricity provision was developed with the Asian Development Bank (ADB) and the World Bank. It aims to deploy up to 30 GW of additional power capacity by 2030, including 5 GW of PV, 3.8 GW of hydropower, 2.4 GW of nuclear and up to 3 GW of wind energy.[1045]

Vietnam

Vietnam, with its growing economy and energy demand, for decades had been seen a model country to develop nuclear power, and in October 2010, Vietnam signed an intergovernmental agreement with Russia's Atomstroyexport to build the Ninh Thuan-1 nuclear power plant, using VVER-1200 reactors. Construction was expected to begin in 2014, with the turnkey project being owned and operated by the state utility Vietnam Electricity (EVN). A second agreement was also signed with Japanese companies to develop an additional plant.[1046] However, ambitions were severely curtailed in November 2016, when 92 percent of the members of the National Assembly approved a government motion to cancel the proposed nuclear projects with both Russia and Japan, due to slowing electricity demand increases, concerns about safety, and rising construction costs.[1047]

Despite this, a draft power plan published by the Ministry of Industry and Trade in July 2020 envisages building nuclear power plants with a capacity of 1 GW by 2040 and 5 GW by 2045.[1048] This would require the restart of program preparations in the second half of the 2020s.

In the meantime, the deployment of solar PV is happening at a remarkable scale. In December 2020 alone, a record 6.7 GW of rooftop solar was installed, making a total of 9.3 GW during the year. The country counts already over 100,000 rooftop solar installations. The latest Power Development Plan schedules no additional coal-fired plants during 2026–2030 with 9.5 GW

1043 - *NEI*, "Uzbekistan's nuclear aspirations", 9 April 2019, see https://www.neimagazine.com/features/featureuzbekistans-nuclear-aspirations-7145738/, accessed 1 May 2021.

1044 - *WNN*, "Russia and Uzbekistan agree to start survey of new plant site", 17 May 2019, see https://www.world-nuclear-news.org/Articles/Russia-and-Uzbekistan-agree-to-start-survey-of-new, accessed 1 May 2021.

1045 - *NEI*, "Uzbekistan's energy plans", 29 July 2020, see https://www.neimagazine.com/features/featureuzbekistans-energy-plans-8051183/, accessed 1 May 2021.

1046 - *WNN*, "Vietnam prepares for nuclear power", 6 October 2011, see https://www.world-nuclear-news.org/Articles/Vietnam-prepares-for-nuclear-power, accessed 1 May 2021.

1047 - *NIW*, "Briefs – Vietnam", 28 November 2016.

1048 - Anh Minh, "Vietnam mulls return to nuclear energy after 2035", *VnExpress International*, 9 July 2020, see https://e.vnexpress.net/news/business/economy/vietnam-mulls-return-to-nuclear-energy-after-2035-4127854.html, accessed 1 May 2021.

coal projects scrapped, while solar and wind are predicted to make up 28 percent of total system capacity in 2030 and 41 percent in 2045.

MIDDLE EAST

Egypt

The Egyptian nuclear vision began in the mid-1950s with the establishment of the Egyptian Atomic Energy Commission (currently known as the Atomic Energy Authority). Egypt started to explore the possibilities of building nuclear power reactors in the mid-1960s and established the Nuclear Power Plants Authority (NPPA) in the mid-1970s. Initial plans envisioned 10 reactors being operational by the end of the century.

Despite discussions with Chinese, French, German, and Russian suppliers, little development occurred for several decades except for selecting, in 1984, Dabaa on Egypt's Mediterranean coastline to host Egypt's first nuclear power plant.[1049] Nuclear plans were suspended indefinitely after the 1986 Chernobyl disaster and only in 2006, under former President Hosni Mubarak, was it announced that plans were to be revived.

In recent years, Egypt has stepped up its efforts and in February 2015, Rosatom and Egypt's NPPA signed a cooperation agreement, followed in November 2015 by an intergovernmental agreement for the construction of four VVER-1200 reactors at Dabaa, for a total installed capacity of 4.8 GW.[1050]

In May 2016 it was announced that Egypt had concluded a US$25 billion loan with Russia for nuclear construction, at three percent interest for 85 percent of the construction cost, to be paid back through the sale of electricity scheduled to begin on 15 October 2029.[1051] In December 2017, the construction cost of the project was reported to be US$30 billion.[1052] Three other deals were signed to cover the supply of nuclear fuel for 60 years, operation and maintenance for the first 10 years of operation, and training of personnel.

The current phase is focused on site preparation and licensing and is already behind schedule. The site chosen for construction lies 300 km from Cairo at El-Dabaa city in the Governorate of Matrouh on the north-west coast of Egypt on the Mediterranean Sea. In December 2018, Anatolos Kovatnov, the head of engineering work at the El Dabaa project, stated that Rosatom had submitted all the documents required, and hoped to obtain the permits to start construction at the first unit of the Dabaa plant in 2020.[1053] In March 2019, the Egyptian

1049 - Joy Nasr and Ali Ahmad, "Middle East Nuclear Energy Monitor: Country Perspectives 2018", Annual Report, Issam Fares Institute for Public Policy and International Affairs, American University of Beirut, January 2019, see https://www.aub.edu.lb/ifi/Documents/publications/research_reports/2018-2019/20190103_middle_east_nuclear_energy_monitor_country_perspectives_2018.pdf, accessed 17 July 2021.

1050 - Omar Fahmy, Asma Alsharif and Luke Baker, "Egypt, Russia sign deal to build a nuclear power plant", *Reuters*, 19 November 2015, see https://www.reuters.com/article/us-nuclear-russia-egypt-idUSKCN0T81YY20151119, accessed 17 July 2021.

1051 - Al-Masry Al-Youm, "Three Egyptian companies win tender for Dabaa nuclear plant", *Egypt Independent*, 17 February 2020, see https://egyptindependent.com/three-egyptian-companies-win-tender-for-dabaa-nuclear-plant/, accessed 17 July 2021.

1052 - Reem Hosam El-din, "Dabaa nuclear plant, SCZone: ambitions, plans ahead", *Daily News Egypt*, 12 December 2017, see https://dailynewsegypt.com/2017/12/12/dabaa-nuclear-plant-sczone-ambitions-plans-ahead/, accessed 13 December 2017.

1053 - *NEI*, "Work progressing at Egypt's El Dabaa NPP", 12 December 2018, see https://www.neimagazine.com/news/newswork-progressing-at-egypts-el-dabaa-npp-6896457, accessed 25 July 2021.

NPPA was granted a site permit for the reactors, the first step toward getting a construction permit.[1054]

In December 2019, Australian energy group Worley Limited was awarded a consultant contract to advise Egypt in the building process.[1055] In February 2020, Atomstroyexport, a subsidiary of Rosatom, announced that three Egyptian firms—Petrojet, Hassan Allam, and The Arab Contractors—had won a tender for the first phase of work on the plant, expected to begin in the summer of 2020 and continue through 2022.[1056] Earlier in the month, Atomstroyexport had held a training for Egyptian engineers at the Kursk-II plant under construction in Russia.[1057]

In 2018, the Egyptian Government projected that Dabaa Unit 1 would be commercially operating as of 2026 and subsequent units in 2028.[1058] This schedule was based on construction start in 2020. However, the construction license application for Dabaa Unit 1 and Unit 2 was only submitted on 30 June 2021,[1059] and is not expected to be granted before 2022.

On 14 July 2021, the Egyptian Nuclear and Radiological Regulatory Authority (ENRRA) was reported by the Egyptian economic newspaper *Enterprise* as stating that Dabaa will not be completed before 2030 due to the disruption caused by the coronavirus pandemic. Despite this, Electricity and Renewable Minister Mohammed Shaker stated on 16 July 2021 that the plant is not facing any obstacles and will begin operation in 2026.[1060] A four-year construction schedule is highly unrealistic. The information about the postponement to 2030 was confirmed on 28 July 2021.[1061]

Questions have been raised as to whether ENRRA, established in 2010, has the capacity and political independence to effectively oversee the project. Additionally, while Egyptian officials estimate that the project will bring the country US$246 billion in revenues over 60 years, some experts have raised concerns that the project will lead to a substantial increase in Egypt's external debt.[1062] The NGO Egyptian Initiative for Personal Rights also criticized that "the process of public participation (...) was not satisfactorily done".[1063] As if to highlight the lack of transparency, the latest IAEA assessment of Egypt's regulatory competence, the Integrated

1054 - *NEI*, "Egypt's El-Dabaa NPP granted site permit", 16 April 2019, see https://www.neimagazine.com/news/newsegypts-el-dabaa-npp-granted-site-permit-7156405/, accessed 17 July 2021.

1055 - *NEI*, "Worley wins contract to advise Egypt on nuclear plant construction", 31 December 2019, see https://www.neimagazine.com/news/newsworley-wins-contract-to-advise-egypt-on-nuclear-plant-construction-7581139, accessed 17 July 2021.

1056 - Al-Masry Al-Youm, "Three Egyptian companies win tender for Dabaa nuclear plant", *Egypt Independent,* op. cit.

1057 - *GCR*, "First contracts awarded for Egypt's $25bn Dabaa nuclear power station", *Global Construction Review*, 18 February 2020, see http://www.globalconstructionreview.com/news/first-contracts-awarded-egypts-25bn-dabaa-nuclear-/, accessed 17 July 2021.

1058 - *NEI, "Active progress on Egypt's El Dabaa", 22 October 2018, see* https://www.neimagazine.com/news/newsactive-progress-on-egypts-el-dabaa-npp-6820883, accessed 17 July 2021.

1059 - Rosatom, "Rosatom State Atomic Energy Corporation ROSATOM global leader in nuclear technologies nuclear energy", Press Release, 1 July 2021, see https://rosatom.ru/en/press-centre/news/nuclear-power-plants-authority-of-egypt-handed-over-the-licensing-documentation-for-el-dabaa-npp-con/, accessed 29 July 2021.

1060 - Mohammed Abu Zaid, "Egypt's nuclear project on target, minister says", *Arab News*, 16 July 2021, see https://www.arabnews.com/node/1894936/business-economy, accessed 17 July 2021.

1061 - George Mikhail, "Because of the pandemic, the Dabaa nuclear plant will not end before", *Al Monitor*, 28 July 2021, see https://www.al-monitor.com/originals/2021/07/egypt-postpones-nuclear-power-plant-amid-tensions-russia-over-nile-dam, accessed 19 August 2021.

1062 - Warsaw Institute, "Russia Kicks Off Work On Egypt's First Nuclear Power Plant", 26 February 2020, see https://warsawinstitute.org/russia-kicks-off-work-egypts-first-nuclear-power-plant/, accessed 17 July 2021.

1063 - Egyptian Initiative for Personal Rights, "'Without guarantees' A study on nuclear energy and the Dabaa project", 21 November 2019, see https://eipr.org/en/publications/without-guarantees-el-dabaa-nuclear-energy-project, accessed 17 July 2021.

Nuclear Infrastructure Review (INIR), was completed and handed over to the government on 24 September 2020.[1064] Unlike other country INIR's, as of 1 July 2021, it has not been made public.

From the perspective of nuclear security, Egypt's nuclear program poses several challenges. Independent experts have remarked that in recent years, "the rate, impact and sophistication of jihadi attacks in Egypt increased significantly and it is not unthinkable for Egypt's nuclear facilities to be targeted".[1065]

In Egypt, the installed capacity of non-hydropower renewables (solar and wind) was around 2.7 GW, as of December 2019.[1066] In 2016, the Egyptian Government had launched the "2035 Integrated Sustainable Energy Strategy", according to which it plans to generate 42 percent of the electricity through renewable energy sources, namely solar PV, concentrated solar-thermal power, wind energy and hydropower.[1067] In the same strategy, the percentage allocated for nuclear energy is just 3 percent, raising questions about the real value for investing in nuclear electricity that is only going to have such a small overall contribution to the national power mix. In parallel, the Egyptian Government has launched a series of energy reforms such as a feed-in-tariff that incentivized private sector to get involved in the country's electricity sector, providing new financing pathways.[1068]

Egypt is also making strides in the development of a domestic and regional natural gas market. Besides being host to Zohr, the largest gas field in the Eastern Mediterranean,[1069] Egypt has invested in gas import and export infrastructure to position itself as regional hub, and in the process, become self-sufficient. (See WNISR2020 – Middle East Focus). These developments will have a great impact on Egypt's electricity supply security as well as the future steps the country may take in shaping its energy policy. Despite the prioritization on renewables and natural gas, the Egyptian Government remains committed to building four nuclear reactors at the Dabaa site.

By 2035, Egypt's Dabaa nuclear power plant is projected to contribute only 3 percent of the country's electricity generation; a rather small share given the scale of planned investment (~US$60 billion).

1064 - IAEA, "IAEA Delivers INIR Mission Reports to Belarus and Egypt", 24 September 2020, see https://www.iaea.org/newscenter/news/iaea-delivers-inir-mission-reports-to-belarus-and-egypt, accessed 17 July 2021.

1065 - Kareem Gerges and Ali Ahmad, "Egypt's Nuclear Power Program: Security and Economic Risks", Policy Brief #6/2018, Issam Fares Institute for Public Policy and International Affairs, American University of Beirut, October 2018, see https://www.aub.edu.lb/ifi/Documents/publications/policy_briefs/2018-2019/20181018_egypt_nuclear_power_program.pdf, accessed 17 July 2021.

1066 - Mohamed Farag, "Egypt will produce 61,000MW of renewable energy, of which 12,000MW concentrated solar power", *Daily News Egypt*, as published on *helioscsp.com*, 28 December 2019, see http://helioscsp.com/egypt-will-produce-61000mw-of-renewable-energy-of-which- 12000mw-concentrated-solar-power/, accessed 17 July 2021.

1067 - NREA, "Renewable Energy Targets", New and Renewable Energy Authority, Ministry of Electricity and Renewable Energy, 2016, see http://nrea.gov.eg/test/en/About/Strategy, accessed 17 July 2021.

1068 - Oxford Business Group, "Egypt's energy sector undergoes reforms to regulations, energy mix", 19 March 2017, see https://oxfordbusinessgroup.com/analysis/composition-makeover-sector-undergoing-reforms-regulations-and-energy-mix, accessed 29 July 2021.

1069 - Ehab Farouk and Yousef Saba, "UPDATE 1-Egypt's Zohr gas field output rises to 2.7 bln cubic feet per day - minister", *Reuters,* 21 August 2019, see https://www.reuters.com/article/egypt-energy-idAFL5N25H1VW, accessed 17 July 2021.

Jordan

Jordan has been interested in acquiring nuclear power for over a decade. The Jordan Atomic Energy Commission (JAEC), the country's nuclear power authority, was established in 2008.[1070] In 2015, Jordan signed a US$10-billion deal with Russia's state-owned Rosatom to build two 1000-MW reactors in the kingdom.[1071] The deal called for 51 percent of the plant to be owned and financed by Jordan, with the remaining 49 percent by Rosatom.[1072] Jordan aimed to have the first unit be operational by 2021, and the second by 2025.[1073] After three years, JAEC said that the project had collapsed because Russia had required it to secure the necessary financial resources for the project via commercial loans, which would have made the prices of electricity generated uncompetitive.[1074]

Since then, JAEC's focus turned to Small Modular Reactors (SMRs, see Chapter on SMRs) and it signed a series of Memoranda of Understanding (MoU) on SMRs. Over the past few years, different SMR vendors have been reported as involved in discussions to construct their design. SMR designs that seem to be under consideration are Xe-100,[1075] SMART,[1076] and China's High Temperature Reactor.[1077] However, none of these appear to be progressing fast. One reason for the delay might be that Jordan is reluctant to host a first-of-a-kind SMR design. In 2019, a JAEC official told *Nuclear Intelligence Weekly* (*NIW*) "We're not going to be the test body" for SMR developers and that Jordan will require any SMR design it builds to be licensed in its country of origin "or by a reputable regulatory body".[1078] There are also more fundamental problems with SMRs for a country like Jordan, including economics and the availability of access to appropriate quantities of cooling water.[1079]

In the early years after the JAEC was established, a key argument offered for pursuing nuclear power was that the country's growing energy demand cannot be met with renewable energy.[1080] Ironically, during a local talk show in 2021, the head of JAEC, Dr. Khaled Toukan, admitted that nuclear has no place in Jordan as the country has access to an abundant energy potential

1070 - JAEC, "Jordan Atomic Energy Commission", 2021, see http://www.jaec.gov.jo/Pages/viewpage?pageID=1, accessed 1 May 2021.

1071 - *AP*, "Russia to build Jordan's first nuclear power plant", *Al Jazeera*, 24 March 2015, see https://www.aljazeera.com/news/2015/3/24/russia-to-build-jordans-first-nuclear-power-plant, accessed 3 May 2021.

1072 - Mohammad Ghazal, "'Nuclear commission preparing for two agreements with Russian reactor vendor'", *Jordan Times*, 10 March 2014, see http://www.jordantimes.com/news/local/nuclear-commission-preparing-two-agreements-russian-reactor-vendor, accessed 8 May 2018.

1073 - *WNN*, "Jordan, Russia sign project development agreement", 23 September 2014, see https://www.world-nuclear-news.org/Articles/Jordan,-Russia-sign-project-development-agreement, accessed 22 May 2021.

1074 - Mohammad Ghazal, "Funding issues behind scrapping nuclear deal with Russia", *Jordan Times*, 12 June 2018, see http://www.jordantimes.com/news/local/funding-issues-behind-scrapping-nuclear-deal-russia-%E2%80%94-jaec, accessed 5 July 2018.

1075 - Stephanie Cooke, "X-energy's CEO Clay Sell On the HTGR", *NIW*, 30 April 2021.

1076 - Phil Chaffee, "Smart SMR Cements Saudi-Korean Partnership", *NIW*, 10 July 2020.

1077 - Mohammad Ghazal, "Jordan, China in 'serious talks' to build gas-cooled $1b reactor", *Jordan Times*, 28 April 2018, see https://www.jordantimes.com/news/local/jordan-china-serious-talks%E2%80%99-build-gas-cooled-1b-reactor; also Ali Ahmad and M. V. Ramana, "HTRs will not help establish nuclear power in Jordan", *Jordan Times*, 10 May 2018, see http://www.jordantimes.com/opinion/ali-ahmad-and-m-v-ramana/htrs-will-not-help-establish-nuclear-power-jordan, both accessed May 2018.

1078 - Phil Chaffee, "Jordan: NuScale a Finalist in SMR Competition", *NIW, 18 January 2019*.

1079 - M.V Ramana and Ali Ahmad, "Wishful thinking and real problems: Small modular reactors, planning constraints, and nuclear power in Jordan", *Energy Policy, June 2016*.

1080 - See, for example, Suha Philip Ma'ayeh, "Jordan pushes forward with plan for first nuclear power station", *The National News*, 11 July 2011, see https://www.thenationalnews.com/world/mena/jordan-pushes-forward-with-plan-for-first-nuclear-power-station-1.435825, accessed 30 April 2021.

from other sources.[1081] Between 2014—when Jordan was at the closing stages of negotiating an agreement with Russia for two nuclear reactors—and 2019, the share of renewables in the electricity sector in Jordan grew 19-fold from 0.7 percent to 13 percent in 2019, making Jordan one of the fastest growing markets in renewable energy in the region.[1082] As of 2020, Jordan has a total renewable energy generating capacity of 1.90 GW with solar energy comprising 1.36 GW of that.[1083] According to the Updated Master Strategy of the Ministry of Energy and Mineral Resources (MEMR) for the Energy Sector 2020–2030, the kingdom targets a 31 percent share for renewables in power generation capacity by 2030.[1084]

Turkey

In Turkey, three separate projects have been in the planning stage for many years, with three different reactor designs and three different financing schemes. However, as of mid-2021, construction has only begun on the first of these projects, Akkuyu. Implementation of the other two, Sinop and İğneada, seems increasingly unlikely.

Akkuyu

Over four decades after it was first proposed, construction of a nuclear power plant at Akkuyu in the province of Mersin on Turkey's Mediterranean coast started in April 2018.[1085] The power plant is implemented by Rosatom of Russia under a Build-Own-Operate (BOO) model. An agreement was signed in May 2010 for four VVER1200 reactors (Generation III+), with construction originally expected to start in 2015. Only two months prior to the official construction start in 2018, Rosatom's Turkish partners, who were to hold 49 percent of the shares, quit.[1086] However, Rosatom has stated that it would be able to complete the project even if it is unable to attract local investors.[1087]

In April 2019, Rosatom reported talks with both state-run and private Turkish companies, seeking to sell 49 percent of the project.[1088] Reflecting the failure to secure a buyer for the stake in Akkuyu, on 18 December 2020, Russia's Sovcombank announced that it will provide Rosatom subsidiary Akkuyu Nuclear with a loan of US$300 million help financing the construction of

1081 - *Roya News*, "[illegible]", 23 January 2021, Translated by Reem Salameh, University of British Columbia, see https://www.youtube.com/watch?v=30WolV_yBt8, accessed 1 February 2021.

1082 - IRENA, "Renewables Readiness Assessment: The Hashemite Kingdom of Jordan", February 2021, see https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2021/Feb/IRENA_RRA_Jordan_Summary_2021_EN.pdf?la=en&hash=DE5015E14770A43E9BFF2DFF8FAE684CED6E8EEB, accessed 1 May 2021.

1083 - IRENA, "Renewable Capacity Statistics 2021", March 2021, see https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2021/Apr/IRENA_RE_Capacity_Statistics_2021.pdf, accessed 5 May 2021.

1084 - IRENA, "Renewables Readiness Assessment: The Hashemite Kingdom of Jordan", 2021, op. cit.

1085 - Tuvan Gumrukeu and Orhan Coskun, "Turkey grants Rosatom construction license for first unit of Akkuyu nuclear plant", *Reuters*, 2 April 2018, see https://www.reuters.com/article/us-turkey-russia-nuclearpower/turkey-grants-rosatom-construction-license-for-first-unit-of-akkuyu-nuclear-plant-idUSKCN1H91OY, accessed 18 July 2021.

1086 - Orhan Coskun and Ali Kucukgocmen, "Two Turkish firms out of Russian nuclear plant consortium, other in talks: sources", *Reuters*, 6 February 2018, see https://www.reuters.com/article/us-russia-turkey-nuclear-companies-idUSKBN1FQ1OA, 25 July 2021.

1087 - *Reuters*, "Russia capable of building Akkuyu plant without partners: Minister", as published in *Hurriyet Daily News*, 6 April 2018, see http://www.hurriyetdailynews.com/russia-is-able-to-complete-akkuyu-nuclear-power-plant-construction-russian-minister-129886, accessed 18 July 2021.

1088 - *Ahval*, "Russia's Rosatom in talks to sell 49 pct stake in Akkuyu nuclear plant", 15 April 2019, see https://ahvalnews.com/akkuyu/russias-rosatom-talks-sell-49-pct-stake-akkuyu-nuclear-plant, accessed 18 April 2019.

the plant.[1089] The loan that is to cover a period of seven years came as it was confirmed by Rosatom that attempts to sell a 49 percent stake in the project had not yet been successful.

Anton Dedusenko, deputy director general of Rusatom Energo International, was quoted by *Nuclear Engineering International* (*NEI*) as stating that, "We do not set deadlines, the project is secured with funding, and we are ready to devote the necessary time to the search for partners and the negotiation process, as needed…We will make decisions on the basis of economic expediency, taking into account the requirements of a potential partner and its reliability. And with the obligatory approval of the Turkish side."[1090] The loan agreements were signed between Sovcombank and Akkuyu Nuclear JSC on 9 March 2021.[1091]

The financing of the project is supported by a 15-year Power Purchase Agreement (PPA), which includes 70 percent of the electricity produced from Units 1 and 2 and 30 percent of Units 3 and 4. Therefore 50 percent of the total power from the station is to be sold at a guaranteed price for the first 15 years, with the rest to be sold on the market. Currency fluctuation and the fall in the value of the Turkish lira make the price guarantees in dollars (US$123.50/MWh) problematic.[1092]

In October 2013, the Akkuyu project was announced to become operational by mid-2020, a delay of 18 months over the original schedule.[1093] However, numerous delays have occurred (see previous editions of the WNISR), and by the time construction started in April 2018, first electricity was expected to be generated in 2023 (the 100th anniversary of the founding of the modern state of Turkey), with all four units to be operational by 2025.[1094]

In March 2019, the project management announced that it had finished the concreting of the basemat for the nuclear island for the Unit 1 with physical completion now expected in 2023, with power generation coming at a later date.[1095]

In September 2019, Rosatom announced that the license for Unit 2 had been granted in the previous month, and that it was preparing to install the first steel equipment on Unit 1 in the autumn.[1096] Russia's largest bank, Sberbank, had announced in August 2019 that it would provide a US$400 million loan to Rosatom for the plant's construction.[1097]

1089 - Rosatom, "AKKUYU NUCLEAR JSC receives up to 300 mln USD loan from Sovcombank", Press Release, 30 December 2020, see https://rosatom.ru/en/press-centre/news/akkuyu-nuclear-jsc-receives-up-to-300-mln-usd-loan-from-sovcombank/, accessed 18 July 2021.

1090 - *NEI*, "Russia's Sovcombank provides loan for Turkey's nuclear project", 21 December 2020, see https://www.neimagazine.com/news/newsrussias-sovcombank-provides-loan-turkey-nuclear-project-8421289, accessed 25 July 2021.

1091 - Rosatom, "Akkuyu Nuclear JSC will receive two sustainability linked loans from Sovcombank totaling $300 million", Press Release, 10 March 2021, see https://rosatom.ru/en/press-centre/news/akkuyu-nuclear-jsc-will-receive-two-sustainability-linked-loans-from-sovcombank-totaling-300-million/, accessed 18 July 2021.

1092 - Phil Chaffee, "Newbuild: Revised 2023 Milestone for Akkuyu", NIW, 29 March 2019.

1093 - Orhan Coskun and Humeyra Pamuk, "Turkey's first nuclear plant facing further delays - sources", *Reuters*, 7 February 2014, see https://uk.reuters.com/article/uk-turkey-nuclear-delay/turkeys-first-nuclear-plant-facing-further-delays-sources-idUKBREA160P220140207, accessed 18 July 2021.

1094 - *NEI*, "Construction of Turkey's Akkuyu NPP begins", 4 April 2018, see http://www.neimagazine.com/news/newsconstruction-of-turkeys-akkuyu-npp-begins-6102914/, accessed 22 April 2018.

1095 - Phil Chaffee, "Newbuild: Revised 2023 Milestone for Akkuyu", *NIW*, op. cit.

1096 - Geert De Clercq, "Rosatom wins licence to build second nuclear reactor in Turkey -deputy CEO", *Reuters*, 6 September 2019, see https://www.reuters.com/article/rosatom-nuclearpower-turkey-idUSL5N25X40O, accessed 18 July 2021.

1097 - David Dalton, "Russia's Sberbank To Provide $400 Million Loan For Turkish Reactors", *NucNet*, 21 August 2019, see https://www.nucnet.org/news/russia-s-sberbank-to-provide-usd400-million-loan-8-3-2019, accessed 18 July 2021.

The cost escalation of the project for Turkey was highlighted in December 2020, when it was reported that due to depreciation of the Turkish lira, the cost of the fifteen-year payback had risen from the projected 57 billion lira to 140 billion liras (US$_{2020}$\$19 billion).[1098]

In May 2019, it was reported that construction of Unit 1 had been "held up" due to the discovery of cracks in the foundations, and after further cracks were discovered in the re-laid concrete, a larger section of the foundations had to be redone.[1099] Installation of the Reactor Pressure Vessel for Unit 1 was completed on 1 June 2021.[1100] Akkuyu-1 is planned to be completed in 2023, and with operation no later than March 2025, which is the official target date in the intergovernmental agreement for the plant.[1101]

As for Akkuyu's Unit 2, Turkish media sources in late June 2020 reported that construction has started that same month.[1102] Strangely, as of early July 2020, Rosatom had not communicated about the event. It is only in late July 2020 that the company confirmed and provided a date of April 2020 for first concrete pouring.[1103]

A construction license was granted for Akkuyu Unit 3 on 13 November 2020,[1104] and first concrete was poured on 10 March 2021.[1105]

The safety and security risks from Akkuyu site were recently raised by the Greek government. The first independent assessment of the 1200 MW VVER design was completed by the European Nuclear Safety Regulators Group (ENSREG) in June 2018.[1106] ENSREG concluded that there were significant issues related to the design and safety systems. The assessment of ENSREG contrasts with Rosatom claims that "They are absolutely safe in operation and fully meet the IAEA's post-Fukushima requirements."[1107]

The Greek Foreign Minister, Nikos Dendias, raised the perceived threat from Akkuyu in a phone call with U.S. Secretary of State Antony Blinken in March 2021, stating that it would constitute a security threat to other states in close proximity to Turkey, given Ankara's unwillingness

1098 - Mustafa Sonmez, "Critics say Turkey's unfinished nuclear plant already redundant", *Al Monitor*, 14 December 2020, see https://www.al-monitor.com/originals/2020/12/turkey-nuclear-plant-become-redundant-before-completion.html#ixzz71I8KAnq9, accessed 18 July 2021.

1099 - *Ahval*, "Cracks discovered during construction of Turkey's first nuclear plant", 6 May 2019, see https://ahvalnews.com/akkuyu/cracks-discovered-during-construction-turkeys-first-nuclear-plant, accessed 18 July 2021.

1100 - Akkuyu Nuclear, "The first reactor pressure vessel installed at Akkuyu NPP", Rosatom, News Release, 1 June 2021, see http://www.akkuyu.com/the-first-reactor-pressure-vessel-installed-at-akkuyu-npp/update, accessed 18 July 2021.

1101 - Caroline Peachey, "Concrete progress at Akkuyu", *NEI*, 10 April 2019, see https://www.neimagazine.com/features/featureconcrete-progress-at-akkuyu-7148151/, accessed 18 July 2021.

1102 - *Daily Sabah*, "Construction starts on 2nd unit of Turkey's 1st nuclear power plant Akkuyu", 28 June 2020, see https://www.dailysabah.com/business/energy/construction-starts-on-2nd-unit-of-turkeys-1st-nuclear-power-plant-akkuyu, accessed 18 July 2021.

1103 - Phil Chaffee, "Turkey: Rosatom Confirms Akkuyu-2's April First Concrete Pour", *NIW*, 24 July 2020.

1104 - Akkuyu Nuclear, "Akkuyu Nuclear JSC Obtains the Construction License of Akkuyu NPP Third Unit", Rosatom, News Release, 23 November 2020, see http://www.akkuyu.com/akkuyu-nuclear-jsc-obtains-the-construction-license-of-akkuyu-npp-third-unit/update, accessed 18 July 2021.

1105 - Akkuyu Nuclear, "Construction of Akkuyu NPP Unit 3 Begins", Rosatom, News Release, 10 March 2021, see http://www.akkuyu.com/construction-of-akkuyu-npp-unit-3-begins/update, accessed 18 July 2021.

1106 - ENSREG, "EU Peer Review Report of the Belarus Stress Tests", June 2018, see http://www.ensreg.eu/sites/default/files/attachments/hlg_p2018-36_155_belarus_stress_test_peer_review_report_0.pdf, accessed 18 July 2021.

1107 - Thomas Nielsen, "First emergency shutdown of reactor type to be built in Finland", *The Barents Observer*, 25 November 2016, see https://thebarentsobserver.com/en/civil-society-and-media/2016/11/first-emergency-shutdown-reactor-type-be-built-finland, accessed 18 July 2021.

to share information on the plant, concluding that it could become a new “Chernobyl” in the eastern Mediterranean.[1108]

In March 2020, a group of Turkish NGOs filed a court case against the Ministry of Environment and Urbanization to halt the construction work of the Akkuyu project because of the lack of a valid environmental impact assessment and generation license.[1109] Specific concerns expressed include the proximity of the Akkuyu Nuclear Power Plant site to the active North Anatolian Ecemiş seismic fault and that operation by Rosatom poses a national security threat.[1110]

The Akkuyu site lies 26 km from the Ecemiş fault line where the Eurasian and African tectonic plates meet. “I’m not against nuclear power. I’m simply against ignorant nuclear planning” said Tolga Yarman in 2011, a professor in the nuclear engineering department of Istanbul’s Okan University, and one of the original nuclear engineers who signed off on the original Akkuyu site license in 1976 when it was believed the fault was not active.[1111] In 2019, deputy director for the Akkuyu project, Mikhail Cherdantsev said that surveys carried out show that the Edzhemis fault line passing through part of Gülnar district does not run in close vicinity to the Akkuyu NPP site.[1112] Cherdantsev also reiterated the claim that the plant had been designed to withstand an earthquake of up to 9 points magnitude.

Small Modular Reactors

In addition to the existing planned nuclear projects, Turkey is exploring the potential for SMRs. In March 2020, the U.K.’s Rolls-Royce and Turkey’s state-owned EÜAS International ICC signed an agreement to study the potential for SMRs from a technical, licensing, commercial and investment perspective and the possibility of joint production in Turkey and globally.[1113]

1108 - *Greek City Times*, “Dendias says Turkey’s Russian-built Akkuyu nuclear power plant could be a new “Chernobyl””, 14 March 2021, see https://greekcitytimes.com/2021/03/14/dendias-akkuyu-chernobyl/, accessed 18 July 2021.

1109 - Ali Ekber ŞEN, “Akkuyu Nükleer Güç Santrali’ne durdurma davası”, *Hayat*, 11 March 2020 (in Turkish), see https://www.sozcu.com.tr/hayatim/yasam-haberleri/akkuyu-nukleer-guc-santraline-durdurma-davasi/, accessed 18 July 2021.

1110 - Ibidem.

1111 - Julia Harte, “Building of Turkey’s First Nuclear Plant, Sited on a Fault Line, Facing Fresh Questions”, *Reuters*, 25 March 2011, see https://www.reuters.com/article/idUS122778134920110325, accessed 18 July 2021.

1112 - Caroline Peachey, “Concrete progress at Akkuyu”, *NEI*, op. cit.

1113 - *WNN*, “Turkish Utility to Cooperate with Rolls-Royce in SMRs”, 20 March 2020.

Public Attitudes and Social Implications

The spread of an anti-nuclear sentiment within the Turkish public dates back to the 1970s and is rooted in the country's well-established environmental justice movements.[1114] Fueled by the fear of a repetition of disasters like Chernobyl or Fukushima, social mobilization against nuclear power plants has been taking place in big cities and near the selected nuclear sites, protesting safety threats, legality of waste disposal, high costs and administrative shortcomings among other issues.[1115]

Since it was licensed in 1976, the choice of the Akkuyu site has been criticized for its seismic risks, which have received more attention in the wake of the Fukushima disaster.[1116] Since then, various public surveys have been conducted to assess the public's sentiment towards Turkey's nuclear power plans (see WNISR2020). According to a survey in 2018, two thirds of the Turkish public do not support their country's efforts to build nuclear power plants, stating that "it is clearly risky, nuclear power plants should never be built."[1117]

Sinop

Sinop is on Turkey's northern Black Sea coast and was planned to host a 4.4 GW power plant of four units of the ATMEA reactor-design. If completed, these would have been the first reactors of this design, jointly developed by Japanese Mitsubishi and French AREVA (now Framatome, again).[1118] In April 2015, Turkish President Erdogan approved parliament's ratification of the intergovernmental agreement with Japan.[1119]

However, after three and a half years of unsuccessful attempts to renegotiate the deal (see previous editions of the WNISR), in December 2018, the Japanese newspaper *Nikkei* reported that Mitsubishi Heavy Industries (MHI) was set to withdraw, finally ending the project.[1120] On 19 January 2020, Energy Minister Fatih Dönmez finally confirmed that the time schedule and pricing of Sinop fell short of the ministry's expectations. "We agreed with the Japanese side to not continue our cooperation regarding this matter."[1121]

While there is neither an apparent nuclear builder nor an officially selected design, the Turkish authorities have moved forward with an administrative Environmental Impact

1114 - Pinar Temocin, "Framing Opposition to Nuclear Power: The Case of Akkuyu in Southeast Turkey", Institute for Peace and Unification Studies, Seoul National University, Asian Journal of Peacebuilding, November 2018.

1115 - Mustafa Kibaroglu, "Turkey's Quest for Peaceful Nuclear Power", *The Nonproliferation Review*, September 1997; and Mustafa Balat, "Energy and Nuclear Power Planning Study for Turkey", Energy Exploration & Exploitation, 1 February 2006.

1116 - Julia Harte, "Building of Turkey's First Nuclear Plant, Sited on a Fault Line, Facing Fresh Questions", *Reuters*, 25 March 2011, see https://www.reuters.com/article/idUS122778134920110325, accessed 18 July 2021.

1117 - Servet Yanatma, "Türkiye'de halkın üçte ikisi nükleer santrallere karş [Two-Thirds of the People in Turkey Are Against Nuclear Power Plants; The Support Rate Among AKP Members is 50 Percent]", *euronews*, 18 March 2019 (in Turkish), see https://tr.euronews.com/2019/03/18/turkiye-halkin-ucte-ikisi-nukleer-santrallere-karsi-ak-partililerde-destek-orani-yuzde-50, accessed 18 July 2021.

1118 - *WNN*, "Turkish utility eyes large stake in Sinop project", 12 May 2015, see http://www.world-nuclear-news.org/C-Turkish-utility-eyes-large-stake-in-Sinop-project-12051501.html, accessed 18 July 2021.

1119 - *WNN*, "Ground broken for Turkey's first nuclear power plant", 15 April 2015, see https://www.world-nuclear-news.org/NN-Ground-broken-for-Turkeys-first-nuclear-power-plant-1541501.html, accessed 18 July 2021.

1120 - Matsukubo Hijime, "Mitsubishi Heavy Industries withdraws from the NPP project in Sinop, Turkey ~NPP makers need to switch to realistic track in the age of decommissioning~", Citizens' Nuclear Information Center, 30 January 2019, see http://www.cnic.jp/english/?p=4271, accessed 18 July 2021.

1121 - *NEI*, "Turkey looks to cancel Japan Sinop project", 27 January 2020, see https://www.neimagazine.com/news/newsturkey-looks-to-cancel-japan-sinop-project-7653758/, accessed 18 July 2021.

Assessment (EIA). The company that has submitted the EIA application on 30 March 2020 is Assystem ENVY Energy and Environmental Investment on behalf of EUAS International ICC Sinop Nuclear Power Plant, Jersey Islands, Turkey Central Branch.[1122] The EIA report strangely mentions the Flamanville-3 EPR reactor in France, currently under construction, as "reference reactor", while the original EIA from 2018 was based on the AREVA-Mitsubishi ATMEA design, which has never gone beyond the design phase anywhere. Neither of the French companies EDF or subsidiary Framatome have communicated on the issue. On 15 September 2020, it was reported that the Ministry of Environment had approved the EIA for Sinop.[1123] However, the Sinop Anti-Nuclear Platform (NKP) announced their intention to file a lawsuit against the EIA.

İğneada

In October 2015, the Turkish Government confirmed it was aiming to build a third nuclear power plant at the İğneada site.[1124] The most likely constructors would be Westinghouse and the Chinese State Nuclear Power Technology Corporation (SNPTC) and a tripartite agreement was already signed in November 2014.[1125] Chinese companies have been said to be "aggressively" pursuing the contract, reportedly worth an estimated US$22–25 billion.[1126] In 2016, China and Turkey ratified a nuclear co-operation agreement similar to the mechanism used to develop the country's other nuclear projects.[1127]

However, the financial collapse of Westinghouse, which filed for bankruptcy in March 2017, likely contributed to the quiet abandoning of the project.[1128]

Saudi Arabia

Nuclear energy in Saudi Arabia is being developed by the King Abdullah City for Atomic and Renewable Energy (KA-CARE), which was established by a Royal decree in 2010.[1129] The following year, the "coordinator of scientific collaboration at KA-CARE" announced plans "to construct 16 nuclear power reactors over the next 20 years at a cost of more than 300 billion riyals ($80 billion)".[1130] In June 2011, a KA-CARE report suggested that "work on the kingdom's

1122 - Ibidem.

1123 - *BIA*, "Ministry approves Environmental Impact Assessment report of Sinop Nuclear Plant", *bianet*, 15 September 2020, see https://m.bianet.org/english/environment/230872-ministry-approves-environmental-impact-assessment-report-of-sinop-nuclear-plant, accessed 18 July 2021.

1124 - David O'Byrne, "Turkey Confirms Site for Third Nuclear Plant", *European Power Daily*, 15 October 2015.

1125 - *WNN*, "Tripartite agreement on third Turkish plant", 24 November 2014, see https://www.world-nuclear-news.org/NN-Tripartite-agreement-on-third-Turkish-plant-2411147.html, accessed 27 July 2021.

1126 - Lyu Chang, "Chinese Bidders Expected for Turkey's Nuclear Project", *China Daily*, 15 March 2016, see http://www.chinadaily.com.cn/business/2016-03/15/content_23865840.htm, accessed 27 July 2021.

1127 - *NEI*, "China Eyes Turkey's Third NPP", 2 September 2016, see https://www.neimagazine.com/news/newschina-eyes-turkeys-third-npp-4996063, accessed 27 July 2021.

1128 - Phil Chaffee, "Turkey: Second and Third NPPs Face Headwinds", *NIW*, 28 July 2017.

1129 - Abdullah bin Abdul Aziz Al Saud, "Royal Decree establishing King Abdullah City for Atomic and Renewable Energy", 2010, see https://www.climate-laws.org/geographies/saudi-arabia/policies/royal-decree-establishing-king-abdullah-city-for-atomic-and-renewable-energy-2010, accessed 11 June 2021.

1130 - WNA, "Nuclear Power in Saudi Arabia", World Nuclear Association, 2013, see http://www.world-nuclear.org/info/Country-Profiles/Countries-O-S/Saudi-Arabia/.

first nuclear reactor could start by 2014, for completion by 2020".[1131] As of June 2021, KA-CARE has not started construction of even one nuclear power plant.

What Saudi Arabia has done has been to sign a series of agreements with other countries and their nuclear agencies. Among these countries are Argentina,[1132] France,[1133] Russia,[1134] China,[1135] Hungary,[1136] and South Korea.[1137] Of these, the agreement between KA-CARE and the Korea Atomic Energy Research Institute (KAERI) is perhaps most distinctive, because the Memorandum of Understanding (MoU) signed in 2015 involves an agreement to jointly promote the SMART (System-integrated Modular Advanced Reactor) in international markets, focusing on the Middle East.[1138] SMART is a 330 MWth pressurized water reactor developed by KAERI designed for electricity generation as well as thermal applications such as seawater desalination.

In 2017, KA-CARE announced that it was soliciting nuclear capacity proposals with a combined capacity of roughly 2.8 GW from China, Japan, Russia, and South Korea.[1139] It was also reported that two sites on the coast near the UAE and Qatari borders had been shortlisted.[1140] During the same year, there were also reports that Westinghouse was discussing a group bid for two nuclear power reactor tenders in Saudi Arabia.[1141]

In 2018, following a review of infrastructure development in Saudi Arabia, the IAEA announced that the country "has established a legislative framework and carried out comprehensive

1131 - Emily Meredith, "Kuwait Shelves Nuclear Power Plans Amid Fukushima Rethink", *International Oil Daily*, 5 October 2011.

1132 - *WNN*, "Saudi Arabia and Argentina form R&D joint venture", 9 March 2015, see https://world-nuclear-news.org/Articles/Saudi-Arabia-and-Argentina-form-R-D-joint-venture, accessed 1 June 2021; Government of the Argentine Republic and Government of the Kingdom of Saudi Arabia, "Cooperation Agreement Between the Government of the Argentine Republic and the Government of the Kingdom of Saudi Arabia on Peaceful Uses of Nuclear Energy", 28 June 2011, Registered with the Secretariat of the United National 6 November 2013, see https://www.un-ilibrary.org/content/books/9789210453349s002-c006, accessed 14 July 2021.

1133 - KA-CARE, "The Kingdom of Saudi Arabia Signs with the French Republic a Letter of Intent to Study the Feasibility of Constructing Two Reactors", 24 June 2015, see https://www.energy.gov.sa/en/mediacenter/news/Pages/news157.aspx, accessed 14 July 2021.

1134 - *WNN*, "Russia, Saudi Arabia strengthen ties in nuclear energy", 6 October 2017, see https://world-nuclear-news.org/Articles/Russia,-Saudi-Arabia-strengthen-ties-in-nuclear-en, accessed 30 May 2021; and KA-CARE, "Saudi Arabia sign an idolater cooperation agreement in the areas of peaceful nuclear energy with the Federal Republic of Russia", 18 June 2015, see https://www.energy.gov.sa/en/mediacenter/news/Pages/news156.aspx, accessed 14 July 2021.

1135 - KA-CARE, "King Abdullah City for Atomic and Renewable Energy Signs a Memorandum of Understandig with China National Nuclear Cooperation", 8 August 2014, see https://www.energy.gov.sa/en/mediacenter/news/Pages/news81.aspx, accessed 14 July 2021.

1136 - KA-CARE, "The Kingdom of Saudi Arabia concludes a cooperation agreement with Hungary on the peaceful uses of atomic energy", 19 October 2015, see https://www.energy.gov.sa/en/mediacenter/news/Pages/news177.aspx, accessed 14 July 2021.

1137 - KA-CARE, "MOU's Signature", 3 March 2015, see https://www.energy.gov.sa/en/mediacenter/news/Pages/news120.aspx, accessed 14 July 2021; and *WNN*, "Saudi Arabia teams up with Korea on SMART", 4 March 2015, see http://world-nuclear-news.org/NN-Saudi-Arabia-teams-up-with-Korea-on-SMART-0403154.html, accessed 30 May 2021; and *WNN*, "Saudi Arabia and Korea further SMART cooperation", 3 September 2015, see https://world-nuclear-news.org/Articles/Saudi-Arabia-and-Korea-further-SMART-cooperation, accessed 28 May 2021.

1138 - *WNN*, "Korea, Saudi Arabia to cooperate on SMART deployment", 20 September 2019, see https://world-nuclear-news.org/Articles/Korea,-Saudi-Arabia-to-cooperate-on-SMART-deployme, accessed 3 June 2021; and *WNN*, "Korea, Saudi Arabia progress with SMART collaboration", 7 January 2020, see https://www.world-nuclear-news.org/Articles/Korea-Saudi-Arabia-progress-with-SMART-collaborati, accessed 4 July 2020; also KAERI, "KAERI and K.A.CARE signed SMART PPE Agreement", 3 September 2015, see https://www.kaeri.re.kr/board/view?pageNum=6&rowCnt=10&no1=143&linkId=4865&menuId=MENU00718, accessed 9 July 2021.

1139 - Stephanie Cooke and Phil Chaffee, "Reactor Vendors Poised to Bid on Saudi RFI", *NIW*, 15 December 2017.

1140 - Andrew Roscoe, "Saudi Arabia shortlists two sites for first nuclear power project", *MEED*, 22 January 2018, see https://www.meed.com/exclusive-saudi-arabia-shortlists-two-sites-first-nuclear-power-project, accessed 11 June 2021.

1141 - Reem Shamseddine, Stephen Kalin and Geert De Clercq, "Exclusive: Westinghouse discussing group bid for Saudi nuclear tender - sources", *Reuters*, 21 November 2017, see https://www.reuters.com/article/us-saudi-nuclear-usa-exclusive-idUSKBN1DL1BF, accessed 7 June 2021.

studies to support the next steps of the program”.[1142] KA-CARE has also entered into a contract with the French company Assystem to conduct site characterization and impact studies for the first nuclear power plant.[1143]

While Saudi nuclear plans have been gradually going through different stages of planning, installed renewable energy capacity in Saudi Arabia has dramatically expanded, from a mere 3 MW in 2011 to 413 MW in 2020, of which 409 MW is solar capacity.[1144] Perhaps due to the pandemic, the capacity did not expand in 2020. Saudi Arabia has announced ambitious plans to expand renewable energy so that it constitutes 50 percent of its energy by 2030,[1145] and become a leader in hydrogen production.[1146]

In April 2021, two consortiums led by Saudi developer Acwa Power established a new world record for the lowest price for solar power by signing Power Purchasing Agreements (PPAs) at US$¢1.04/Wh (US$10.4/MWh) and US$¢1.239/kWh (US$12.39/MWh) for two projects with respectively 600 MW and 1.6 GW.[1147]

CONTINENTAL EUROPE

Poland

Poland planned the development of a series of nuclear power stations in the 1980s and started construction of two VVER1000/320 reactors in Żarnowiec on the Baltic coast, but both construction and further plans were halted following the Chernobyl accident. Since then, there has been a long, expensive and time-consuming series of attempts to restart the nuclear program. In 2008, Poland announced that it was going to re-enter the nuclear arena and in November 2010, the Ministry of Economy put forward a Nuclear Energy Program. On 28 January 2014, the Polish Government adopted a document with the title “Polish Nuclear Power Programme” outlining the framework of the strategy. The plan included proposals to build 6 GW of nuclear power capacity with the first reactor starting up by 2024. The reactor types then under consideration included AREVA’s EPR, Westinghouse’s AP1000, and Hitachi-GE’s ABWR. Since then, AREVA went bankrupt and was broken up, while Westinghouse filed for bankruptcy protection and was sold to a Canadian holding, and Hitachi-GE has never completed an ABWR.

1142 - *WNN*, “IAEA reports on Saudi Arabia’s nuclear infrastructure”, 28 January 2019, see https://world-nuclear-news.org/Articles/IAEA-reports-on-Saudi-Arabia-s-nuclear-infrastruct, accessed 3 June 2021.

1143 - *WNN*, “Assystem to assess potential Saudi sites”, 4 July 2018, see https://world-nuclear-news.org/Articles/Assystem-to-assess-potential-Saudi-sites, accessed 1 June 2021.

1144 - IRENA, “Renewable Capacity Statistics 2021”, March 2021, see https://www.irena.org/publications/2021/March/Renewable-Capacity-Statistics-2021, accessed 6 June 2021.

1145 - Joe Lo, “Saudi Arabia aims for 50% renewable energy by 2030, backs huge tree planting initiative”, *Climate Home News*, 31 March 2021, see https://www.climatechangenews.com/2021/03/31/saudi-arabia-aims-50-renewable-energy-2030-backs-huge-tree-planting-initiative/, accessed 5 June 2021.

1146 - Matthew Martin, Salma El Wardany and Abeer Abu Omar, “Saudi Arabia Aims to Become Next Germany of Renewable Energy”, *Bloomberg*, 27 January 2021, see https://www.bloomberg.com/news/articles/2021-01-27/saudi-arabia-aims-to-become-the-germany-of-renewable-energy, accessed 5 June 2021.

1147 - *Energy & Utilities*, “Saudi Arabia achieves two new world record solar tariffs”, 9 April 2021, see https://energy-utilities.com/saudi-arabia-achieves-two-new-world-record-solar-news111675.html, accessed 26 April 2021.

In January 2013, the Polish state-owned utility PGE (Polska Grupa Energetyczna) selected WorleyParsons to conduct a five-year, US$81.5 million study, on the siting and development of a nuclear power plant with a capacity of up to 3 GW. At that time, the project was estimated at US$13–19 billion and construction was to begin in 2019. In January 2014, PGE received four bids from companies looking to become the company's "Owner's Engineer" to help in the tendering and development of the project, which was eventually awarded to AMEC Nuclear U.K. in July 2014. The timetable demanded that PGE make a final investment decision on the two plants by early 2017.[1148] That did not happen.

In November 2018, the Government published a draft strategic energy development program, which called for the construction of four reactors (providing 6–10 GW of capacity) by 2040, with the first in operation by 2033[1149]—a decade later than a plan published just five years earlier—with up to six units with a combined capacity of 6-9 GWe to be put into operation by 2043.[1150] The Ministry of Energy envisaged the site selection for the first plant in 2020, while the technology would be chosen in 2021.[1151]

In October 2020, the Council of Ministers adopted the government's long-term Polish Nuclear Power Program. Its main objective is to build and commission nuclear power plants in Poland with a total installed capacity of approximately 6—9 GWe based on Generation III (+) pressurized water reactors, with operation during the 2030s, while the share of nuclear power in the energy mix of 2045 is predicted to be about 20 percent. According to the documentation, the timetable is as follows:

- 2021 – choice of technology;
- 2022 – environmental and location decision;
- 2026 – a building permit is obtained and construction commenced;
- 2033–2037 – an operating permit is issued by the President of the National Atomic Energy Agency and three nuclear power plant units are commissioned (EJ1).[1152]

The timetable seems unrealistic, with little chance that a technology can be chosen in 2021 nor a decision on siting in 2022. The cost of the investment is expected to be US$40 billion.[1153] The Government is said to be aware that it will need to give financial support for the construction and therefore it will seek State Aid approval from the European Commissions.

1148 - David Dalton, "Amec Wins USD 430 Million Contract To Support Polish New-Build", *Nucnet*, 9 July 2014, see https://www.nucnet.org/all-the-news/2014/07/21/amec-wins-usd-430-million-contract-to-support-polish-new-build, accessed 1 May 2021.

1149 - Gary Peach, "Newbuild: Power Demand in Poland Bolsters Case for Nuclear", *NIW*, 26 November 2018.

1150 - *WNN*, "Poland sets financing target for nuclear plant", 19 November 2019, see https://www.world-nuclear-news.org/Articles/Poland-sets-financing-target-for-nuclear-plant, accessed 1 May 2021.

1151 - *WNN*, "Poland already preparing for nuclear plant, says energy minister", 16 May 2019, see https://www.world-nuclear-news.org/Articles/Poland-already-preparing-for-nuclear-plant,-says-e, accessed 1 May 2021.

1152 - *CMS Law-Now*, "The 2020 Polish Nuclear Power Programme – main objectives", 26 October 2020, see https://www.cms-lawnow.com/ealerts/2020/10/the-2020-polish-nuclear-power-programme-main-objectives, accessed 1 May 2021.

1153 - *Nuclear Energy Insider*, "Poland pledges $40 billion for new nuclear – CNL, Kairos to jointly develop SMR", *Reuters*, 15 September 2021, see https://www.reutersevents.com/nuclear/poland-pledges-40-billion-new-nuclear-cnl-kairos-jointly-develop-smr, accessed 1 May 2021.

Nuclear vendors are keen to be under consideration, with Westinghouse rapidly promoting the AP1000[1154], while the Government has also made overtures to Japan[1155] and France.[1156]

AFRICA

In continental Africa, only South Africa has an operating nuclear power plant (see Annex 1 – South Africa). This is despite sporadic support from national governments and encouragement from international vendors, now particularly China and Russia.

Across the continent, electricity generation increased from 672 TWh in 2010 to 870 TWh in 2019, with natural gas and coal (the latter largely in South Africa) accounting for 40 percent and 30 percent respectively, hydropower representing a further 16 percent, oil 9 percent, non-hydro renewables (solar, wind etc.) 3 percent and nuclear less than 2 percent. Africa does however have a significant role for the global nuclear industry with Namibia and Niger the world's fourth- and fifth-largest uranium producers.

According to the World Nuclear Association (WNA), China has agreements with—but no plants under construction—in Kenya, Sudan and Uganda, while Russia signed agreements with Algeria, Congo, Egypt, Ethiopia, Ghana, Morocco, Nigeria, Sudan, Rwanda and Zambia.[1157] In September 2020, Russia signed an MoU for cooperation with the African Commission on Nuclear Energy (AFCONE), to establish a basis for Russia to help African countries with various projects related to nuclear energy.[1158] The vast majority of these are little more than political statements of support designed to increase diplomatic links with key infrastructure providers and recipients.

However, over the past year some developments have occurred. Of significance is Rwanda that in October 2019 signed an agreement with Rosatom to build a nuclear science center, with the intention of developing an interest in Small Modular Reactors (SMRs).[1159] In Nigeria, in November 2019, the Senate called on the Government to consider including nuclear power in the power mix to give a mandate to the Atomic Energy Commission to negotiate with international nuclear vendors. Nigeria has previously sought the support of the IAEA to develop plans for up to 4 GWe of nuclear capacity by 2025, which are obviously not achievable, at least in the originally envisaged timeframe.[1160]

1154 - *NEI*, "Westinghouse seeks participation in Poland's nuclear programme", 18 March 2021, see https://www.neimagazine.com/news/newswestinghouse-seeks-participation-in-polands-nuclear-programme-8609350, accessed 1 May 2021.

1155 - Daishi Chiba, "Poland minister seeks Japanese partners for nuclear project", *Nikkei Asia*, 3 December 2021, see https://asia.nikkei.com/Editor-s-Picks/Interview/Poland-minister-seeks-Japanese-partners-for-nuclear-project, accessed 1 May 2021.

1156 - Wojciech Jakóbik, "France in the game for a nuclear contract in Poland. The final decision is close", *BiznesAlert*, 3 February 2021, see https://biznesalert.com/france-in-the-game-for-a-nuclear-contract-in-poland-the-final-decision-is-close/, accessed 4 May 2021.

1157 - WNA, "Emerging Nuclear Energy Countries", March 2021, see https://world-nuclear.org/information-library/country-profiles/others/emerging-nuclear-energy-countries.aspx, accessed 1 May 2021.

1158 - *NEI*, "Russia to co-operate with Afcone", 29 September 2020, see https://www.neimagazine.com/news/newsrussia-to-co-operate-with-afcone-8153681/, accessed 1 May 2021.

1159 - Katya Golubkova and Alexander Winning, "Russia's Rosatom, Rwanda sign deal to build nuclear science center", *Reuters*, 24 October 2019, see https://www.reuters.com/article/us-russia-rwanda-nuclear-idUSKBN1X32DV, accessed 1 May 2021.

1160 - *WNN*, "Nigerian Senate calls for inclusion of nuclear in energy mix", 21 November 2019, see https://www.world-nuclear-news.org/Articles/Senate-calls-for-nuclear-inclusion-in-Nigeria-s-en, accessed 1 May 2021.

SMALL MODULAR REACTORS

As nuclear energy continues to face major economic challenges, the nuclear industry and governments that are supportive of nuclear power continue to push new reactor designs as the solution to the industry's woes. These designs are dubbed with multiple labels, such as Advanced Reactors, Generation IV reactors, or, most prominently, Small Modular Reactors (SMRs).[1161] The evidence so far suggests that the smaller reactor projects may suffer from many similar challenges as large nuclear reactors and maybe from some new ones. What follows is an update of earlier analysis (in particular WNISR2015, WNISR2017, WNISR2019 and WNISR2020) on SMR programs in selected countries (in alphabetical order).

ARGENTINA

The National Atomic Energy Commission of Argentina (CNEA) has been constructing the CAREM-25 reactor since February 2014,[1162] after nearly 30 years of design development.[1163] The project's completion date has been continuously pushed back. A presentation by a CNEA official in September 2020 estimated progress at 58 percent.[1164] The summary of a webinar conducted in November 2020 quoted the CNEA President as saying that the "physical completion of Carem 25 is at 70%".[1165] It was also reported that successive Argentinian administrations have "already invested more than USD$400 million" on the project. However, the overall cost of the project was reported as US$700 million in 2017.[1166] There is no update about when the reactor might become operational.

CANADA

Canada has become a preferred destination for several SMR vendors, thanks to government support for the technology. Both the federal government and several provincial governments have been advocating for SMRs. In 2018, the federal government funded the Canadian Nuclear Association, "a non-profit organization established in 1960 to represent the nuclear industry in Canada and promote the development and growth of nuclear technologies for peaceful purposes", to produce a "roadmap which will identify the opportunities for on and off-grid

1161 - The acronym SMR is also used to mean "small and medium-sized reactor" by the International Atomic Energy Agency (IAEA). For the IAEA, a "small" reactor is one having electrical output less than 300 MWe and a "medium" reactor is one having a power output between 300 MWe and 700 MWe.

1162 - *WNN*, "Construction of CAREM underway", 10 February 2014, see http://www.world-nuclear-news.org/NN-Construction-of-CAREM-underway-1002144.html, accessed 7 May 2021.

1163 - Silvia Lucila Molina, Natalia Sofía Tucci Branco and María Noelia Dusau, "CAREM Reactor: An Innovative and Achievable Option for Enhancing Nuclear Energy Supply", presented at the INTER JURA 2018, International Nuclear Law Association, 4 November 2018, see https://emirates.meeting-app.events/inla2018/congress-papers, accessed 29 June 2019.

1164 - Osvaldo Calzetta, "CAREM Project, the Argentinian Small Modular Reactor", Latin American Section, American Nuclear Society, Nuclear Energy Atomic Commission of Argentina, 17 September 2020, see https://las-ans.org.br/carem-project-the-argentinian-small-modular-reactor-currently-in-development/, accessed 21 June 2021.

1165 - Ibrahim Ababou, "CAREM 25 Prototype reaching 70% completion", Nuclear Business Platform, as published on LinkedIn, 2020, see https://www.linkedin.com/pulse/carem-25-prototype-reaching-70-completion-ibrahim-ababou/, accessed 21 June 2021.

1166 - *Bnamericas*, "Argentine nuclear reactor due to start up in 2020", 17 April 2017, see https://www.bnamericas.com/en/news/argentine-nuclear-reactor-due-to-start-up-in-2020, accessed 21 June 2021.

applications of Small Modular Reactors (SMRs) in Canada".[1167] In December 2020, Minister of Natural Resources, Seamus O'Regan, released an action plan for SMRs, which listed seven principles starting with the intention to act "together and within our jurisdictions and areas of authority to support the development and deployment of various SMR technologies in Canada, with first units in operation by the late 2020s".[1168]

The announcement was sandwiched between decisions to invest relative large amounts of money into companies seeking to develop SMRs. The Ontario based Terrestrial Energy received CAD20 million (around US$16 million) in October 2020.[1169] A few months after the action plan was released, in March 2021, the Federal Government provided over CAD50 million (around US$40 million) to Moltex to subsidize development of its reactor design.[1170] Both Terrestrial Energy and Moltex are pursuing molten salt reactor designs, and questions have been raised about their viability.[1171] In between these two announcements, the province of New Brunswick awarded CAD20 million (around US$16 million) in February 2021 to ARC-100, a sodium cooled fast reactor design.[1172]

Two of the electricity supplying companies have also been supportive of SMRs. This is most pronounced in Ontario, the province with the vast majority of nuclear power plants in Canada. In October 2020, Ontario Power Generation announced agreements with GE Hitachi, Terrestrial Energy and X-energy to help deploy SMRs.[1173] Ontario Power Generation (OPG) holds a site preparation license for the Darlington site and in 2021 it applied to renew this license.[1174] Besides Ontario, the only other province in Canada with nuclear power plants is New Brunswick, and the province's electricity utility, NB Power, is working with two SMR vendors, Moltex and ARC-100, to "advance their technologies for use in New Brunswick".[1175] At the same time, the ten year plan adopted by NB-Power in 2019 for the period 2021–2030 and the strategic plan for 2011–2040 see no new nuclear power from SMRs coming online; the 2020

1167 - NRCAN, "Canadian Small Modular Reactor (SMR) Roadmap", Natural Resources Canada, 2 May 2018, see https://www.nrcan.gc.ca/science-and-data/funding-partnerships/funding-opportunities/current-investments/canadian-small-modular-reactor-smr-roadmap/21084; and CNA, "About – Members", Canadian Nuclear Association, 2020, see https://cna.ca/about-cna/members/, both accessed 13 October 2020.

1168 - NRCAN, "Statement of Principles", SMR Action Plan, 18 December 2020, see https://smractionplan.ca/content/statement-principles, accessed 22 June 2021.

1169 - Terrestrial Energy, "Terrestrial Energy Receives Canadian Government Funding for IMSR Generation IV Nuclear Plant", 15 October 2020, see http://www.terrestrialenergy.com/2020/10/terrestrial-energy-receives-canadian-government-funding-for-imsr-generation-iv-nuclear-plant/, accessed 22 June 2021.

1170 - Jacques Poitras, "Feds to put millions into small nuclear reactor development in N.B.", *CBC News*, 18 March 2021, see https://www.cbc.ca/news/canada/new-brunswick/feds-millions-small-nuclear-reactors-1.5955274, accessed 19 March 2021.

1171 - Jacques Poitras, "Former U.S. regulator questions small nuclear reactor technology", *CBC News*, 15 January 2021, see https://www.cbc.ca/news/canada/new-brunswick/nuclear-waste-reactors-new-brunswick-allison-macfarlane-moltex-arc-1.5873542, accessed 15 January 2021.

1172 - Jacques Poitras, "Nuclear energy company gets $20M boost from province, Higgs says", *CBC* News, 15 January 2021, see https://www.cbc.ca/news/canada/new-brunswick/small-modular-nuclear-reactors-new-brunswick-1.5908995, accessed 22 June 2021.

1173 - *WNN*, "OPG advances towards SMR deployment", 6 October 2020, see https://www.world-nuclear-news.org/Articles/OPG-advances-towards-SMR-deployment, accessed 22 June 2021.

1174 - David Dalton, "OPG Applies For Renewal Of Darlington Nuclear Site Licence", *NucNet*, 22 March 2021, see https://www.nucnet.org/news/opg-applies-for-renewal-of-darlington-nuclear-site-licence-3-1-2021, accessed 22 June 2021.

1175 - Alex Woodworth, "An Update on Advanced Small Modular Reactor (SMR) in New Brunswick", *INSiGHT Magazine,* Fredericton Chamber of Commerce, 25 April 2021, see https://www.frederictonchamber.ca/insight/2021/04/25/an-update-on-advanced-small-modular-reactor-smr-in-new-brunswick/, accessed 22 June 2021.

Integrated Resource Plan did not include SMRs because "cost estimates remain uncertain at this time".[1176]

The Canadian Nuclear Safety Commission (CNSC) has been offering the "pre-licensing vendor design review", an optional service for SMR vendors, as a way to signal its readiness to license SMRs. However, CNSC does make it clear that such a review is "not an application for a licence to prepare a site or to construct or operate a nuclear power facility" and that the "review does not certify a reactor design or involve the issuance of a licence" and that the "conclusions of any design review do not bind or otherwise influence decisions made by the Commission".[1177]

Over the past year, the Moltex SSR-W300 design completed the Phase 1 review process and the May 2021 report from CNSC identified a number of areas where Moltex is still lacking and several potential problems about the safety, including about quality assurance programs, Moltex's proposal of not having a secondary control room, and the reliability of shutdown systems.[1178] In August 2020, Holtec International SMR-160 design also completed the Phase 1 review process, and CNSC highlighted the need to confirm the adequacy of Holtec's fuel qualification program and the means to shut down the reactor under all conditions.[1179]

CHINA

The High Temperature Reactors (HTR-PM) under construction at Shidaowan (Shidao Bay) in the eastern Shandong province continue to be delayed. Construction of the HTR-PM, which consists of two 100-MW modules driving one 200 MW turbine, commenced in December 2012. At that time, the Huaneng Shandong Shidao Bay Nuclear Power Company Ltd. (HSNPC), the builder and operator of the units, announced that the plant will "start generating commercial electricity by the end of 2017".[1180] Since then, the start date has been continuously pushed back (see earlier WNISR editions for details). According to a June 2020 presentation, "criticality and power operation" were scheduled for later in the year.[1181] But even the cold functional test was completed only in November 2020.[1182] Hot functional tests started in January 2021, and the first fuel was shipped to the site in the same month.[1183]

1176 - NB Power, "Strategic Plans", 2021, see https://www.nbpower.com/en/about-us/accountability-reports/strategic-plans, accessed 22 June 2021.

1177 - CNSC, "Pre-Licensing Vendor Design Review", Canadian Nuclear Safety Commission, 25 May 2021, see https://cnsc.gc.ca/eng/reactors/power-plants/pre-licensing-vendor-design-review/index.cfm, accessed 21 June 2021.

1178 - CNSC, "Phase 1 pre-licensing vendor design review executive summary: Moltex Energy", 25 May 2021, see https://cnsc.gc.ca/eng/reactors/power-plants/pre-licensing-vendor-design-review/moltex-energy-executive-summary.cfm, accessed 21 June 2021.

1179 - CNSC, "Phase 1 Pre-Licensing Vendor Design Review Executive Summary: SMR, LLC.", 20 August 2020, see https://cnsc.gc.ca/eng/reactors/power-plants/pre-licensing-vendor-design-review/holtec-international-executive-summary.cfm, accessed 21 June 2021.

1180 - David Dalton, "China Begins Construction Of First Generation IV HTR-PM Unit", *NucNet*, 7 January 2013, see http://www.nucnet.org/all-the-news/2013/01/07/china-begins-construction-of-first-generation-iv-htr-pm-unit, accessed 10 January 2013.

1181 - Fu Li, "Chinese HTR Program", and INET, Tsinghua University, Presented at the IFNEC SMR Webinar Series, 23 June 2020, see https://www.ifnec.org/ifnec/upload/docs/application/pdf/2020-06/slides_deck_-_webinar_4.pdf, accessed 6 July 2020.

1182 - C.F. Yu, "CNNC Rolls Out Additional HTGR Plans", *NIW*, 13 November 2020.

1183 - *WNN*, "Hot functional testing of HTR-PM reactors starts", 4 January 2021, see https://www.world-nuclear-news.org/Articles/Hot-functional-testing-of-HTR-PM-reactors-starts, accessed 4 January 2021; and *NEI*, "First fuel shipped to China's HTR-PM project", 13 January 2021, see https://www.neimagazine.com/news/newsfirst-fuel-shipped-to-chinas-htr-pm-project-8453226, accessed 23 June 2021.

There appear to be no plans to construct more reactors of the same design. However, in November 2020, China National Nuclear Corporation (CNNC) released "four tender documents soliciting technology partners for conducting marine environmental, seismic, geology, and safety assessments at a completely new nuclear site: Xin'an, a town within Haiyang City in Shandong province" and according to "the tender documents CNNC plans to first construct two 600-MW HTGRs at the newly unveiled site".[1184] The larger power level suggests that CNNC is scaling up the reactor to gain from economies of scale; at 600 MW, these new reactor designs would no longer fit the International Atomic Energy Agency (IAEA) definition of a small reactor as being below 300 MW capacity.

The other SMR design that seems to be seriously under consideration is CNNC's ACP100. In July 2019, it was reported that CNNC is starting to "build an ACP100 small modular reactor at Changjiang in Hainan, an island province in the south of the country" and the formal construction was to "begin by the end" of 2019.[1185] While no construction start has been reported, in April 2021, the government approved the project.[1186] However, in May 2021, the Ministry of Ecology and Environment published a letter on its website that summarizes the nuclear safety inspection report and called upon the owner to take effective measures to implement the safety management requirements put forward in the inspection report.[1187] Even prior to the start of construction, CNNC admitted that the construction cost per kilowatt of the proposed ACP100 demonstration project "is 2 times higher than that of a large NPP [nuclear power plant]".[1188] There are a number of other SMR designs at various stages of development but none of them are reportedly slated for construction anytime soon.[1189]

INDIA

India's Department of Atomic Energy (DAE) has been developing the Advanced Heavy Water Reactor (AHWR) design since the 1990s with plans to have one operating by 2011.[1190] It has since been delayed continuously. Earlier this year, the Indian government announced that it had already "accorded in-principle approval" all the way back in 2016 for building the AHWR at the Tarapur site (which already hosts four operating reactors and a reprocessing plant).[1191] But in the intervening five years, no actual plans for construction seem to have matured. In a 2019

1184 - C.F. Yu, "CNNC Rolls Out Additional HTGR Plans", *NIW*, 2020, op. cit.

1185 - David Dalton, "CNNC Announces Plans For 'Linglong One' SMR", *NucNet*, 23 July 2019, see https://www.nucnet.org/news/cnnc-announces-plans-for-linglong-one-smr-7-2-2019, accessed 26 June 2020.

1186 - *Reuters*, "China gives green light to nuclear units to cut carbon, sources say", as published by *South China Morning Post*, 15 April 2021, see https://www.scmp.com/news/china/politics/article/3129691/china-gives-green-light-five-nuclear-units-cut-carbon-and-aim, accessed 15 May 2021.

1187 - National Nuclear Safety Administration, "关于印发《海南昌江多用途模块式小型堆科技示范工程核岛基础浇筑第一罐混凝土前准备情况核安全检查报告》的函", Ministry of Ecology and Environment of the People's Republic of China, 8 May 2021, see http://www.mee.gov.cn/xxgk2018/xxgk/xxgk07/202105/t20210508_832105.html, accessed 24 June 2021.

1188 - Danrong Song, "Opportunities and Challenges in SMR and Its Practice in ACP100", CNNC, Presented at the 17th INPRO Dialogue Forum on Opportunities and Challenges in Small Modular Reactors, 2 July 2019, see https://nucleus.iaea.org/sites/INPRO/df17/IV.1.-DanrongSong-ACP100.pdf, accessed 4 July 2020.

1189 - C. F. Yu, "Chinese SMR Program Faces Slowdown and Secrecy", *NIW*, 24 July 2020.

1190 - V. K Chaturvedi, "CMD's page", Nu-Power, 2000.

1191 - Rajya Sabha, "Unstarred question No. 3368: Uranium and Thorium reserves in the country", Department of Atomic Energy, Answered 25 March 2021, by Jitendra Singh, Minister of State for Personnel, Public Grievances & Pensions and Prime Minister's Office, Government of India, see https://dae.gov.in/writereaddata/rs%20usq%203368.pdf, accessed 23 June 2021.

presentation at an IAEA meeting on SMRs, the AHWR was entitled an "R&D programme" but not mentioned in the list of reactors "under construction and planned".[1192] The terminology and the absence of any announcements about construction suggest that the AHWR is unlikely to get underway anytime soon.

RUSSIA

Russia's interest in SMRs has largely been on fast reactor designs, although it is also developing light water reactor (LWR) based SMR designs, notably for the far eastern part of Russia.

Such an LWR-based SMR design, the KLT-40S, intended for deployment on a barge as a floating nuclear power plant, is the only one that has so far been deployed in Russia. Two such reactors, deployed on a barge called the Akademik Lomonosov, were commissioned in May 2020 after lengthy delays and cost overruns (see WNISR2020 and earlier WNISR editions). The Akademik Lomonosov's performance after it was commissioned has been poor; the 2020 load factors for the two reactors were just 29 and 16 percent according to the IAEA's PRIS database.

Russia's state-owned Rosatom is now promoting the RITM series of reactors, and, in November 2020, announced plans to build a land-based (RITM-200N) in the village of Ust-Kuyga, in Yakutia, again in the far eastern part of Russia.[1193] If constructed, it could be Russia's first land based SMR. According to the World Nuclear Association (WNA), start of construction is planned for 2024.[1194] In June 2020, the Marketing Director for Rosatom projected that the RITM-200N will be commissioned in 2027.[1195]

The RITM-200 and the KLT-40S are part of a larger Russian strategy to develop the Arctic and eastern Siberia to obtain minerals and hydrocarbons.[1196] In October 2020, Russian President Vladimir Putin signed an executive order entitled "On the Strategy for Developing the Russian Arctic Zone and Ensuring National Security until 2035" that calls for "the construction of at least five new nuclear-powered icebreakers of the Project 22220 series, and three of the Project 10510 series" that are "needed to ensure year-round navigation along the Northern Sea Route".[1197]

But the main focus of Russian SMR efforts are fast neutron designs. In June 2021, Rosatom announced it had commenced constructing of the first lead-cooled BREST-300 fast reactor

1192 - Alok Chaurey and Bhabha Atomic Research Centre, "R&D Programme in BARC on AHWR-300 Design & Technology Development and Innovative Reactors", Presented at the Second Meeting of the Technical Working Group for Small and Medium-sized or Modular Reactor, 9 July 2019, see https://nucleus.iaea.org/sites/htgr-kb/twg-smr/SitePages/2019.aspx, accessed 25 June 2020.

1193 - *WNN*, "Rosatom plans first land-based SMR for Russian Far East", 11 November 2020, see https://www.world-nuclear-news.org/Articles/Rosatom-plans-first-land-based-SMR-for-Russian-Far, accessed 27 June 2021.

1194 - WNA, "Nuclear Power in Russia", Updated April 2021, see https://www.world-nuclear.org/information-library/country-profiles/countries-o-s/russia-nuclear-power.aspx, accessed 10 May 2021.

1195 - Elena Pashina, "Rosatom RITM series SMRs", Rusatom Overseas, Presented at the IFNEC SMR Webinar Series "SMR Vendor Forum – An Open Discussion with Global Vendors to Review Designs and Benefits", 23 June 2020, see https://www.ifnec.org/ifnec/upload/docs/application/pdf/2020-06/slides_deck_-_webinar_4.pdf, accessed 6 July 2020.

1196 - Gary Peach, "Frontier Expansion via Floating NPPs", *NIW*, 4 June 2021.

1197 - *WNN*, "Putin decrees development of Arctic with more nuclear icebreakers", 30 October 2020, see https://www.world-nuclear-news.org/Articles/Putin-decrees-development-of-Arctic-with-more-nucl, accessed 27 June 2021.

at the Siberian Chemical Combine (SCC) in Seversk.[1198] This follows an announcement from May 2020 about preparatory work at that site, and a December 2019 announcement about a RUB26.3 billion (USD412 million) contract for construction being awarded.[1199] According to Yevgeny Adamov, former minister of atomic energy and a champion of lead-cooled fast reactors, BREST-300 should cost RUB100 billion (USD1.4 billion).[1200]

The BREST design is significantly delayed. The "Federal Program for Advanced Nuclear Technologies" adopted by Russia in January 2012 had called for building three commercial fast neutron reactors by 2020, including the BREST-300, as well as the lead-bismuth cooled SVBR-100, and the sodium-cooled BN-1200.[1201] The federal budget for 2013 allocated RUB25.7 billion for "the design and construction of the pilot demonstrative fast-neutron lead cooled reactor BREST".[1202] By the following year, the Technical Lead of the IAEA's SMR Technology Development division projected that the BREST-300 and SVBR-100 would be deployed by 2018.[1203] The BREST-300 reactor is now projected to enter operation in 2026.[1204]

In the meanwhile, Russian analysts suggest that the SVBR-100 reactor design has been "effectively discontinued".[1205] The WNA also maintains that the SVBR-100 has "been cancelled".[1206]

SOUTH KOREA

South Korea's main SMR design, the System-Integrated Modular Advanced Reactor (SMART), a 100-MW Pressurized Water Reactor, was one of the first to be licensed, having received a Standard Design Approval from Korea's Nuclear Safety and Security Commission (NSSC) in July 2012.[1207] But there have been no orders within South Korea, primarily because of adverse

1198 - Darrell Proctor, "Nuclear First—Work Starts on Russian Fast Neutron Reactor", *POWER Magazine*, 8 June 2021, see https://www.powermag.com/nuclear-first-work-starts-on-russian-fast-neutron-reactor/, accessed 27 June 2021. However, it remains uncertain whether the launch event actually involved the technical construction start with the concreting of the base slab of the reactor building.

1199 - *NEI*, "Preparatory construction for Brest-300 reactor begins in Russia", 22 May 2020, see https://www.neimagazine.com/news/newspreparatory-construction-for-brest-300-reactor-begins-in-russia-7936880; and *WNN*, "Russia awards contract to build BREST reactor", 5 December 2019, see https://world-nuclear-news.org/Articles/Russia-awards-contract-to-build-BREST-reactor, both accessed 7 July 2020.

1200 - Gary Peach, "Construction Starts on Lead-Cooled Fast Reactor", *NIW*, 11 June 2021.

1201 - Gary Peach, "Russia: Large Commercial Breeder Design Targeted for 2014", *NIW*, 16 March 2012.

1202 - Anatoli Diakov, "Status and prospects for Russia's fuel cycle", *Science & Global Security*, 2013.

1203 - M. Hadid Subki, "Global Development Trends, Prospects and Issues for SMRs Deployment", presented at the 23rd TWG - GCR Meeting, 5 March 2013.

1204 - Darrell Proctor, "Nuclear First—Work Starts on Russian Fast Neutron Reactor", *Power Magazine*, 2021, op. cit.

1205 - Anatoli Diakov and Pavel Podvig, "Construction of Russia's BN-1200 fast-neutron reactor delayed until 2030s", *IPFM Blog*, 20 August 2019, see http://fissilematerials.org/blog/2019/08/the_construction_of_the_b.html, accessed 7 July 2020.

1206 - WNA, "Generation IV Nuclear Reactors", December 2020, see https://world-nuclear.org/information-library/nuclear-fuel-cycle/nuclear-power-reactors/generation-iv-nuclear-reactors.aspx, accessed 27 June 2021.

1207 - Kwon Dong-joon, "Korean All-in-one SMR Won World's First Standard Design Approval", *Korea IT News*, *Electronic Times Interne*t, 5 July 2012, see http://english.etnews.com/20120705200008, accessed 1 May 2017.

economics. Indeed, the description of SMART in the IAEA's 2020 edition of its book on SMRs is more candid about this challenge than most other SMR designs in stating that

> the target overnight plant construction cost of a FOAK[1208] unit is [US]$10000/kW(e) and an operating and maintenance cost of 2.8 ¢/kWh. For NOAK[1209] unit of SMART, the total cost is expected to be 30~40% lesser.[1210]

The high cost is likely the reason that in April 2021, Korea Hydro & Nuclear Power (KHNP) announced that it is "carrying out a project to improve the" SMART design, with the aim of obtaining "a license for the improved SMART by 2028".[1211]

At the same time, there is an ongoing effort to export SMART reactors, especially in the Middle East, which has been a major focus of nuclear reactor vendors.[1212] South Korea has been working with Saudi Arabia in the hope that the country will not be the only customer but would also play a role in facilitating other sales. The cooperation started in 2015 when the Korea Atomic Energy Research Institute (KAERI) signed a Memorandum of Understanding with the King Abdullah City for Atomic and Renewable Energy (KA-CARE), to "conduct a three-year preliminary study to review the feasibility of constructing SMART reactors in Saudi Arabia".[1213] In January 2020, the agreement was updated to accommodate "a request from Saudi Arabia that KHNP participates in the project as the company's experience in the construction and operation of power reactors would reduce risks in the construction of the first SMART unit".[1214]

The partnership between Saudi Arabia and South Korea is somewhat atypical and Saudi engineers have been playing a role in a redesign of the SMART reactor; it is reported that "Saudi engineers wanted a truly passive system, rather than the hybrid active/passive system in the licensed 100 MW Smart design, and a joint team…engineered away the active pump and active power needs of the reactor. The joint team also uprated the reactor by 10%, from 330 MW thermal to 365 MWt, and from 100 MWe to 110 MWe".[1215] An application for yet another NSSC standard design approval for this design was submitted in October 2020, and the review process is underway.

In June 2021, KAERI and Samsung Heavy Industries announced plans to develop molten salt reactors for marine propulsion and floating nuclear power plants but commercial operations were projected to be only "in the mid-2030s".[1216]

1208 - First-of-a-kind.

1209 - Nth-of-a-kind.

1210 - See page 56 in IAEA, "Advances in Small Modular Reactor Technology Developments — A Supplement to IAEA Advanced Reactors Information System (ARIS) 2020 Edition", September 2020, see https://aris.iaea.org/Publications/20-02619E_ALWCR_ARIS_Booklet_WEB.pdf.

1211 - Jung Min-hee, "KHNP to Accelerate Development of Innovative SMRs", *Businesskorea*, 20 April 2021, see http://www.businesskorea.co.kr/news/articleView.html?idxno=65179, accessed 24 June 2021.

1212 - M. V. Ramana and Zia Mian, "Scrambling to sell a nuclear Middle East", *Bulletin of the Atomic Scientists*, 2016.

1213 - *WNN*, "Saudi Arabia teams up with Korea on SMART", 4 March 2015, see http://world-nuclear-news.org/NN-Saudi-Arabia-teams-up-with-Korea-on-SMART-0403154.html, accessed 30 May 2021.

1214 - *WNN*, "Korea, Saudi Arabia progress with SMART collaboration", 7 January 2020, see https://www.world-nuclear-news.org/Articles/Korea-Saudi-Arabia-progress-with-SMART-collaborati, accessed 4 July 2020.

1215 - Phil Chaffee, "Smart SMR Cements Saudi-Korean Partnership", *NIW*, 10 July 2020.

1216 - Charles Lee, "South Korea companies develop molten salt reactor for shipping, power generation", *S&P Global Platts*, 22 June 2021, see https://www.spglobal.com/platts/en/market-insights/latest-news/metals/062221-south-korea-companies-develop-molten-salt-reactor-for-shipping-power-generation, accessed 23 June 2021.

UNITED KINGDOM

The United Kingdom's interest in SMRs follows a 2014 feasibility study carried out by the National Nuclear Laboratory and funded by seven nuclear organizations, including Rolls Royce.[1217] The following year's budget included a promise to spend "at least £250 million" (US$$_{2015}$380 million) to "position the UK as a global leader in innovative nuclear technologies" and on a competition to identify the best SMR-design and aim to build "one of the world's first SMRs in the UK in the 2020s".[1218] That funding was never made available; but in November 2020, as part of an economic stimulus plan to recover from the coronavirus pandemic, the government announced a plan to deliver "new and advanced nuclear power".[1219]

The new plan includes the announcement of "up to £385 million [US$$_{2020}$499 million] in an Advanced Nuclear Fund" that is subject to "value-for-money and future spending rounds"; the figure includes "up to £215 million [US$$_{2020}$278 million] into Small Modular Reactors to develop a domestic smaller-scale power plant technology design that could potentially be built in factories and then assembled on site" and "up to £170 million [US$$_{2020}$220 million] for a research and development programme on Advanced Modular Reactors". There is also a promise that this funding "will unlock up to £300 million [US$$_{2020}$388 million] private sector match-funding" although such funding has so far not been forthcoming.

The company that is expected to benefit from the "up to £215 million [US$$_{2020}$278 million]" funding package for SMRs is Rolls Royce. Rolls Royce's SMR design, which has been named "UK SMR", started being designed to generate 440 MW, i.e., not meeting the definition of a small reactor.[1220] More recently, its design output has been increased to 470 MW.[1221] This increase is not surprising, and other SMR vendors have also increased the power outputs for their SMR designs, presumably to take advantage of economies of scale; the U.S. NuScale design is a good example.[1222] In May 2021, the U.K. SMR consortium announced plans to submit the design for regulatory assessment "in the second half of this year".[1223]

1217 - *WNN*, "National Nuclear Laboratory urges UK investment in SMRs", 4 December 2014, see https://www.world-nuclear-news.org/NN-National-Nuclear-Laboratory-urges-UK-investment-in-SMRs-4121401.html, accessed 6 July 2019.

1218 - Damian Carrington, "George Osborne puts UK at the heart of global race for mini-nuclear reactors", *The Guardian*, 24 November 2015, see https://www.theguardian.com/environment/2015/nov/24/mini-nuclear-reactors-answer-to-climate-change-crisis, accessed 6 July 2019.

1219 - Department for Business, Energy & Industrial Strategy and Prime Minister's Office, "The Ten Point Plan for a Green Industrial Revolution", Policy Paper, U.K. Government, Updated 18 November 2020, see https://www.gov.uk/government/publications/the-ten-point-plan-for-a-green-industrial-revolution/title, accessed 27 June 2021.

1220 - Rolls Royce, "UK SMR: A National Endeavour", September 2017, see https://www.uknuclearsmr.org/uk-smr-a-national-endeavour-report/, accessed 6 July 2019.

1221 - *WNN*, "Rolls-Royce on track for 2030 delivery of UK SMR", 11 February 2021, see https://world-nuclear-news.org/Articles/Rolls-Royce-on-track-for-2030-delivery-of-UK-SMR, accessed 27 June 2021.

1222 - Stephanie Cooke, "NuScale Moves to Larger-Scale Modules", *NIW*, 12 February 2021; and M. V. Ramana, "Eyes wide shut: Problems with the Utah associated municipal power systems proposal to construct NuScale small modular nuclear reactors", Oregon Physicians for Social Responsibility, September 2020, see https://www.oregonpsr.org/small_modular_reactors_smrs, accessed 13 October 2020.

1223 - *WNN*, "UK SMR to start regulatory process this autumn", 17 May 2021, see https://www.world-nuclear-news.org/Articles/UK-SMR-to-start-regulatory-process-this-autumn, accessed 27 June 2021.

UNITED STATES

The United States continues to actively pursue SMRs and the U.S. Department of Energy (DOE) has invested hundreds of millions of dollars into promoting research and development work on SMRs over the past decade. In 2020, the DOE awarded US$80 million each to Terrapower (for their Natrium reactor design) and X-energy "in initial funding to test, license, and build" within seven years.[1224] It is estimated that each of these designs "could receive a total of between $400 million and $4 billion in funding over the next 5 to 7 years".[1225] Both companies have entered into agreements with Energy Northwest in Washington State.[1226] However, in June 2021 it was announced that the Terrapower reactor project will instead be built at a site in Wyoming, owned by PacifiCorp.[1227]

The NuScale design is widely regarded as the closest to deployment in the U.S., because it is the first SMR design to have received a Final Safety Evaluation Report (FSER) from the U.S. Nuclear Regulatory Commission (NRC).[1228] The FSER covers a design with 50-MW modules and the application was submitted in 2016.[1229] However, in a sign of the economic challenges it confronts, the output of the NuScale design has been increased from 50 MW to first 60 MW,[1230] and then to 77 MW per module.[1231] The output had already been increased multiple times.[1232] NuScale would have to submit new design details to the NRC for the uprate to be permitted.

Meanwhile, the first NuScale project to be constructed in Idaho with electricity to be purchased by Utah Associated Municipal Power Systems (UAMPS) has been looking more tentative. In 2020, at least eight municipalities withdrew from the project, and others cut the power levels they had committed to.[1233] As a result, the level of subscription to this project declined from 213 MW to 100.6 MW.[1234] In other words, less than a ninth of the output of a typical 12-pack of

1224 - Rita Baranwal, "It's Time for the United States to Demonstrate Advanced Reactors", Office of Nuclear Energy, U.S. Department of Energy, 14 October 2020, see https://www.energy.gov/ne/articles/it-s-time-united-states-demonstrate-advanced-reactors-0, accessed 27 June 2021.

1225 - Adrian Cho, "Department of Energy picks two advanced nuclear reactors for demonstration projects", *Science*, 16 October 2020, see https://www.sciencemag.org/news/2020/10/department-energy-picks-two-advanced-nuclear-reactors-demonstration-projects, accessed 27 June 2021.

1226 - Wendy Culverwell, "Federal awards put Tri-Cities on map for next generation nuclear power", *Tri-Cities Area Journal of Business*, 25 December 2020, see https://www.tricitiesbusinessnews.com/2020/12/energy-nw/, accessed 27 June 2021.

1227 - *Journal of Business*, "Tri-Cities loses TerraPower advanced nuclear plant to coal site in Wyoming", June 2021, see https://www.tricitiesbusinessnews.com/2021/06/terrapower/, accessed 30 August 2021.

1228 - *WNN*, "NuScale SMR receives US design certification approval", 1 September 2020, see https://world-nuclear-news.org/Articles/NuScale-SMR-receives-US-design-certification-appro, accessed 1 September 2020.

1229 - NuScale Power, "NuScale Submits First Ever Small Modular Reactor Design Certification Application (DCA)", 12 January 2012, see http://newsroom.nuscalepower.com/press-release/company/nuscale-submits-first-ever-small-modular-reactor-design-certification-applicat, accessed 29 April 2017.

1230 - NuScale Power, "Breakthrough for NuScale Power; Increase in its SMR Output Delivers Customers 20 Percent More Power", 6 June 2018, see https://newsroom.nuscalepower.com/press-releases/news-details/2018/Breakthrough-for-NuScale-Power-Increase-in-Its-SMR-Output-Delivers-Customers-20-Percent-More-Power/default.aspx, accessed 27 June 2021.

1231 - Stephanie Cooke, "NuScale Moves to Larger-Scale Modules", *NIW*, 2021, op. cit.

1232 - M.V. Ramana, "Eyes Wide Shut: Problems with the Utah Associated Municipal Power Systems Proposal to Construct NuScale Small Modular Nuclear Reactors", Oregon Physicians for Social Responsibility, 2020, op. cit.

1233 - Sonal Patel, "Shakeup for 720-mw nuclear SMR project as more cities withdraw participation", *Power Magazine*, 29 October 2020, see https://www.powermag.com/shakeup-for-720-mw-nuclear-smr-project-as-more-cities-withdraw-participation/, accessed 29 October 2020.

1234 - UAMPS, "Carbon Free Power Project Resource 'Option' Update", Utah Associated Municipal Power Systems, February 2021, see https://losalamos.granicus.com/DocumentViewer.php?file=losalamos_7a21a2e19e64df6f2949137241f1d18a.pdf&view=1, accessed 27 June 2021.

77-MW NuScale modules has guaranteed purchasers.[1235] As costs for the project increase, it is possible that even more subscribers quit the project. Another source of potential delays are the financial troubles of Fluor Corporation, reflected in its stock prices that dropped to less than a third of the roughly US$60 price in October 2018. NuScale has entered into agreements with other utilities, for example, the Grant County Public Utility,[1236] but their potential uptake is quite limited.

CONCLUSION

The amplification of the talk about SMRs and related media coverage over the past year is not reflected by any major industrial achievements on the ground. There have been additional funding announcements, but no additional design certifications beyond an already outdated NuScale design in the U.S.; further delays in the construction of units in Argentina and China; no concrete steps toward construction of further units, with the exception of the BREST-300 in Russia, which is at the edge of the definition of SMRs, did not follow any design certification as practiced in most western industrialized countries, and is years behind schedule.

In August 2020, a report on Poland's draft nuclear newbuild plan dismissed the SMR concept saying:

> To date, no construction contracts have been concluded, and there is no complete design and implementation documentation (construction projects) that could be subject to verification... Therefore, at the present stage, it is not possible to reliably estimate the future costs of such facilities. The philosophy of both the integrated construction and the 'addition' of new reactors (modules), adopted in many cases by the designers, indicates possible operational problems and high costs of renovation works...[1237]

The critique appears coherent as far as it goes, but it does not quite reflect the growing evidence that SMRs, like large reactors, will continue to be subject to delays and cost overruns, and the high likelihood that they would not be economical even under the most favorable circumstances.

1235 - In July 2021, NuScale announced it could go with a "6-pack" with 462 MW at a cost of US$ 5.3 billion; see Michael McAuliffe, "UAMPS to go with six-unit NuScale SMR plant, smaller than original", *Nucleonics Week*, 22 July 2021.

1236 - NuScale and Grant County Public Utility District, "NuScale Power and Grant County Public Utility District Sign Memorandum of Understanding to Explore Nuclear Energy Deployment in Washington State", *BusinessWire*, 26 May 2021, see https://www.businesswire.com/news/home/20210526005248/en/NuScale-Power-and-Grant-County-Public-Utility-District-Sign-Memorandum-of-Understanding-to-Explore-Nuclear-Energy-Deployment-in-Washington-State, accessed 27 June 2021.

1237 - Phil Chaffee, "Is Poland Angling for a US Newbuild Deal?", *NIW*, 21 August 2020.

NUCLEAR POWER VS. RENEWABLE ENERGY DEPLOYMENT

INTRODUCTION

2021 is a pivotal year for climate change policy with the upcoming 26th meeting of the parties of the United Nations Framework Convention on Climate Change (COP26, UNFCCC) in November. This is a key meeting of the UNFCCC as all parties are expected to review and revise their Nationally Determined Contributions (NDCs), which contain their adaptation and mitigation plans until 2030. Over the past year, blocs such as the EU, and countries including Germany, Japan, the U.K., and the U.S. have put forward national strategies to accelerate their carbon abatement targets and plans. These plans, according to Climate Analytics, if fully implemented, will reduce global warming and contain rises in global temperatures to 2.4°C (degrees Celsius) above pre-industrial levels, compared to a likely increase of 2.9°C assumed within the 2015 Paris Agreement.[1238]

While this progress has been welcome, it still falls short of the objectives of the Paris Agreement to limit global warming to well below 2°C, preferably to 1.5°C, compared to pre-industrial levels. Therefore, it is expected that all countries, but especially the major emitters, will come forward with more carbon mitigation plans, including sector initiatives. Furthermore, in and around COP26, non-state actors, such as cities and industrial sectors, are expected to put forward strategies to accelerate the development of low-carbon technologies and practices.

In preparation for COP26, which is being held in the city of Glasgow in Scotland, the International Energy Agency (IEA) published a report outlining a strategy for the energy sector to meet the temperature targets of the Paris Agreement, and concluded that in their scenario "by 2050, almost 90% of electricity generation comes from renewable sources, with wind and solar PV together accounting for nearly 70%".[1239] This is a remarkable perspective from the IEA, which in its scenarios has so long underestimated and downplayed the role for renewable energy.

The IEA assumes in this scenario that nuclear will maintain its share of the global power market at about 10 percent. This would require an increase in output (from 2,698 to 5,497 TWh) due to the overall growth in energy demand and the continued electrification of the transport and heating sector. Given the developments of nuclear power over the past 30 years, with only very limited increases in use—in 1990 nuclear produced about 2,000 TWh and 2,553 TWh in 2020—it would require a sea-change in the fortunes of the technology. Rather, there is

1238 - Climate Analytics, "Global update: Projected warming from Paris pledges drops to 2.4 degrees after US Summit: analysis", 4 May 2021, see https://climateanalytics.org/latest/global-update-projected-warming-from-paris-pledges-drops-to-24-degrees-after-us-summit-analysis/, accessed 6 June 2021.

1239 - IEA, "Net Zero by 2050 – A Roadmap for the Global Energy Sector", International Energy Agency, May 2021, see https://www.iea.org/reports/net-zero-by-2050, accessed 6 June 2021.

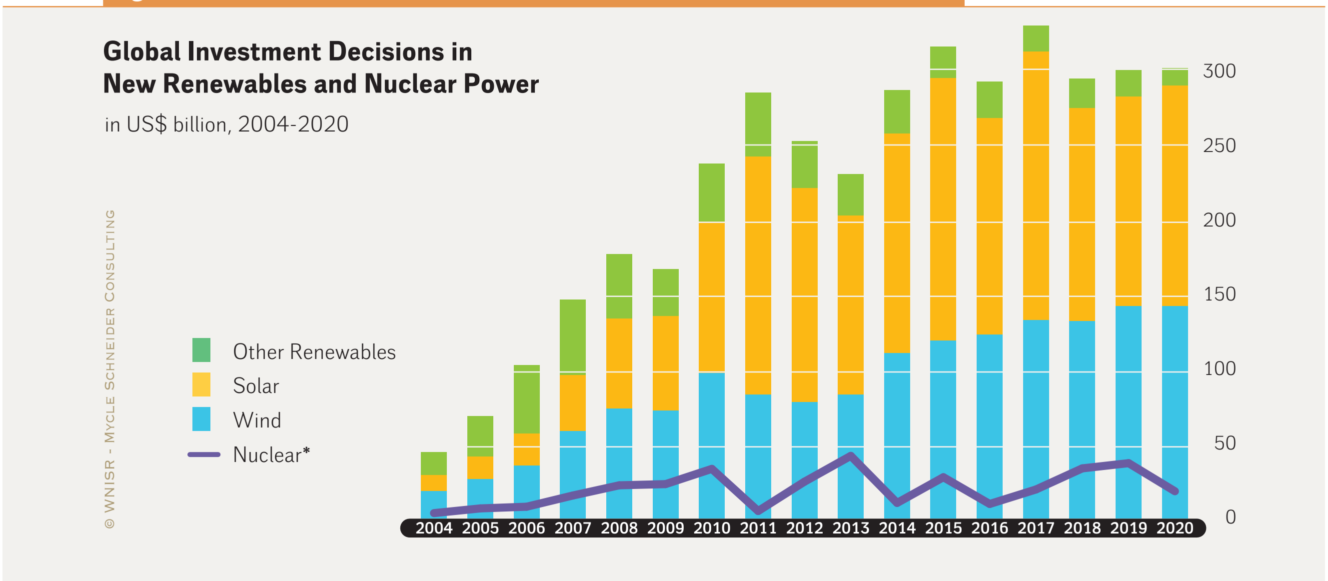
growing recognition that even with a rapid increase in the global use of electricity, renewables, primarily solar and wind, will do the "heavy lifting".

From an analytical position this is not surprising, as this chapter shows—and has done so for several years—renewables are out-deploying and are significantly cheaper than nuclear power. Consequently, more investment is taking place in renewables, which leads to lower price and more deployment experience, creating a virtuous circle in which renewables are becoming cheaper than all other forms of electricity generation.

INVESTMENT

Figure 42 compares the annual investment decisions for constructing new nuclear plants with those for renewable energy since 2004. Construction began on five nuclear reactors in 2020, four in China and one in Turkey. The total reported and estimated investment for the construction of the 2020-projects is around US$18.3 billion for 5 GW. This is one eighth of the individual investments in wind and solar, with over US$142 billion investment in wind power and US$149 billion in solar. The total investment in non-hydro renewables globally, despite the economic impact of the COVID-19 pandemic, was US$303.5 billion. Significantly, falling capital costs enabled record volumes of both solar (132 GW) and wind (73 GW) power plants to be installed despite relatively small increases in investment.[1240]

Figure 42 · Global Investment Decisions in Renewables and Nuclear Power 2004–2020



Sources: FS-UNEP/BNEF 2018, 2020, REN21 2019, BNEF 2021 and WNISR Original Research, 2021

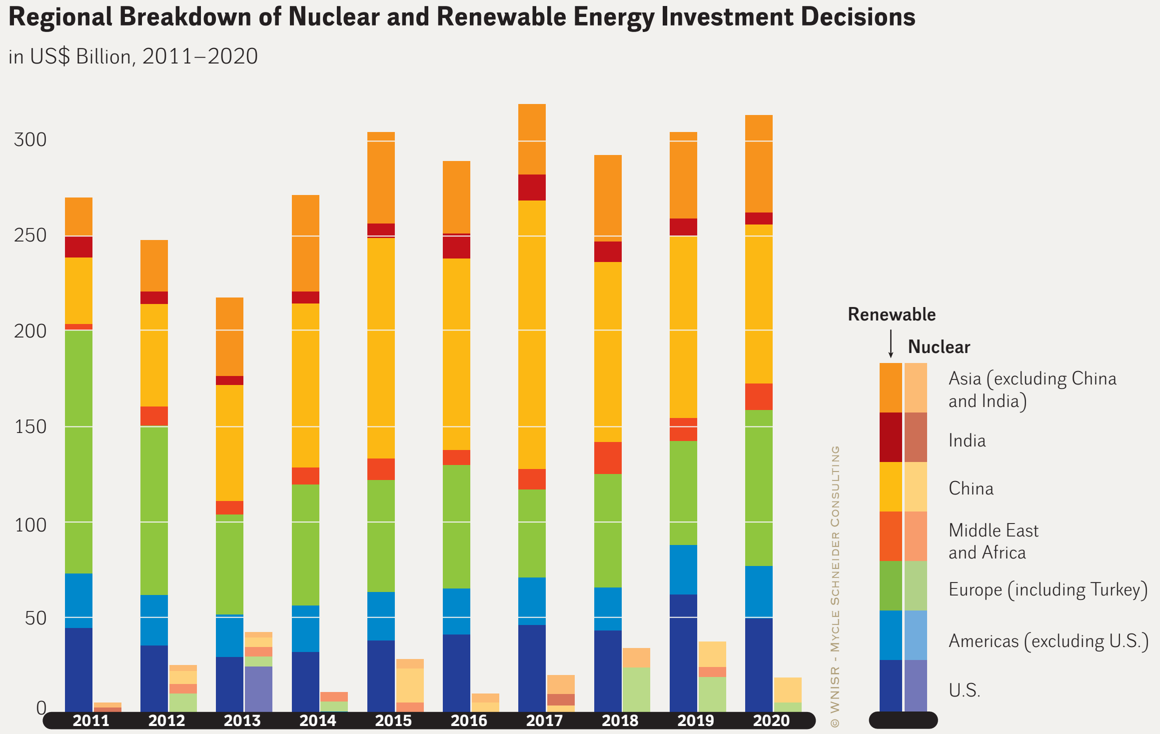
Note:

*In the absence of comprehensive, publicly available investment estimates for nuclear power by year, and to simplify the approach, WNISR includes the total projected investment costs in the year in which construction was started, rather than spreading them out over the entire construction period. Furthermore, nuclear investment figures do not include revised budgets if—as generally is the case—cost overruns occur.

1240 - BNEF, "Energy Transition Investment Hit $500 Billion in 2020 – For First Time", BloombergNEF, 19 January 2021, see https://about.bnef.com/blog/energy-transition-investment-hit-500-billion-in-2020-for-first-time/, accessed 6 June 2021.

Globally, the relative importance of Europe and North America for renewable energy investments diminished, with the rise of Asia, especially China (see Figure 43) although that relative dominance shrank in recent years. Chinese nominal-dollar renewable investment rose from US$26 billion in 2008 to US$140 billion in 2017 before a steep cut to US$94 billion in 2018, US$95 billion in 2019 and US$85 billion in 2020. The last and lowest figure is just about equal to the *total cumulative* investment in nuclear power plants in China since 2008, which is also approximately US$85 billion.

Figure 43 · Regional Breakdown of Nuclear and Renewable Energy Investment Decisions 2011–2020



Sources: REN21, BNEF/UNEP, WNISR Original Analysis, 2021

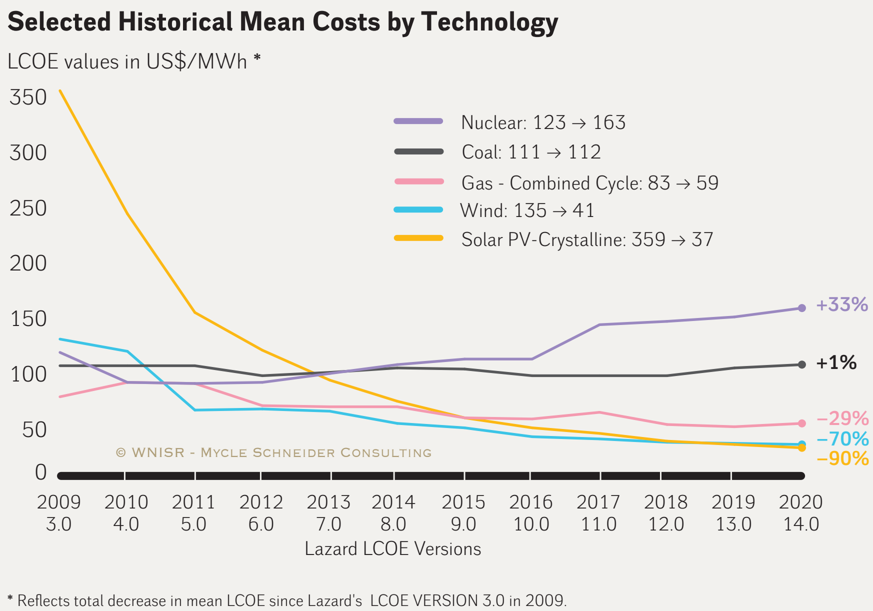
TECHNOLOGY COSTS

The annual Levelized Cost of Energy (LCOE) analysis for the U.S. last updated by Lazard, one of the oldest banks in the world, in October 2020[1241], suggests that unsubsidized average electricity generating costs declined between 2015 and 2020 in the case of solar PV (crystalline, utility-scale) from US$64 to US$37 per MWh, and for onshore wind from US$55 to US$40 per MWh, while nuclear power costs went up from US$117 to US$163 per MWh. Over the past five years alone, the LCOE of nuclear electricity has risen by 39 percent, while renewables have now become the cheapest of any type of power generation.

1241 - Lazard, "Levelized Cost of Energy and of Storage – 2020", 19 October 2020, see http://www.lazard.com/perspective/levelized-cost-of-energy-and-levelized-cost-of-storage-2020/, accessed 6 June 2021.

Since 2009, when Lazard started publishing its LCOE estimates in the current format, solar PV costs dropped by 90 percent, onshore wind by 70 percent, while nuclear power increased by one third (see Figure 44).

Figure 44 · The Declining Costs of Renewables vs. Traditional Power Sources



Source: Lazard Estimates, 2020[1242]

Notes

LCOE=Levelized Cost of Energy

*This graph reflects the average of unsubsidized high and low LCOE range for a given version of LCOE study. It primarily relates to the North American renewable energy landscape but reflects broader/global cost declines.

Globally the cost of renewables is now significantly below that of either nuclear power or gas. According to Bloomberg New Energy Finance (BNEF), wind and solar power are now the cheapest form of new electricity in most of the world. Furthermore, BNEF anticipates that it will be more expensive to operate existing coal or natural gas power plants in five years than to build new solar or wind farms.[1243]

The first half of 2021 saw a number of remarkably low prices for renewable electricity. In April in Saudi Arabia a 600 MW Shuaibah solar project to be developed by a consortium of ACWA Power, Gulf Investment and Al Babtain Contracting achieved a record low electricity price at US$ 10.40/MWh. This beats the previous global record low claimed by Portugal in August 2020 of €11.14/MWh (US$13.23/MWh) for a solar project.[1244] In Spain in January 2021, the Government auctioned tenders for 3 GW of renewable capacity, with the lowest awarded

1242 - Lazard, "Levelized Cost of Energy and of Storage – 2020", 2020, op. cit.

1243 - Jeremy Hodges, "Wind, Solar Are Cheapest Power Source In Most Places, BNEF Says", *Bloomberg*, 19 October 2020, see https://www.bloomberg.com/news/articles/2020-10-19/wind-solar-are-cheapest-power-source-in-most-places-bnef-says, accessed 6 June 2021.

1244 - Sophie Vorrath, "Saudi solar plant locks in new record low price for power: 1.04c/kWh", *RenewEconomy*, 13 April 2021, see https://reneweconomy.com.au/saudi-solar-plant-locks-in-new-record-low-price-for-power-1-04c-kwh/, accessed 10 July 2021.

contracts for €15/MWh (US$18/MWh) for solar and €20/MWh (US$24/MWh) for onshore wind.[1245]

In their annual review of renewable energy costs, the International Renewable Energy Agency (IRENA) concludes:

> In 2020, the global weighted-average levelized cost of electricity (LCOE) from new capacity additions of onshore wind declined by 13%, compared to 2019. Over the same period, the LCOE of offshore wind fell by 9% and that of utility-scale photovoltaics (PV) by 7%.[1246]

IRENA agrees with BNEF and calculated that 800 GW of existing coal-fired capacity have higher *operating costs* than new utility-scale solar PV at US$57/MWh and onshore wind at US$39/MWh, including US$0.005/kWh for additional system integration costs. Replacing these coal-fired plants would cut annual system costs by US$32 billion per year and reduce annual emissions by around 3 billion tons of CO2.[1247]

The same logic applies to the operation of nuclear power plants. The running of aging nuclear power plants generally leads to higher operating and maintenance costs. Only in the U.S., the nuclear industry has claimed a cost reduction from an average US$44.6/MWh in 2012 to US$30.4/MWh in 2019, in particular due to a significant drop in investments.[1248] The analyses of potential implications on safety and security are not within the scope of this report. The U.S. nuclear operators have managed an impressive load factor of around 90 percent for most of the past two decades. That helps managing costs.

In France, the Court of Accounts (Cour des comptes) calculated in 2016 a nuclear generating cost of $€_{2013}$62.6/MWh ($US\$_{2021}$78/MWh) for a national production of 410 TWh. The Court made it very clear that the overall costs were much more sensitive to the volume of production than to investment costs.[1249] In 2020, the French volume of generated nuclear power remained 18 percent below the reference production with a load factor at mediocre 67 percent (see France Focus). No doubt, the massive French refurbishment program—€100 billion (US$118 billion) for the period 2014–2030—has so far not led to increased productivity, rather on the contrary. There is no doubt that renewable power generating prices as seen in Portugal and Spain undercut French nuclear operating costs severalfold. Even in the U.S., with much lower operating costs, operating reactors are pushed out of the market unless they are heavily subsidized (see United States Focus).

As renewable energies keep becoming cheaper, the cost of electricity produced from renewables is dropping below the operation, maintenance, and fuel costs for nuclear power plants in many countries. This was extensively demonstrated in the WNISR2019 Chapter on Climate Change and Nuclear Power.

1245 - Wind Europe, "Onshore wind energy scores lowest ever price under new Spanish auction design", 27 January 2021, see https://windeurope.org/newsroom/news/onshore-wind-energy-scores-lowest-ever-price-under-new-spanish-auction-design/, accessed 10 July 2021.

1246 - IRENA, "Renewable Power Generation Costs in 2020", June 2021, see https://www.irena.org/publications/2021/Jun/Renewable-Power-Costs-in-2020, accessed 26 June 2021.

1247 - Ibidem.

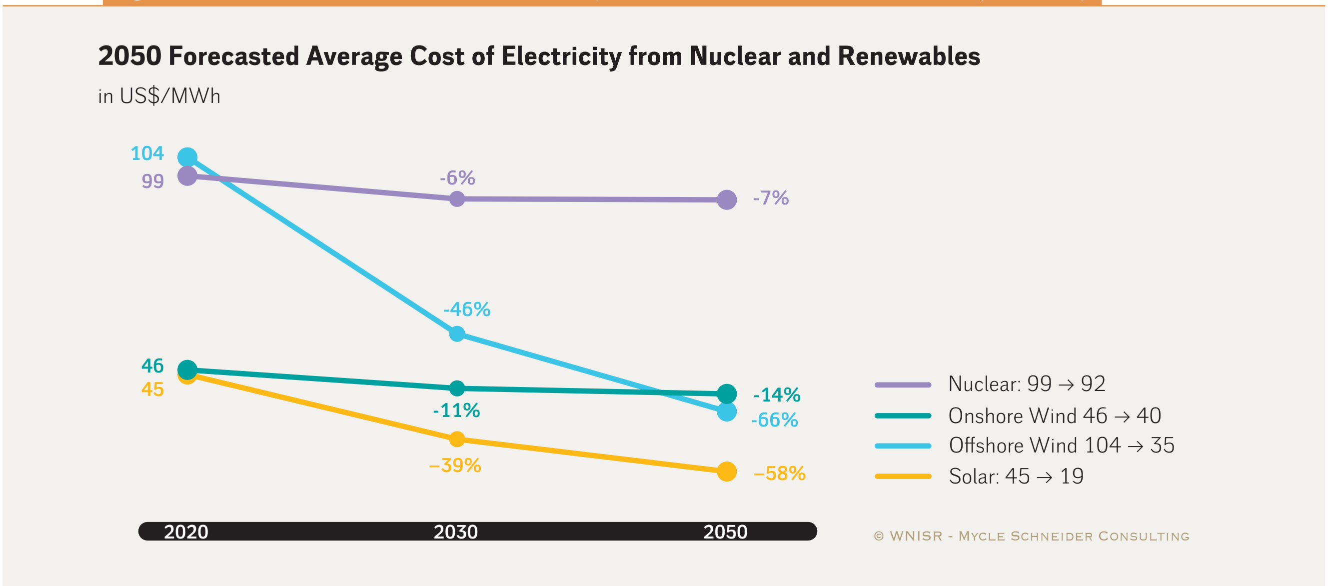
1248 - NEI, "Nuclear Costs in Context", Nuclear Energy Institute, 21 October 2020, see https://www.nei.org/resources/reports-briefs/nuclear-costs-in-context, accessed 2 September 2021.

1249 - A 50 percent reduction in output would double the generating costs. See Cour des comptes, "Rapport Public 2016", Tome 1, February 2016.

As the share of variable renewables (VRE), such as solar and wind, increases there will be challenges for grid management. System flexibility will be key, with a variety of solutions available, such as energy storage in various forms, demand side management, interconnection, and backup generation. Even with relatively high levels of VRE the technologies and costs are widely known. An assessment undertaken by the UK Energy Research Center found that median values for operating reserve costs were less than €5/MWh (US$6/MWh) when VRE contributed up to 35 percent of annual electricity production, and less than €10/MWh (US$12/MWh) when VRE contribution is up to 45 percent.[1250]

With limited experience of even greater penetrations of renewables the costs are less certain, but storage costs are falling rapidly. Lithium-ion batteries, which are both used in electric vehicles and for short term grid balancing, were above US$1,100/kWh in 2010 and have fallen 89 percent in real terms to US$137/kWh in 2020. By 2023, average prices are expected to be close to US$100/kWh according to BNEF.[1251] However, there is less certainty over the medium- and long-term (seasonal storage) for electricity, but a variety of options, such as green hydrogen or synthetic fuels are being tested and deployed. Green hydrogen produced with renewable resources costs about US$3–6.6/kg, according to the European Commission's July 2020 hydrogen strategy. Fossil-based hydrogen costs about US$1.80/kg. However, Norwegian electrolyzer-maker NEL ASA in January 2021 announced a goal of producing green hydrogen at US$1.50/kg by 2025.[1252]

Figure 45 · IEA 2050 Forecasted Cost of Electricity from Nuclear and Renewables, LCOE (US$/MWh)



Source: IEA, 2021[1253]

1250 - Philip J. Heptonstall and Robert J. K. Gross, "A systematic review of the costs and impacts of integrating variable renewables into power grids", *Nature Energy*, January 2021.

1251 - BloombergNEF, "Battery Pack Prices Cited Below $100/kWh for the First Time in 2020, While Market Average Sits at $137/kWh", 16 December 2020, see https://about.bnef.com/blog/battery-pack-prices-cited-below-100-kwh-for-the-first-time-in-2020-while-market-average-sits-at-137-kwh/, accessed 19 December 2020.

1252 - Tom DiChristopher, "Experts explain why green hydrogen costs have fallen and will keep falling", *SP Global*, 5 March 2021, see https://www.spglobal.com/marketintelligence/en/news-insights/latest-news-headlines/experts-explain-why-green-hydrogen-costs-have-fallen-and-will-keep-falling-63037203, accessed 10 July 2021.

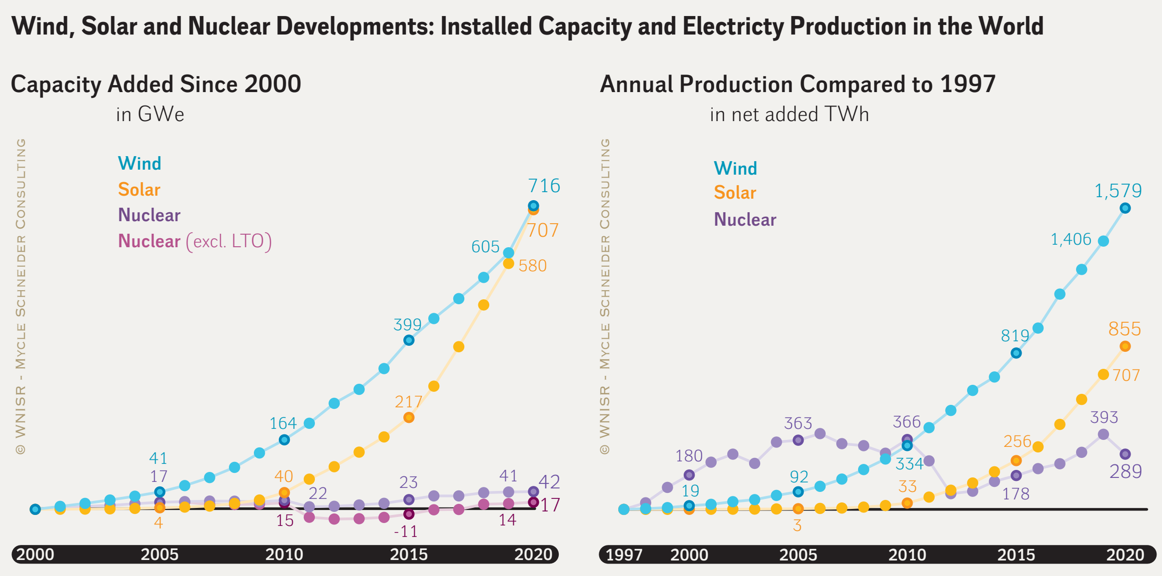
1253 - IEA, "Net Zero by 2050 – A Roadmap for the Global Energy Sector", May 2021, op. cit.

In their Net Zero report, the IEA highlights the extent to which the divergence of nuclear and renewable costs is expected to continue. While the IEA for 2020 indicates much lower figures for nuclear power costs and higher estimates for wind and solar costs than e.g. Lazard (see Figure 44 and Figure 45), the agency does not see any improvement coming for nuclear but major continued cost declines for offshore wind and solar. By 2050, solar PV costs are projected to be one fifth of those from nuclear power, across the EU, China, India, and U.S. (see Figure 45). In such circumstances, the building of any nuclear power plant would have to be driven by powerful non-market motivations.

INSTALLED CAPACITY AND ELECTRICITY GENERATION

Despite the relative slowdown in investment in renewables, the rapid reduction in construction costs per MW mean that there is still a significant rise in the net annual increase in installed capacity. In total, a record 256 GW of new-renewable energy capacity (excluding hydro) was installed in 2020, according to REN21, exceeding the previous record by nearly 30 percent.[1254]

Figure 46 · Variation of Wind, Solar and Nuclear Capacity and Electricity Production in the World



Sources: WNISR with IAEA-PRIS, IRENA, BP Statistical Review, 2021

Note pertaining to figures 46 to 56: Unless otherwise indicated, production data for nuclear are net generation, according to IAEA-PRIS; renewables gross data are from BP Statistical Review. Gross nuclear TWh numbers, when explicitly used, are also from BP. Installed capacity data are from IRENA for wind and solar and based on IAEA-PRIS for nuclear.

The pace of wind deployment has picked up again and, despite the difficult conditions during the COVID-19 pandemic, the deployment of wind power was thriving in 2020 with a net increase in global capacity of 111 GW, according to IRENA, a near doubling of the 58 GW

1254 - REN21, "Renewables 2021 Global Status Report", 14 June 2021, see http://www.unep.org/resources/report/renewables-2021-global-status-report, accessed 18 June 2021.

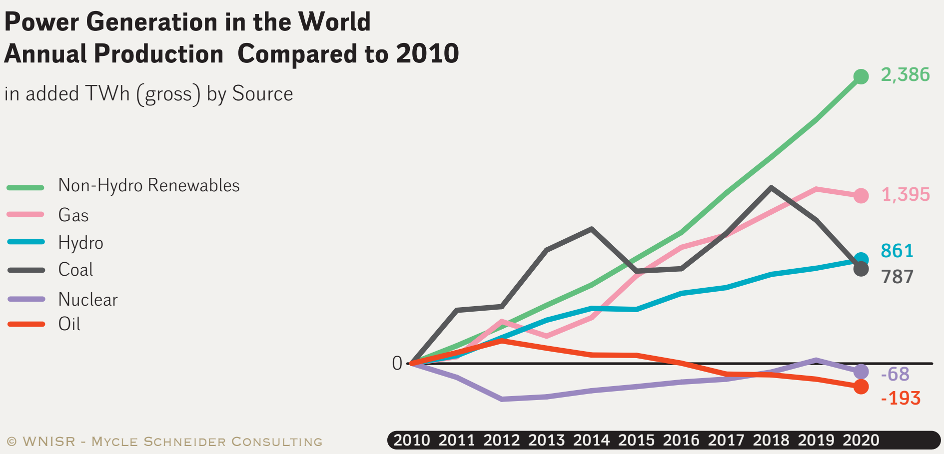
addition in 2019. Solar PV increased by 127 GW, a 22.5 percent increase over the 97.6 GW expansion in 2019.

Figure 46 illustrates the extent to which renewables have been deployed at scale since the start of the millennium, an increase in capacity of 716 GW for wind and of 707 GW for solar, according to IRENA, compared to the relative stagnation of nuclear power capacity, which over this period increased by around 42 GW, including all reactors currently in Long-Term Outage (LTO). Considering that 25 GW of nuclear power were in LTO as of the end of 2020, and thus not operating, the balance is an addition of 16.8 GW operating capacity compared to 2000.

The characteristics of electricity generating technologies vary due to different load factors. In general, over the year, operating nuclear power plants produce more electricity per MW installed than renewables. However, as can be seen in Figure 46, compared to 1997, when the Kyoto Protocol was signed, there has been an additional 1,579 TWh of wind power in 2020, over 855 TWh more electricity from solar PV, compared to an additional 289 TWh (309 TWh gross)[1255] of nuclear energy. In other words, over that 23-year period, wind turbines added 5.5-times more low-carbon electricity to the world's grids than nuclear power added, while solar panels contributed three times more to the increase.

In 2020, according to BP, the annual global growth rates for the generation from wind power were 11.9 percent (19.1 percent in 2019), 20.9 percent (24.3 percent in 2019) for solar PV, and –3.9 percent (+3.7 percent in 2019) for nuclear power.

Figure 47 · Net Added Electricity Generation by Power Source 2010–2020



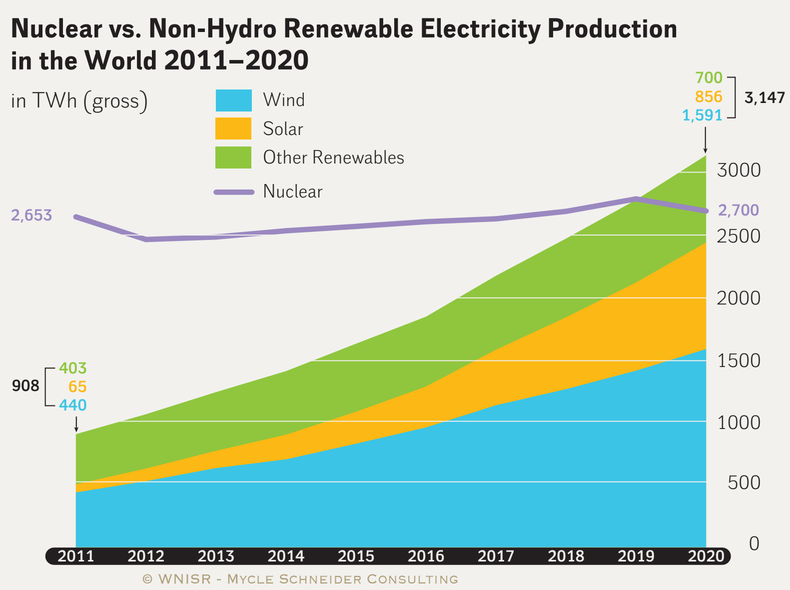
Source: BP Statistical Review, 2021

The growth of renewable energy is now not only outcompeting nuclear power but is rapidly overtaking fossil fuels and has become the source of economic choice for new generation. Figure 47 shows the extent to which, over the past decade, different energy sources have

1255 - Unless otherwise indicated, production data for renewables are in gross TWh from BP, nuclear production data are usually net TWh from IAEA-PRIS, gross nuclear TWh numbers are also from BP.

increased their electricity production. The energy source that has provided the greatest amount of additional electricity over the past decade is non-hydro renewables, generating an additional 2,386 TWh of power. The sector with the next largest growth was gas, then hydro and coal. Due to the collapse of production in nuclear in 2020, generation was lower than in 2010 and only oil had a greater decline in production over the past decade.

Figure 48 · Nuclear vs. Non-Hydro Renewable Electricity Production in the World

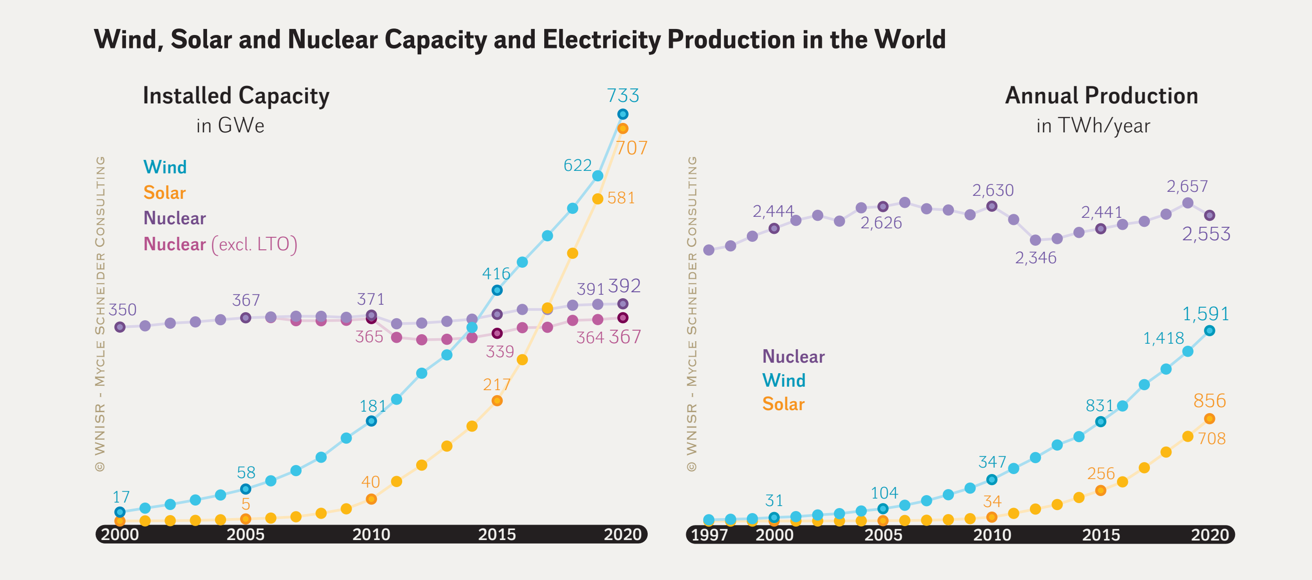


Sources: BP Statistical Review, 2021

In 2019, for the first time, non-hydro renewables—solar, wind, and mainly biomass—generated more power than nuclear plants. In 2020, with the significant drop of nuclear output, the gap widened, and renewables generated globally 16.5 percent more electricity than nuclear reactors (see Figure 48).

As Figure 49 shows, the individual installed capacity of both solar and wind is now approaching double that of nuclear power, which has been achieved in just two decades. While their combined outputs are still slightly lower than that of nuclear power, it is possible that in 2021 this will be revised. If this occurs it will have taken these industries just 20 years to achieve what the nuclear industry has done in more than half a century.

Figure 49 · Wind, Solar and Nuclear Installed Capacity and Electricity Production in the World



Sources: WNISR, IAEA-PRIS, IRENA, BP Statistical Review, 2021

STATUS AND TRENDS IN CHINA, THE EUROPEAN UNION, INDIA, AND THE UNITED STATES

China

China remains one of the most important countries in terms of renewable energy manufacturing and deployment, and the latest Ernst & Young Renewable Energy Country Attractiveness index has China in second spot behind the U.S.[1256]

In the case of China, there is usually a range of numbers for capacity and production volumes of energy, depending on the sources, especially for renewable sources. According to the China Electricity Council, by the end of 2020, the total installed capacity of renewable energy was 794 GW, up 9 percent from the previous year. This included 370 GW of hydro, 281 GW of wind and 253 GW of solar, which account for 41 percent of the installed capacity. The installed capacity of nuclear is 47.5 GW, with 2 GW installed in 2020. As can be seen in Figure 50 the growth of both solar and wind has been consistent and rapid—with annual growth rates in the last decade averaging 85 percent and 28 percent respectively—rising by 250 GW for solar, 235 GW for wind and just 36 GW of nuclear capacity.

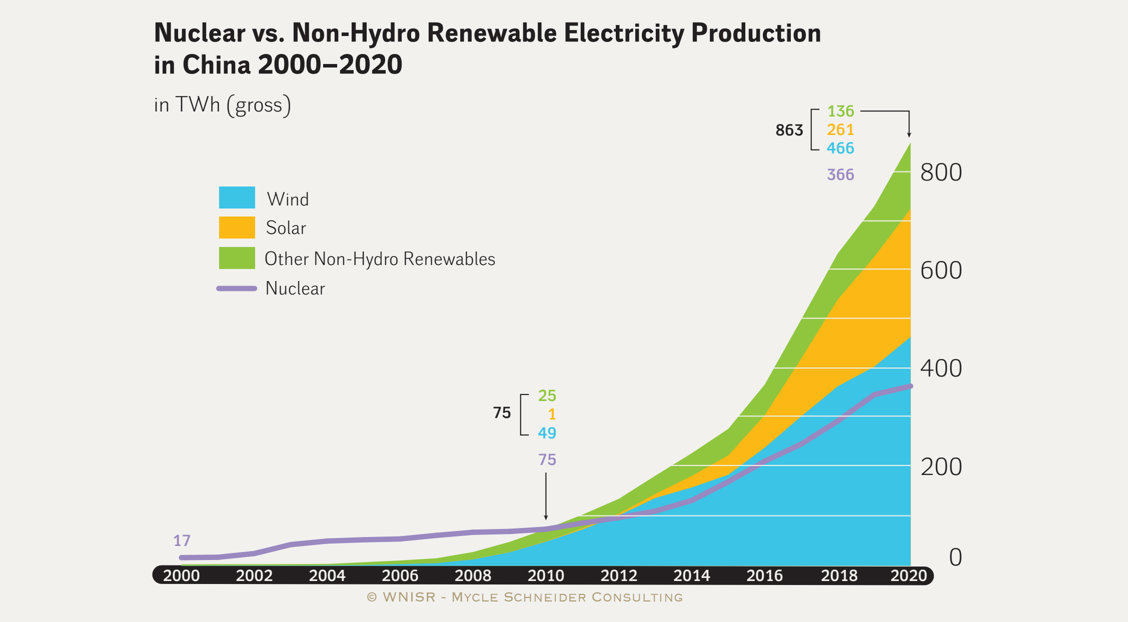
In 2020, renewable-energy-based power generation grew faster than any other energy sources, with wind producing 466 TWh, solar, 261 TWh, compared to 366 TWh gross for nuclear and 1,355 TWh gross for hydro according to data from the China Electricity Council. In 2020, wind increased its production by 15 percent, solar 17 percent, and nuclear 5 percent.[1257]

1256 - EY, "Renewable Energy Country Attractiveness Index", May 2021, see https://www.ey.com/en_uk/recai, accessed 1 June 2021.

1257 - China Electricity Council, "2020 electricity & other energy statistics (preliminary)", *China Energy Portal*, 22 January 2021, see https://chinaenergyportal.org/2020-electricity-other-energy-statistics-preliminary/, accessed 1 June 2021.

Nuclear output grew by an impressive 4.8 times between 2010 and 2020, while wind increased 9.4 times and solar over 350 times. As can be seen in Figure 50 and Figure 51, based on international figures published by BP and the IAEA (which differ slightly from those published by Chinese organizations) the total amount of energy generated by non-hydro renewables in 2020 is more than double that by nuclear power. This growth is all the more remarkable, as these technologies only surpassed nuclear power a decade ago, and China is by far the world's leading proponent of nuclear power.

Figure 50 · Nuclear vs Non-Hydro Renewables in China 2000–2020

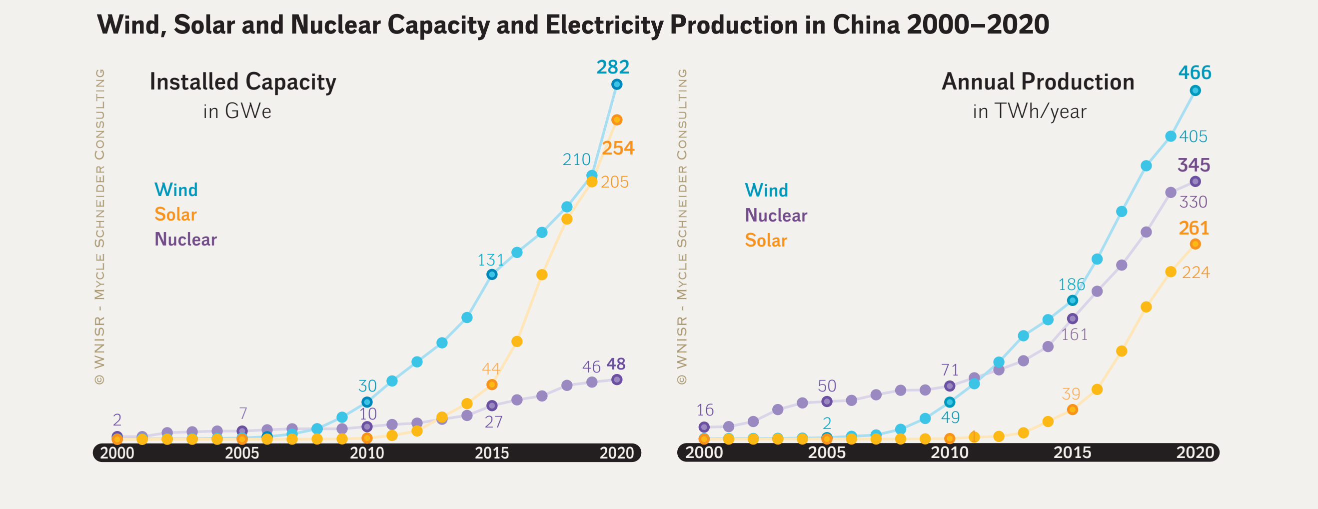


Sources: BP Statistical Review, 2021

China's energy and climate policies are determined primarily by five-year plans and the National Energy Strategy (2016–2030), set initially on the national level and then translated into provincial- and city-level targets. In March 2021, the Central Government announced its intentions for the 14th Five Year Plan (2021–2025), suggesting that the share of non-fossil fuels in the energy mix increase to 20 percent, up from 15 percent in the current 5-year plan. Key high-level targets for the energy sector were also to improve the economy's energy intensity by 13.5 percent and carbon intensity by 18 percent over these five years.

China's initial NDC submission to the UNFCCC in 2015 indicated that it would aim to peak CO_2 emissions around 2030 and make best efforts to peak early. In September 2020, to the surprise of many, President Xi said China would aim to have CO_2 emissions peak before 2030 and achieve carbon neutrality by 2060.

Figure 51 · Wind, Solar and Nuclear Installed Capacity and Electricity Production in China 2000–2020



Sources: IRENA, BP, IAEA-PRIS, WNISR, 2021

Then, at the UN Climate Ambition Summit in December 2020, President Xi announced that China would lower its CO_2 emissions per unit of GDP by 65 percent from 2005 levels and increase the share of non-fossil fuels in primary energy consumption to around 25 percent by 2030. This target is for energy as a whole, and it is suggested that by 2030 at least 40 percent of electricity will come from non-fossils.[1258] This target would require a combined 1,200 GW of solar and wind by 2030, which, while representing a vast increase from current installed capacity levels, is along current trajectories, rather than a step-change in the rate of growth.[1259]

The targets for nuclear are less clear, but some government researchers suggest it could be about 130 GW by 2030, a more than doubling of current capacity.[1260] However, such targets are, given the long construction times of nuclear—in most countries at least five years, ten years on global average, and even in China an average of six years over the past decade—are unlikely, with only 17 GW currently under-construction. Therefore, at best, China will have another 20 GW of nuclear capacity operating by the end of the 14th Five Year Plan, totaling 68.5 GW. Therefore 100 GW of operating nuclear capacity by 2030 seems more realistic, which would still make it the world's largest reactor fleet, but an order of magnitude below the installed capacity and significantly below the output of each, solar and wind, individually.

1258 - Muyu Xu and David Stanway, "China plans to raise minimum renewable power purchase to 40% by 2030: government document", *Reuters*, 10 February 2021, see https://www.reuters.com/article/us-china-climatechange-renewables-idUSKBN2AA0BA, accessed 2 June 2021.

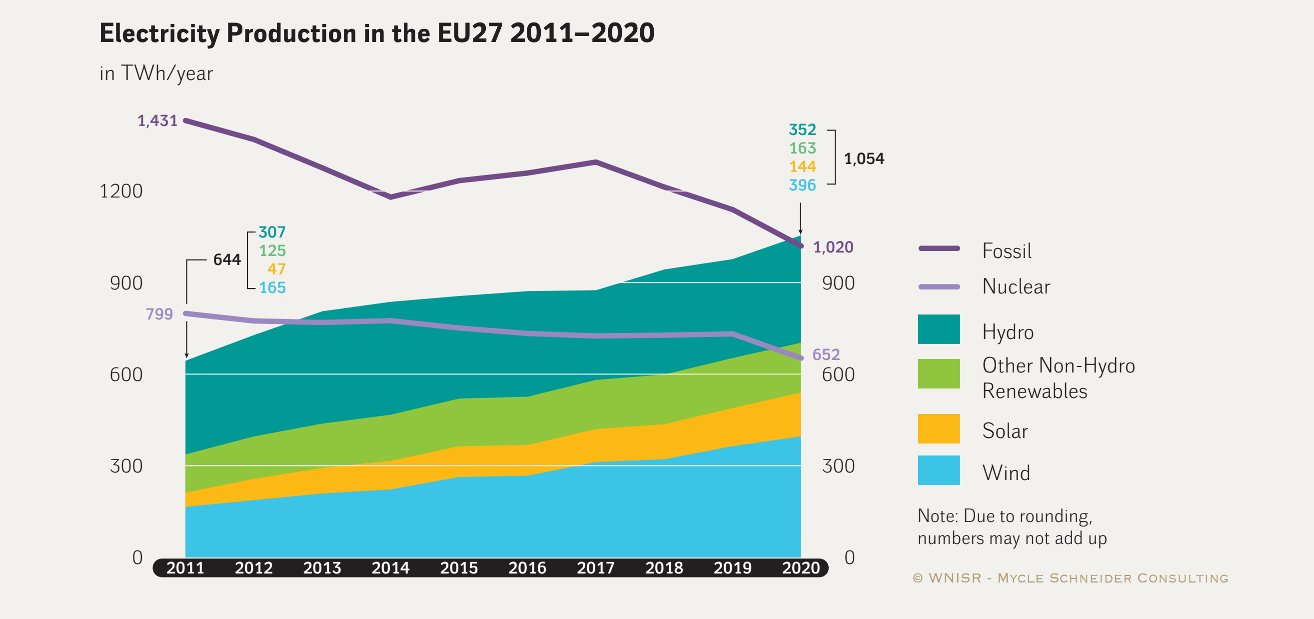
1259 - Lin Jiang and He Gang, "China can benefit from a more ambitious 2030 solar and wind target", *China Dialogue*, 2 February 2021, see https://chinadialogue.net/en/energy/china-can-benefit-from-a-more-ambitious-2030-solar-and-wind-target/, accessed 2 June 2021.

1260 - Jason Rogers and Feifei Shen, "China to miss nuclear energy target this year, but has eyes set on dominating sector by 2030", *The Print*, 2 June 2020, see https://theprint.in/world/china-to-miss-nuclear-energy-target-this-year-but-has-eyes-set-on-dominating-sector-by-2030/433899/, accessed 2 June 2021.

European Union

In the European Union (EU), renewables, including hydro, continue to grow and for the first time they overtook fossil fuels to become the primary source of power in 2020. Renewables rose to generate 38 percent of Europe's electricity in 2020 (compared to 34.6 percent in 2019), with fossil fuels falling to 37 percent. Coal fell by 20 percent in the year, halved its production from 2015, and gas-produced electricity decreased by 4 percent.

Figure 52 · Electricity Generation in the EU27 by Fuel, 2011–2020



Sources: IAEA-PRIS, Agora Energiewende and Ember, 2021

Nuclear generation fell by 11 percent, its largest fall since 1990. Wind generation rose 9 percent in 2020 and solar production rose 15 percent, together generating a fifth of Europe's electricity in 2020 (wind 14 percent, solar 5 percent).

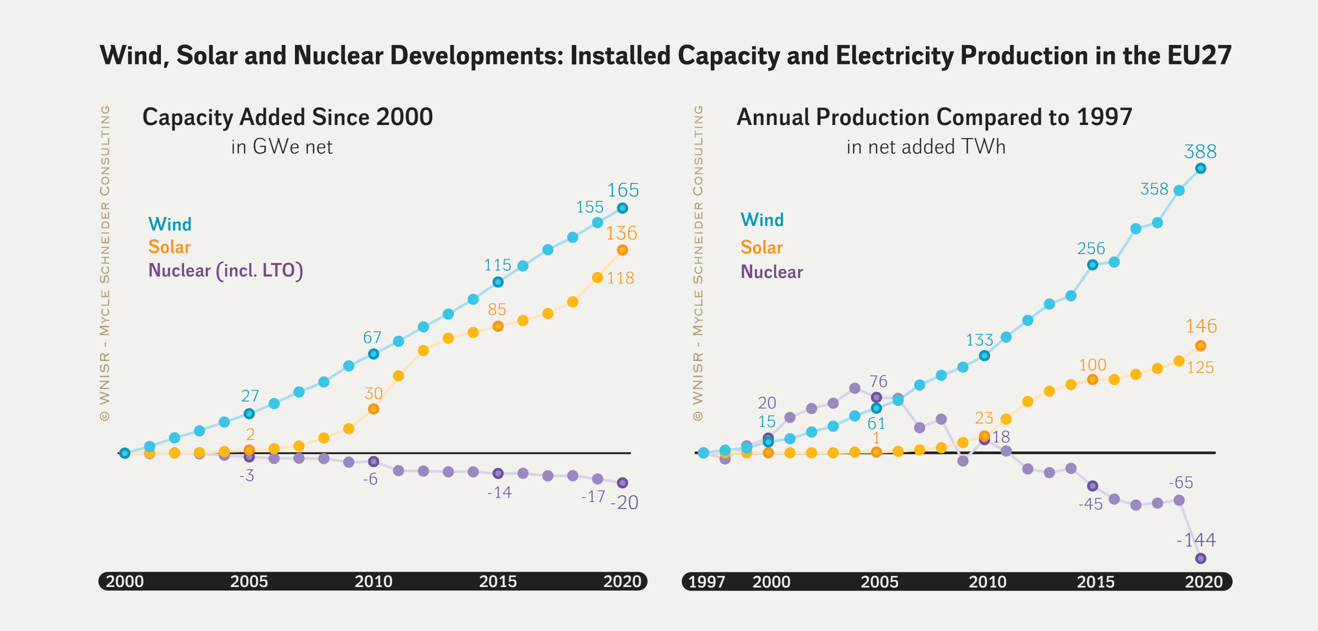
2020 is also the first time that *non-hydro* renewables generate with 702 TWh more power than nuclear reactors with 652 TWh (688 TWh gross) in the EU27 (see Figure 52).

In many countries of the EU27 the share of electricity production is much higher with Denmark generating 62 percent and Ireland about 35 percent of their electricity from wind and solar in 2020.[1261]

Since 2000, wind added 164.5 GW of installed capacity, solar 136.2 GW, while nuclear declined by 20 GW. Since the signature of the Kyoto Protocol in 1997, wind and solar increased annual production by 388 TWh and 146 TWh respectively, while nuclear generated 144 TWh *less* power (-151.8 TWh gross) (see Figure 53 and Figure 54).

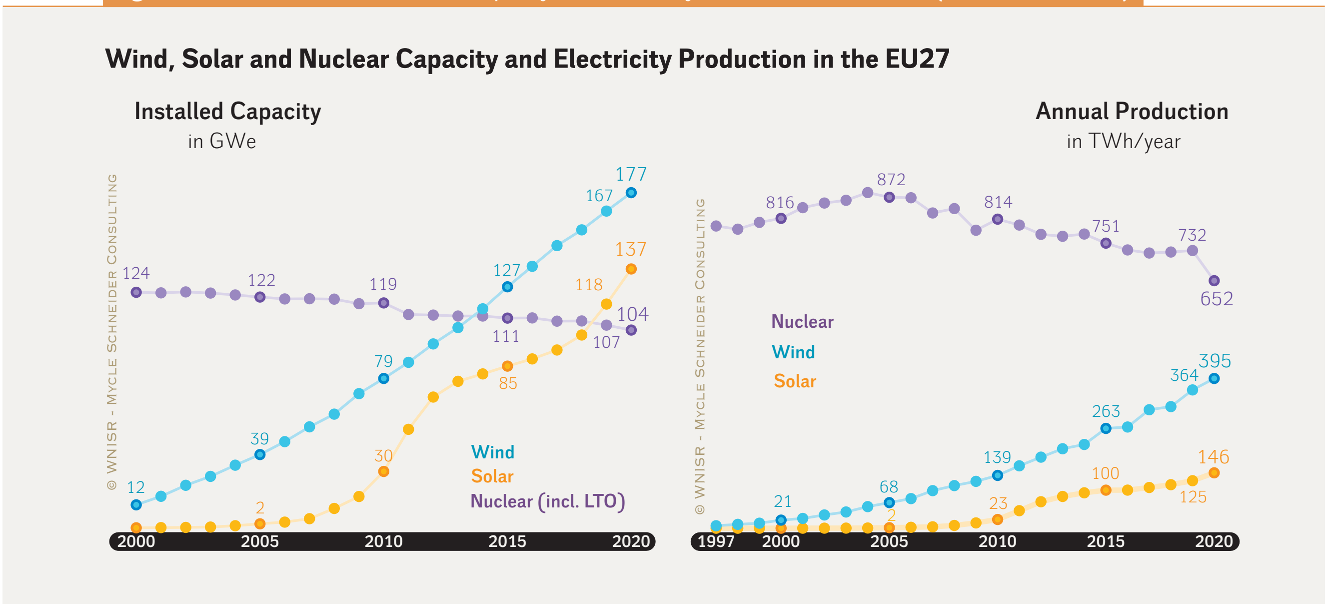
1261 - Agora Energiewende and Ember, "The European Power Sector in 2020 – Up-to-Date Analysis on the Electricity Transition", January 2021, see https://www.agora-energiewende.de/en/publications/the-european-power-sector-in-2020/, accessed 6 June 2021.

Figure 53 · Wind, Solar and Nuclear Capacity and Electricity Production in the EU27 (Developments)



Sources: WNISR with IAEA-PRIS, IRENA, BP, 2021

Figure 54 · Wind, Solar and Nuclear Capacity and Electricity Production in the EU27 (Absolute Numbers)



Sources: WNISR with IAEA-PRIS, IRENA, BP, 2021

Renewables providing 38 percent of electricity means that it is likely that their share exceeded the 20-percent primary-energy target set for 2020—in 2019, renewables provided 19.7 percent of total energy.

In September 2020, the European Commission proposed to increase the EU's greenhouse gases (GHG) reduction target to at least 55 percent by 2030 from 1990 levels, up from the 40-percent minimum target set prior to the signing of the Paris Agreement in 2015. This increase was then approved by the EU Heads of State in December 2020, and formally submitted as a revised NDC to the UNFCCC. The European Commission's background paper for the revised targets states that "the scenarios achieving 55% GHG ambition (including intra EU aviation and navigation emissions in the target scope) arrive at the RES share of between 37.5% to 39%."[1262] This is total energy and would likely mean renewables providing up to 80 percent of power, requiring a significant acceleration of the current rate of renewable electricity deployment. There is no EU-wide nuclear deployment target.

With half the Member States of the EU operating reactors, nuclear power remains a politically divisive issue in Europe. In July 2021, five Member States (Austria, Denmark, Germany, Luxembourg, and Spain) wrote to the European Commission asking that nuclear power be excluded from a list of technologies eligible for EU funding under the European Green Deal as they said "nuclear power is incompatible with the Taxonomy Regulation's 'do no significant harm' principle."[1263] (See Introduction – Nuclear Power and Green Taxonomy). The outcome of this decision will be an important signal not only of the balance of political support for nuclear power, but with limited European funds for deployment and the clear preference for renewables from the private sector the outlook for nuclear power in Europe looks bleak.

India

Since 2010, the installed capacity of solar in India has increased by a factor of over 550 from 70 MW to 39.2 GW at the end of 2020, and wind increased by a factor of 2.8 from 13.8 GW to 38.5 GW, while nuclear capacity has grown over this period from about 4 GW to 6.2 GW.

Figure 55 shows that since the turn of the century, wind power output has grown rapidly, from 1.45 TWh to 60.4 TWh in 2020 and has overtaken nuclear's contribution to electricity generation since 2016, which now stands at 40.4 TWh (44.6 TWh gross). Solar is also growing rapidly, from virtual inexistence with a production of 7 GWh in 2000 to 58.7 TWh in 2020—that represents a sky-rocketing expansion by a factor of 8,000 in two decades. The differences in output between renewables and nuclear will likely increase in the coming years, because of the rapid growth of solar and wind capacity, and stagnation in the nuclear sector.

India has put in place ambitious targets for the deployment of renewables with 175 GW by 2022 including 100 GW solar and 60 GW wind. As of April 2021, however, the target was still a long way off, with the best-case expectation that 65 percent of the 2022 target could be met.

As of the end of 2020, total capacity on the grid was 39 GW each for solar and wind with a further 46 GW (solar and wind) under implementation and 35 GW being tendered.[1264]

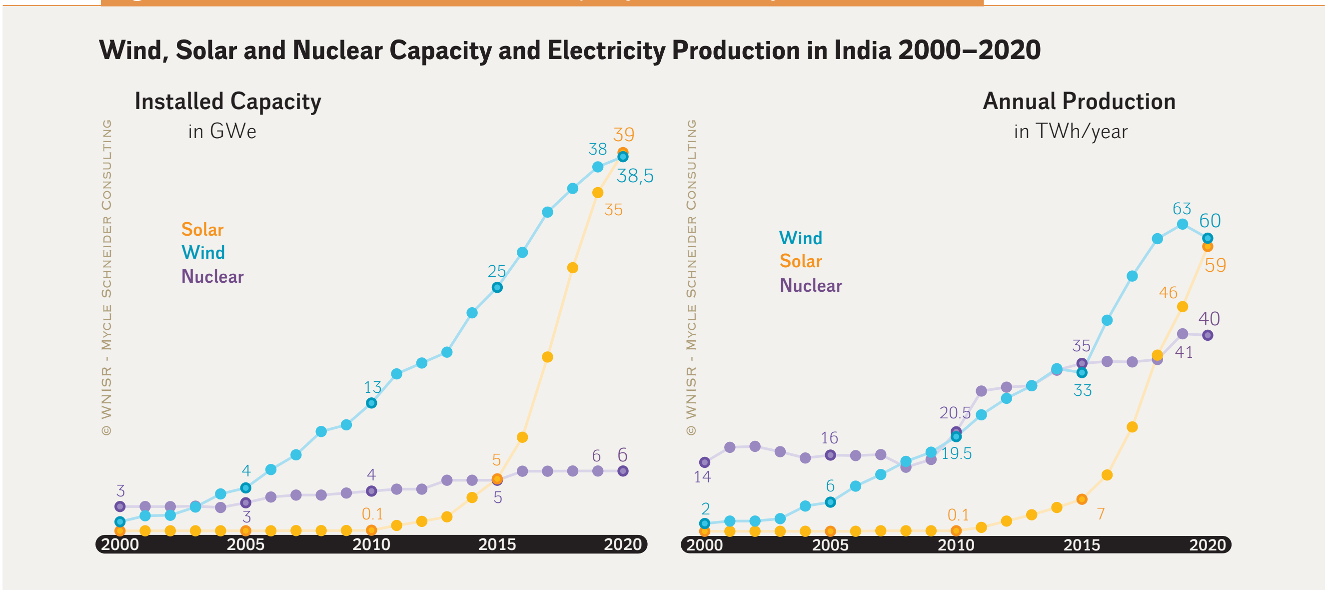
1262 - European Commission, "2030 Climate Target Plan", 11 September 2020, see https://ec.europa.eu/clima/policies/eu-climate-action/2030_ctp_en; and European Commission, "Commission Staff Working Document—Impact Assessment", Accompanying "Communication from the Commission to the Euorpean Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions—Stepping up Europe's 2030 climate ambition—Investing in a climate-neutral future for the benefit of our people", 17 September 2020, see https://ec.europa.eu/clima/sites/clima/files/eu-climate-action/docs/impact_en.pdf, both accessed 6 June 2021.

1263 - Frédéric Simon, "Germany leads call to keep nuclear out of EU green finance taxonomy", *Euractiv*, 2 July 2021, see https://www.euractiv.com/section/energy-environment/news/germany-leads-call-to-keep-nuclear-out-of-eu-green-finance-taxonomy/, accessed 8 July 2021.

1264 - GlobalData, "India on course to achieve only 65-69% of its 2022 renewable target", 26 April 2021, see https://www.power-technology.com/comment/india-achieve-65-69-renewable-target/, accessed 10 June 2021.

The failure to meet targets occurs despite world-beating falling costs. IRENA reported that, in 2020, India had the lowest installation costs for onshore wind globally, at US$1038/kW, a fall of 27 percent in the past decade. The global weighted-average LCOE of onshore wind stood at US$40/MWh, the third lowest (behind China and the U.S.) in the world. For residential and other small-scale PV, IRENA found that India had the lowest LCOE, averaging US$55/MWh.[1265]

Figure 55 · Wind, Solar and Nuclear Installed Capacity and Electricity Production in India



Sources: WNISR with IAEA-PRIS, IRENA, BP, 2021

United States

At the end of 2020, the U.S. had 94 operating commercial nuclear reactors, down from 101 in 2012. In 2019 the industry succeeded in generating a new record volume of electricity, with 809 TWh (852 TWh gross) supplying just under 20 percent of the electricity, but in 2020, there was a 3.6 percent decline and a total of only 790 TWh (831 TWh gross) was produced, the lowest generation level since 2012 (see Figure 56). The decline was as mainly a result of lower overall power demand due to the pandemic and increased production from other sources.

In contrast, the U.S. generated a record amount of renewable energy in 2020, about 12 percent of the total, the sixth year of continual growth. The production of wind surpassed that of hydro in 2019 and increased by 14 percent in 2020, while the generation of solar increased by 22 percent.[1266]

The growth in renewables is expected to increase as more capacity comes online. In both 2019 and 2020 more wind was installed than any other generating source, with 14.2 GW in 2020, a new annual record.[1267]

1265 - IRENA, "Renewable Power Generation Costs in 2020", June 2021, op. cit.

1266 - Mickey Francis, "The United States consumed a record amount of renewable energy in 2020", U.S.EIA, June 2021, see https://www.eia.gov/todayinenergy/detail.php?id=48396, accessed 19 June 2021.

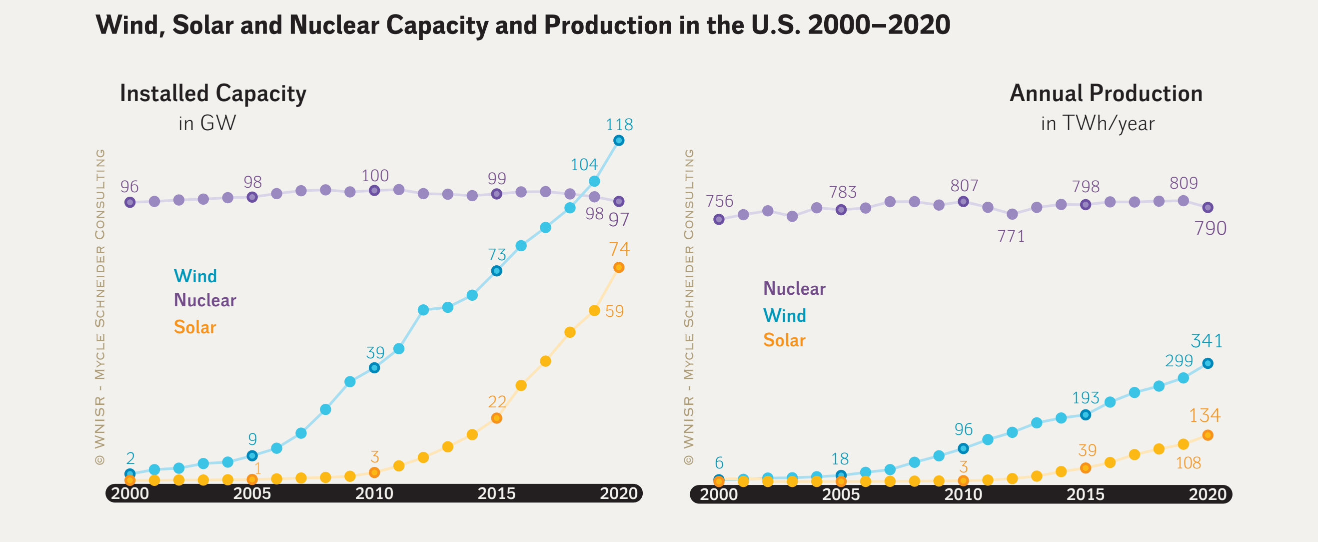
1267 - Richard Bowers and Owen Comstock, "The United States installed more wind turbine capacity in 2020 than in any other year", U.S.EIA, March 2021, see https://www.eia.gov/todayinenergy/detail.php?id=46976, accessed 19 June 2021.

The election of President Biden in 2020 led to a significant change in direction on a number of issues, but particularly on climate change, including the rejoining of the Paris Agreement and a pledge to submit a revised NDC. The administration announced this at the U.S.-convened Climate Leaders' Summit in April 2021 and committed to a 50–52 percent reduction from 2005 levels by 2030. Part of this carbon-reduction plan is in the power sector, with a pledge to put the U.S. "on the path to achieving 100 percent carbon-free electricity by 2035".[1268]

One of the cornerstones of the U.S. post-COVID-19 and low-carbon development plan is the proposed US$2 trillion jobs, infrastructure and clean energy plan. As of June 2021, the scope and scale of the package is unclear as it has to be approved in the legislative houses, in which the democrats have slim majorities. Furthermore, the degree of support for renewable energy and nuclear power is still unclear, with both industries claiming they will receive support. Both nuclear and renewable energy will likely receive additional research and development funding, but it is unlikely that this will be sufficient for the nuclear sector to enable commercial deployment.

However, as documented earlier in the chapter, the costs of renewables in the U.S., see Figure 44, are considerably below that of nuclear energy. Furthermore, the U.S. remains the number one country globally for renewable energy investment, according to the latest Ernst & Young Renewable Energy Country Attractiveness index,[1269] and hosts some of the lowest renewable energy generating costs.[1270]

Figure 56 · Wind, Solar and Nuclear Installed Capacity and Electricity Production in the U.S



Sources: BP, IRENA, IAEA-PRIS, WNISR, 2021

1268 - The White House, "FACT SHEET: The American Jobs Plan", 31 March 2021, see https://www.whitehouse.gov/briefing-room/statements-releases/2021/03/31/fact-sheet-the-american-jobs-plan/, accessed 8 July 2021.

1269 - EY, "Renewable Energy Country Attractiveness Index", Ernst & Young, May 2021, see https://assets.ey.com/content/dam/ey-sites/ey-com/en_gl/topics/power-and-utilities/power-and-utilities-pdf/ey-recai-57-top-40-ladder.pdf, accessed 2 September 2021.

1270 - IRENA, "Renewable Power Generation Costs in 2020", June 2021, op. cit.

CONCLUSION ON NUCLEAR POWER VS. RENEWABLE ENERGY

2021 is a key year for addressing climate change and many countries are upping their policies and measures to reduce Greenhouse Gas Emissions. Over the past decade, the power sector has been at the forefront of decarbonization, as changes in generation can reduce emissions without impacting the grid system significantly or affecting consumers. The opportunities for decarbonizing the power sector have been further enhanced by the falling costs of renewable energy and storage that are undercutting fossil fuels and nuclear generation. Consequently, country after country is now putting in place plans to switch large parts of their electricity generation by 2030.

This is, therefore, also a critical time for the nuclear sector globally. In 2019, for the first time, non-hydro renewables—solar, wind, and mainly biomass—generated more power than nuclear plants in the world. In 2020, the renewable energy industries have demonstrated a much greater resilience to the COVID-19 pandemic than the nuclear sector; and the gap widened, with renewables expanding massively and generating globally 16.5 percent more electricity than nuclear reactors.

Investment levels for nuclear continue to be many multiples below that of renewables, and the annual deployment and generation levels continue to diverge.

Worse, *existing* nuclear power plants are increasingly struggling to cope with their competitors—now mainly renewables (and natural gas in the U.S.)—in the market. In many regions, solar and wind come in at guaranteed prices far below operating and maintenance costs of nuclear reactors.

Unless the process reverses in the next few of years and nuclear power is meaningfully included in the revised NDCs—it is not currently and it is highly unlikely to happen—then nuclear power will be permanently destined to be found only in niche markets of a handful of countries.

NUCLEAR POWER AND CLIMATE CHANGE RESILIENCE

INTRODUCTION

For a long time, the interaction between anthropogenic climate change and energy systems was seen through the lens of decarbonization efforts and the contribution of various energy transformation technologies to harmful emissions, mainly CO_2.[1271] However, as climate change has accelerated, particularly over recent decades,[1272] more attention is now given to examining the vulnerability of power systems to the intensifying impacts of a changing climate. Recent studies have generated evidence that energy generation and services are increasingly disrupted by climate change through the increase in the variability, intensity and predictability of weather conditions.[1273] Consequently, a new focus has emerged in recent years calling for higher emphasis on adaptation and improving the resiliency of electricity generation, transmission and distribution systems in the face of climate change.[1274] Power-system resilience can be broadly defined as the ability to cope with, recover from and minimize the impact of various types of potentially disruptive developments or events.[1275]

Climate-change effects can impact all types and various parts of electricity systems, albeit with different magnitude and variability depending on the energy source, technology and region. According to recent research on the impact of climate change on energy systems, cooling-based thermal power plants, including nuclear, are expected to face reductions in their power output due to reduced streamflow, and warming ambient and streamflow temperatures.[1276] Europe and U.S-based thermal power plants have been shown to be particularly vulnerable to the combined impacts of lower summer river flows and higher river water temperatures.[1277] The France case-study below confirms this analysis.

1271 - According to the International Energy Agency's latest data (March 2021), 40 percent of the total global CO2 emissions are attributed to the burning of fossil fuels (coal 29%, natural gas 9%, oil 2%) in the power sector. See IEA, "Global energy-related CO2 emissions by secton", Updated 25 March 2021, see https://www.iea.org/data-and-statistics/charts/global-energy-related-co2-emissions-by-sector, accessed 6 May 2021.

1272 - Alejandra Borunda, "Past decade was the hottest on record", *National Geographic*, 15 January 2020, see https://www.nationalgeographic.com/science/article/the-decade-we-finally-woke-up-to-climate-change, accessed 26 April 2021.

1273 - Seleshi G. Yalew, Michelle T. H. van Vliet et al., "Impacts of climate change on energy systems in global and regional scenarios", *Nature Energy*, 3 August 2020, see https://www.nature.com/articles/s41560-020-0664-z; and Michael T. Craig, Stuart Cohen et al., "A review of the potential impacts of climate change on bulk power system planning and operations in the United States", *Renewable and Sustainable Energy Reviews*, Vol. 98, 1 December 2018, see http://www.sciencedirect.com/science/article/pii/S1364032118306701; also Roberto Schaeffer, Alexandre Salem Szklo et al., "Energy sector vulnerability to climate change: A review", *Energy*, Vol. 38, 1 February 2012, see http://www.sciencedirect.com/science/article/pii/S0360544211007870, all accessed October 2020.

1274 - Elizabeth L. Ratnam, Kenneth G. H. Baldwin et al., "Electricity system resilience in a world of increased climate change and cybersecurity risk", *The Electricity Journal*, Vol. 33, Issue 9, 1 November 2020, see https://www.sciencedirect.com/science/article/pii/S1040619020301251; Raquel Figueiredo, Pedro Nunes and Miguel C. Brito, "The resilience of a decarbonized power system to climate variability: Portuguese case study", *Energy*, Vol. 224, 1 June 2021, see https://www.sciencedirect.com/science/article/pii/S0360544221003741, both accessed 26 April 2021.

1275 - Adrian J. Hickford, Simon P. Blainey et al., "Resilience engineering: theory and practice in interdependent infrastructure systems", *Environment Systems and Decisions*, Issue September 2018, see https://doi.org/10.1007/s10669-018-9707-4, accessed 25 October 2020.

1276 - Seleshi G. Yalew, Michelle T. H. van Vliet et al., "Impacts of Climate Change on Energy Systems in Global and Regional Scenarios", *Nature Energy*, Issue October 2020, see https://www.nature.com/articles/s41560-020-0664-z, accessed 28 May 2021.

1277 - Michelle T. H. van Vliet, John R. Yearsley et al., "Vulnerability of US and European electricity supply to climate change", *Nature Climate Change*, Issue September 2012, see https://www.nature.com/articles/nclimate1546, accessed 28 May 2021.

It should be noted that nuclear power plants located on seacoasts can also be vulnerable to higher than usual temperatures. In 2018, nuclear reactors in Sweden and Finland were forced to shut down or reduce their power due to temperatures 6–10°C higher than the seasonal average. In Sweden, a 900-MW reactor at the Ringhals plant was shut down as sea-water temperatures exceeded 25°C.[1278]

Costal energy infrastructure could also face challenges as a result of the rising sea level due to warming climate. According to the Intergovernmental Panel on Climate Change (IPCC), the 2100 sea level rise is projected to range between 26–98 cm compared to the 1986–2005 level, depending on the warming scenario.[1279] Rising sea level could compound climate change impacts on general infrastructure as it could directly feed into increasing both the physical hazards and the vulnerabilities. In terms of physical hazards, higher sea level means potential of storm surge as there is more water to be transported by winds, tides, and waves.[1280] As for increasing vulnerabilities, higher sea level also means higher probability of flooding and erosion.

The operations of thermal power plants, including nuclear, are most frequently vulnerable to temperature variations—higher ambient temperatures lower the thermal efficiency of the plant. Nuclear power is also affected by variations of the ambient temperature, but since it depends on water for both primary and secondary cooling, it is especially vulnerable to droughts. The most vulnerable renewable energy source to climate change is hydropower, which is expected given the high dependency on water availability.

Wind and solar systems also have their own vulnerabilities to climate change. Wind energy output is strongly dependent on the wind density at given wind turbine sites. Solar energy output (particularly solar photovoltaics or PV) is dependent on the cloudiness and ambient temperature. The efficiency of solar panels decreases as the ambient temperature increases.[1281] However, technological solutions such as developing of solar panels that are less sensitive to temperature increase, cooling techniques and/or technology-siting optimization are already deployed strategies by solar energy developers.[1282] For example, in India, solar arrays are placed above irrigation canals, which not only provides a hybrid use of space but increases the efficiency of the panels by cooling and at the same time reduces evaporation of irrigation water (See Figure 57). On the other hand, higher temperatures are projected to generally result in an increase in the output energy of concentrated solar thermal power plants.[1283]

1278 - Lefteris Karagiannopoulos, "In hot water: How summer heat has hit Nordic nuclear plants", *Reuters*, 1 August 2018, see https://www.reuters.com/article/us-nordics-nuclearpower-explainer-idUSKBN1KM4ZR, accessed 28 May 2021.

1279 - John A. Church, Peter U. Clark et al., "Chapter 13 – Sea Level Change", in IPCC, "Climate Change 2013: The Physical Science Basis – Fifth Assessment Report of the Intergovernmental Panel on Climate Change", *Cambridge University Press*, 2013, see https://www.ipcc.ch/site/assets/uploads/2018/02/WG1AR5_Chapter13_FINAL.pdf, accessed 1 July 2021.

1280 - Thomas J. Wilbanks and Steven Fernandez, "Climate Change and Infrastructure, Urban Systems, and Vulnerabilities", Oak Ridge National Laboratory, *Island Press*, 2014, see http://link.springer.com/10.5822/978-1-61091-556-4, accessed 1 July 2021.

1281 - Swapnil Dubey, Jatin Narotam Sarvaiya and Bharath Seshadri, "Temperature Dependent Photovoltaic (PV) Efficiency and Its Effect on PV Production in the World – A Review", *Energy Procedia*, 1 January 2013, see https://www.sciencedirect.com/science/article/pii/S1876610213000829, accessed 26 April 2021.

1282 - Swapnil Dubey, Jatin Narotam Sarvaiya and Bharath Seshadri, "Temperature Dependent Photovoltaic (PV) Efficiency and Its Effect on PV Production in the World – A Review", *Energy Procedia*, Volume 33, 2013; and Linus Idoko, Olimpo Anaya-Lara and Alasdair McDonald, "Enhancing PV modules efficiency and power output using multi-concept cooling technique", *Energy Reports*, November 2018, see https://www.sciencedirect.com/science/article/pii/S2352484717302962, accessed 27 April 2021.

1283 - Julia A. Crook, Laura A. Jones et al., "Climate change impacts on future photovoltaic and concentrated solar power energy output", *Energy & Environmental Science*, Issue 9, 26 August 2011, see https://pubs.rsc.org/en/content/articlelanding/2011/ee/c1ee01495a, accessed 16 May 2021.

Figure 57 · Solar Panels Over Irrigation Canals in India

Source: Ioannis Kougias et al., 2016[1284]

Not only energy sources are vulnerable to climate change and the extreme weather events caused by it, the transmission grid is one of the weakest links of the electricity value chain. Because of its vast geographic extent, power transmission grids are at risk of disruption due to different reasons at different locations. High ambient temperature levels lead to greater transmission and distribution losses. Researchers have estimated that for every 5°C air temperature-increase, the capacity of a fully loaded transmission line would be diminished by an average of 7.5 percent.[1285] Climate change could also induce indirect losses on the power grid—for example, heatwaves can induce wildfires, which could lead to cutting off users.[1286]

Nuclear power advocates have argued their favored technology would be indispensable in a world of net-zero emissions as it would provide continuous power generation, compared to the intermittent solar and wind renewables. For example, the International Atomic Energy Agency's (IAEA) Director labeled nuclear power as "present solution" to curbing emissions and "future alternative".[1287] While the assumption is questionable as such (e.g. see France Focus), examining the bi-directional relationship between nuclear power and climate change deserves particular attention, especially with the increase in frequency of nuclear power disruptions due to climatic events. Recent research has shown that the average frequency of climate-induced

1284 - Ioannis Kougias, Katalin Bódis et al., "The potential of water infrastructure to accommodate solar PV systems in Mediterranean islands", *Solar Energy*, July 2016, see https://www.researchgate.net/publication/305169602_The_potential_of_water_infrastructure_to_accommodate_solar_PV_systems_in_Mediterranean_islands, accessed 8 May 2021.

1285 - Jayant A. Sathaye, Larry L. Dale et al., "Estimating impacts of warming temperatures on California's electricity system", *Global Environmental Change*, Vol 23, Issue 2, April 2013, see http://www.sciencedirect.com/science/article/pii/S0959378012001458, accessed 17 January 2021.

1286 - A. Park Williams, John T. Abatzoglou et al., "Observed Impacts of Anthropogenic Climate Change on Wildfire in California", *Earth's Future*, August 2019, see https://onlinelibrary.wiley.com/doi/abs/10.1029/2019EF001210; and Renaud Barbero, John. T. Abatzoglou et al., "Climate change presents increased potential for very large fires in the contiguous United States", *International Journal of Wildland Fire*, Published 16 July 2015, see http://www.publish.csiro.au/?paper=WF15083, both accessed 27 April 2021.

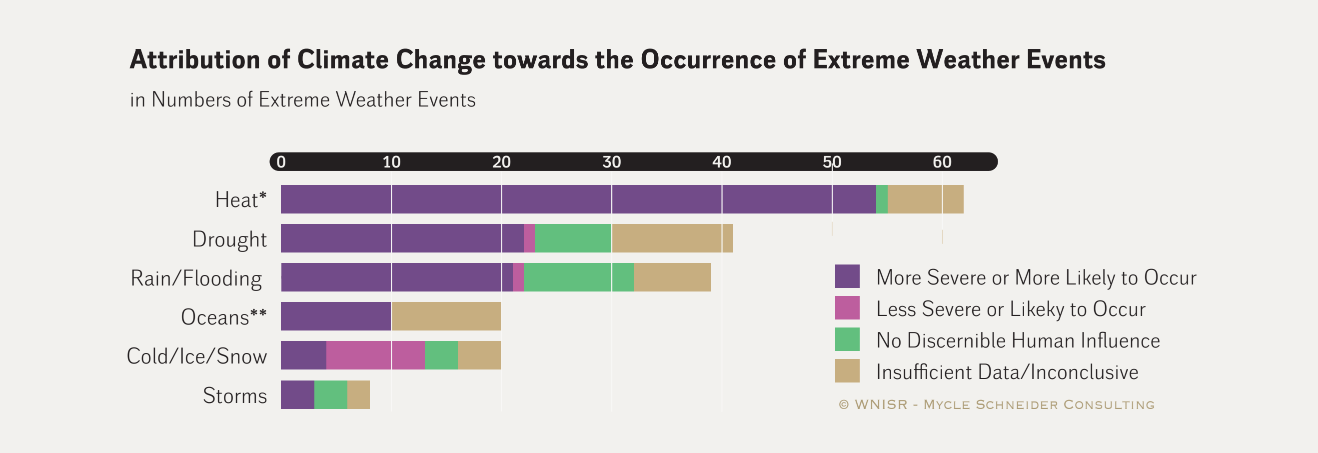
1287 - Department of Nuclear Energy, "IAEA's Grossi Calls for Nuclear Power for Net Zero Emissions as Climate 'Clock is Ticking'", IAEA, 31 March 2021, see https://www.iaea.org/newscenter/news/iaeas-grossi-calls-for-nuclear-power-for-net-zero-emissions-as-climate-clock-is-ticking, accessed 16 May 2021.

disruptions has dramatically increased between the 1990s and 2010s.[1288] The implications of such notable increase of disruptions can be substantial.

Why climatic disruptions matter?

In recent years, substantial evidence has been generated to link anthropogenic climate change to extreme weather events.[1289] The strength of such links varies from one climatic effect to another—for example the links between heatwaves and climate change are particularly strong. According to a *Nature* piece that provided a meta-analysis of published evidence on the attribution of climate change towards extreme weather events, about two-thirds of studied extreme weather events were made more likely or more severe by anthropogenic climate change. As shown in Figure 58, the strongest evidence is on the links of climate change to heat extremes, followed by droughts and extreme rain or flooding.[1290] In the face of the increased frequency, variability and unpredictability of extreme weather events driven by climate change, the need to address climate-related risks is more pressing than ever. Given the vital role of energy assets and infrastructure in modern day living, it is imperative to assess the impacts and risks of climate disruption on various energy technologies, including nuclear power.

Figure 58 · Attribution of climate change towards the occurrence of extreme weather events



Source: *Nature*, July 2018[1291]

Notes

* Heat Includes heatwaves and wildfires

** Oceans includes studies on marine, heat, coral bleaching and marine-ecosystem disruption

The deep Texas freeze that occurred in February 2021, which shut down almost half of the power generating capacity in the state—all technologies experienced outages—is a strong

1288 - Ali Ahmad, "Increase in frequency of nuclear power outages due to changing climate", *Nature Energy*, 5 July 2021, see https://www.nature.com/articles/s41560-021-00849-y, accessed 12 August 2021.

1289 - Dim Coumou and Stefan Rahmstorf, "A decade of weather extremes", Potsdam Institute for Climate Impact Research, *Nature Climate Change*, Issue July 2012, Published 25 March 2012, see https://www.nature.com/articles/nclimate1452, accessed 27 April 2021.

1290 - Quirin Schiermeier, "Droughts, heatwaves and floods: How to tell when climate change is to blame", *Nature*, 30 July 2018, see https://www.nature.com/articles/d41586-018-05849-9, accessed 27 April 2021.

1291 - Ibidem.

reminder of the increasing urgency of integrating strong resilience into energy systems in order cope with extreme weather events.[1292] One of two 1300 MW reactors of the South Texas plant also automatically shut down after a feedwater pump malfunctioned and was lost for 64 hours.[1293] A fragile and disruption-prone power system is bad for citizens, governments and utilities. The impacts of the dramatic power cuts in Texas are still reverberating, with lawsuits and bankruptcies involving the State's major power utilities continuing to unfold.[1294]

Regardless of the power source and the technology applied, projecting to achieve a 100-percent climate-change resilience is like wanting a 100-percent supply security; both are unattainable goals. As long as electricity systems depend on large and centralized power stations connected to the consumers by vast transmission grids, disruptions due to weather events, accidents or attacks are bound to happen.

OVERVIEW OF CLIMATIC DISRUPTIONS TO THE OPERATION OF NUCLEAR POWER PLANTS

The vulnerability of nuclear-power-plant operations to climate change and extreme weather conditions, as surveyed in the limited available literature, represents an increasingly serious challenge.[1295] The quantitative aspects of such disruptions in terms of the frequency of unplanned outages of nuclear power plants due to climatic events and the subsequent generation losses have been shown to be consistently increasing over the years.[1296]

The discussion of the relationship between nuclear power and climate change in this chapter focuses on the electricity generation component, i.e. the direct and indirect impacts of climate change effects on nuclear power plants. It should be noted that climate change may affect other components of the nuclear fuel chain such as uranium mining, nuclear fuel production, spent fuel reprocessing, waste management and disposal facilities. For example, in 2015, a decommissioned uranium extraction site in France was flooded by heavy rain.[1297] Cases of uranium mine flooding, which could increase with a changing climate, pose a serious threat of contaminating water supplies.[1298]

1292 - Maria Caspani, "Cold snap leaves one dead, over 4 million without power in Texas", *Reuters*, 15 February 2021, see https://www.reuters.com/article/us-usa-weather-texas-idUSKBN2AF0OK, accessed 27 April 2021.

1293 - University of Texas at Austin, "The Timeline and Events of the February 2021 Texas Electric Grid Blackouts", July 2021.

1294 - Gary McWilliams, "Lawsuits or bankruptcies? Long horns of Texas power price dilemma", *Reuters*, 11 March 2021, see https://www.reuters.com/article/us-usa-texas-powerregulator-idUSKBN2B324R, accessed 27 April 2021.

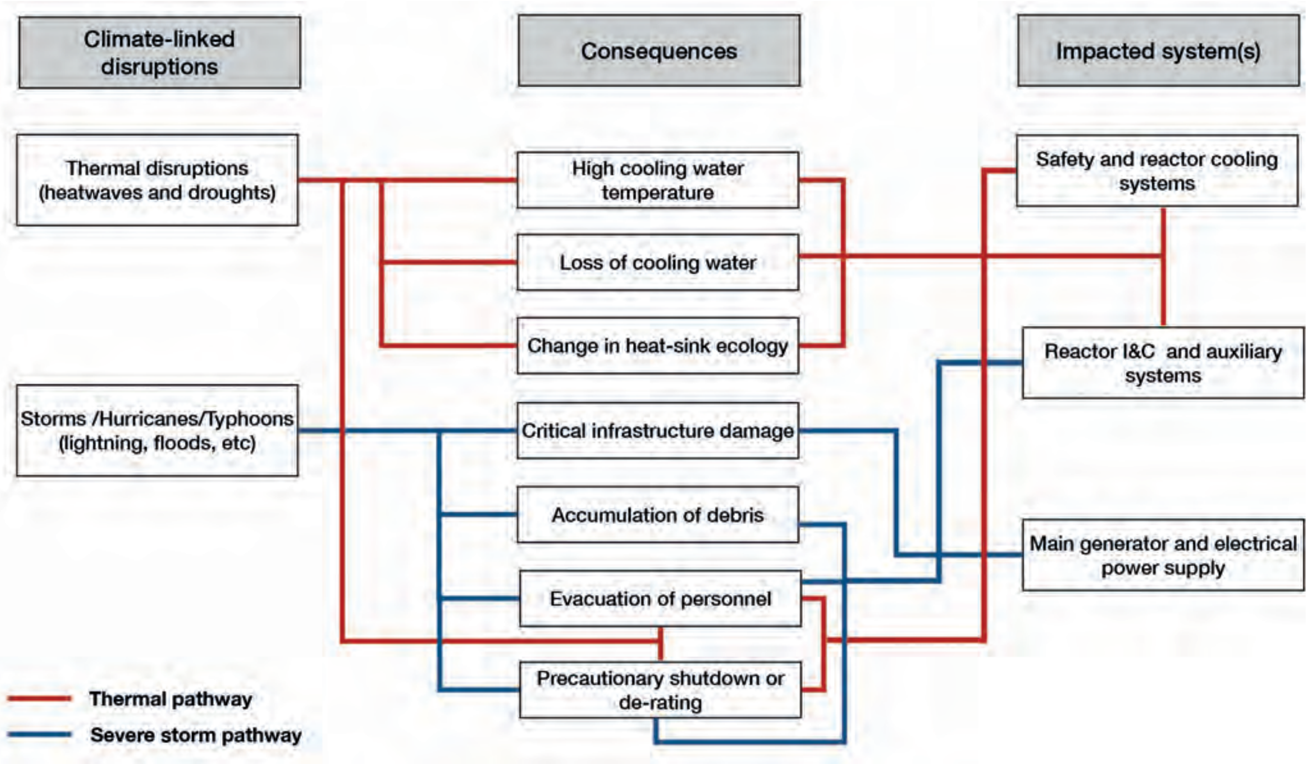
1295 - Kristin Linnerud, Torben K. Mideksa and Gunnar S. Eskeland, "The Impact of Climate Change on Nuclear Power Supply", *The Energy Journal*, Vol. 32, No. 1, 2011, see http://www.jstor.org/stable/41323396, accessed 19 October 2020; and Sarah M. Jordaan, Afreen Siddiqi et al., "The Climate Vulnerabilities of Global Nuclear Power", *Global Environmental Politics*, Vol. 19, Issue 4, 1 November 2019, see https://doi.org/10.1162/glep_a_00527, accessed 24 October 2020.

1296 - Ali Ahmad, "Increase in frequency of nuclear power outages due to changing climate", 5 July 2021, *Nature Energy*, op. cit.

1297 - Aria, "Débordement d'un bassin d'effluents dans une mine d'uranium", Analysis, Research and Information on Accidents Database, Bureau for Analysis of Industrial Risks and Pollutions, 13 September 2015 (in French), see https://www.aria.developpement-durable.gouv.fr/accident/49416/, accessed 4 May 2021.

1298 - Megan Kelly, "Uranium Mine Flooding Near Grand Canyon", Grand Canyon Trust, 5 April 2021, see https://www.grandcanyontrust.org/blog/uranium-mine-flooding-near-grand-canyon, accessed 27 April 2021.

Figure 59 · Pathways of Climate-Induced Disruptions of the Operation of Nuclear Power Plants



Source: Ali Ahmad, *Nature Energy, July 2021*

As a thermal source of energy, the most frequently cited climatic risk to nuclear reactors is the increase in the ambient temperature, which will affect the reactor's cooling quality and reduce its thermal efficiency.[1299] However, different climatic events can disrupt the operations of a nuclear reactor in different ways, as shown in Figure 59. Operating a nuclear reactor is a more delicate process compared to operating other, fossil fuel-based thermal power plants due to the stringent safety requirements to ramp up or down power levels, monitoring and regulations.

As shown in Figure 59, climate change disrupts the operations of nuclear power plants through two main pathways. The first is the thermal pathway, which includes all the outages that result from the limitation on evacuating the thermal power generated within the reactor, triggering either reduced power output or a full outage at zero capacity.[1300] Thermal disruptions relate to the ambient temperature and availability of water. Outages driven by droughts and heatwaves are classified as thermal outages. A relatively high increase in the temperature of the inlet cooling water has two impacts on operating nuclear reactors: (1) it lowers the overall thermal efficiency of the power plant; and (2) it may force the reactor to reduce its load (partially or fully) due to the condenser pressure reaching its maximum value.[1301] Additionally, the outlet

1299 - Kristin Linnerud, Torben K. Mideksa and Gunnar S. Eskeland, "The Impact of Climate Change on Nuclear Power Supply", *The Energy Journal*, 2011, op. cit.

1300 - According to the International Atomic Energy Agency's (IAEA) definition, an outage is when the reactor's actual power is lower than the reference unit power for a period of time. Consequently, outages can be partial (power de-rating) or full (shutdowns). See https://pris.iaea.org/PRIS/Glossary.aspx.

1301 - Sami I. Attia, "The influence of condenser cooling water temperature on the thermal efficiency of a nuclear power plant", *Annals of Nuclear Energy*, Vol. 80, June 2015, see http://www.sciencedirect.com/science/article/pii/S0306454915000985, accessed 24 October 2020.

cooling-water temperature is generally subjected to regulatory limits in order to protect the river or sea ecology, and to respect industrial and drinking water conditions.[1302]

Nuclear plants, as well as most large fossil power plants, produce heat that is converted to electricity using a steam turbine. The turbine allows heat to be exchanged between a hot source (the reactor core) and a cold sink (usually a river or the sea). In the process, the hot source is cooled and thermal energy is transferred to the cold sink.

The amount of thermal energy that can be transferred to a river and, to a lesser degree, to the sea is limited because excessive water temperature can damage the ecosystem, reduce the efficiency of other plants using the same cold sink and deteriorate the conditions to produce drinking water.[1303] This specific consideration is mainly an issue in river heat sinks with nuclear and coal-fired power plants, which together are responsible for the majority of the "thermal pollution" from thermoelectric power plants worldwide.[1304]

The second is the storm pathway, which includes all the outages triggered by violent storms like hurricanes or typhoons, often accompanied by floods, lightning, etc. As shown in Figure 59, the disruptions related to stormy weather conditions particularly impact the electrical power supply systems at the power plant. For example, violent lightning storms have disrupted the operations of nuclear reactors in the past causing significant damage to the electrical systems of the plants, including the nearby grid substation.[1305] For example, the Browns Ferry nuclear plant in northern Alabama, U.S., has been reported to suffer from frequent lightning strikes, which required "considerable equipment replacement and repair".[1306]

In Europe, and particularly in France, which hosts over half of European nuclear reactors, temperature extremes are the main contributor to climatic disruptions.[1307] Over the past two decades, heatwaves have forced shutdown or curtailment of nuclear power reactors in Europe, the largest of which were observed in 2003, 2006, 2015 and 2018.[1308] On the other hand, nuclear

1302 - In France, the temperature of water for human consumption is required to be below 25°C.

1303 - In France, it is normally forbidden to produce water for human consumption from resources hotter than 25°C, this is due to the accelerated development of pathogens and reduced chlorine stability above this threshold. See French Republic, "Annexe I – Limites et Références de Qualité des Eaux Destinées à la Consommation Humaine, à l'Exclusion des Eaux Conditionnées", Annex to "Arrêté du 11 Janvier 2007 relatif aux limites et références de qualité des eaux brutes et des eaux destinées à la consummation humaines mentionnées aux articles R. 1321-2, R. 1321-3, R.1321-7 et E. 1321-38 du code de la santé publique", Modified 4 August 2017 (in French), see https://www.legifrance.gouv.fr/loda/article_lc/LEGIARTI000035438980/2020-08-07/, accessed 19 August 2021.

1304 - Catherine Elizabeth Raptis, Michelle T. H. van Vliet and Stefan Pfister, "Global thermal pollution of rivers from thermoelectric power plants", *Environmental Research Letters*, Vol. 11, N. 10, October 2016, see https://doi.org/10.1088/1748-9326/11/10/104011, accessed 1 July 2021.

1305 - Paul Boughton, "Solving the lightning strike problem at nuclear power plant", *Engineer Live*, 21 February 2013, see https://www.engineerlive.com/content/solving-lightning-strike-problem-nuclear-power-plant, accessed 27 April 2021.

1306 - Ibidem

1307 - Ali Ahmad, "Increase in Frequency of Nuclear Power Outages Due to Changing Climate", *Nature Energy*, July 2021, op. cit.

1308 - *The Guardian*, "Heatwave hits French power production", 12 August 2003, see http://www.theguardian.com/world/2003/aug/12/france.nuclear; and Juliette Jowit and Javier Espinoza, "Heatwave shuts down nuclear power plants", *The Guardian*, 29 July 2006, see http://www.theguardian.com/environment/2006/jul/30/energy.weather; also Craig Morris, "How the European power sector copes during the heat wave", *Energy Transition*, 26 August 2015, see https://energytransition.org/2015/08/european-power-sector-heat-wave/; and Mathieu Rosemain and Simon Carraud, "France's EDF halts four nuclear reactors due to heatwave", *Reuters*, 4 August 2018, see https://www.reuters.com/article/us-france-nuclearpower-weather-idUSKBN1KP0ES, all accessed 28 April 2021.

power plants in North America and East Asia, are particularly susceptible to suffer from cyclone activity.[1309]

Indirect climatic disruptions

Besides the direct effects of climate change and the extreme weather conditions that are highlighted above, climate change could also induce disruptions of nuclear power plants (and other power sources) through an array of indirect causes.

Table 17 lists some of the reported indirect climatic effects that have been contributing causes of unplanned outages of nuclear reactors worldwide. Higher-than-usual temperatures can alter the heat-sink environment, triggering new challenges. For example, in March 2021, the operation of two South Korean reactors was halted due to the spreading of jellyfish-like organisms, which can block the inlet cooling-water channel of the reactors.[1310] These organisms typically appear in numbers in June, but they appeared two months earlier due to earlier-than-normal warm currents.[1311] In fact, studies have shown that jellyfish tend to flourish in warmer waters under the effect of climate change.[1312]

Another example of the impact of indirect effects of climate change is the recurrence of wildfires. Clearly wildfires can happen due to non-climatic reasons, but usually hotter and drier weather conditions are major contributing factors.[1313] Wildfires can impact nuclear power plant operations by cutting off power supply—reactors need electricity to operate vital safety-related functions like core-cooling—(sometimes demand is cut preemptively[1314]) or through the need to evacuate plant personnel. In May 2014, the San Onofre nuclear power plant in California was shut down and its personnel evacuated as a precautionary measure in the face of nearby wildfires.[1315]

1309 - Steven Mufson, "3 nuclear power reactors shut down during Hurricane Sandy", *The Washington Post*, 30 October 2012, see https://www.washingtonpost.com/business/economy/3-nuclear-power-reactors-shut-down-during-sandy/2012/10/30/7ddd3a94-22b6-11e2-8448-81b1ce7d6978_story.html; and Suzanne Goldenberg, "Hurricane Irene shuts down US nuclear reactors", *The Guardian*, 28 August 2011, see http://www.theguardian.com/world/2011/aug/28/hurricane-iren-shuts-nuclear-reactor; also David R Baker, "Florida Nuclear Plants Ready to Shut Down as Dorian Threat Looms", *Bloomberg*, 31 August 2019, see https://www.bloomberg.com/news/articles/2019-08-31/florida-nuclear-plants-ready-to-shut-down-as-dorian-threat-looms, all accessed 28 April 2021.

1310 - Heesu Lee and Aaron Clark, "Tiny Sea Creatures Plague South Korean Nuclear Plant Operations", *Bloomberg*, 7 April 2021, see https://www.bloomberg.com/news/articles/2021-04-07/jellyfish-like-organisms-halt-two-south-korean-nuclear-reactors, accessed 28 April 2021.

1311 - Ibidem.

1312 - Christopher Philip Lynam, Martin K.S. Lilley et al., "Have jellyfish in the Irish Sea benefited from climate change and overfishing?", *Global Change Biology*, 2011, see https://onlinelibrary.wiley.com/doi/abs/10.1111/j.1365-2486.2010.02352.x, accessed 24 October 2020; and Martin J. Attrill, Jade Wright and Martin Edwards, "Climate-related increases in jellyfish frequency suggest a more gelatinous future for the North Sea", *Limnology and Oceanography*, 2007, see https://aslopubs.onlinelibrary.wiley.com/doi/abs/10.4319/lo.2007.52.1.0480, both accessed 24 October 2020.

1313 - Samuel Jonson Sutanto, Claudia Vitolo et al., "Heatwaves, droughts, and fires: Exploring compound and cascading dry hazards at the pan-European scale", *Environment International*, Vol. 134, January 2020, see https://www.sciencedirect.com/science/article/pii/S0160412019308530, accessed 28 April 2021.

1314 - Mark Chediak, John Gittelson and David R. Baker, "PG&E Warns of Power Cuts to 466,000 Customers To Prevent Fires", *Bloomberg*, 24 October 2020, see https://www.bloomberg.com/news/articles/2020-10-24/pg-e-warns-of-power-cuts-to-466-000-customers-to-prevent-fires, accessed 24 October 2020.

1315 - *Power Engineering International*, "Wildfires prompt evacuation of San Onofre Nuclear plant", 15 May 2014, see https://www.power-eng.com/nuclear/wildfires-prompt-evacuation-of-san-onofre-nuclear-plant/, accessed 28 April 2021.

Table 17 – Selection of Indirect Climate-Driven Effects Disrupting Nuclear Power Plant Operation

Effect	Impact
Jellyfish proliferation	Large numbers of jellyfish can block the inlet cooling water channel
Wildfire evacuation	Wildfires could either require evacuation of nuclear plant's personnel or cut off power supply
Flooding debris	Floods can bring debris closer to the inlet cooling water channel and block it
Sea level rise	Increase intensity and height of storms and storm surge

Sources: Various, compiled by WNISR, 2021

CASE STUDY FRANCE

With approximately two thirds of its electrical energy from nuclear reactors, France is uniquely dependent on nuclear power plants. As discussed in the previous section, this dependence can become a challenge when weather conditions, such as extreme heat or drought, make it harder to safely and reliably operate reactors.

Although weather-related disruptions of nuclear power production were reported in France as early as 1976[1316], the general public became familiar with this risk after the massive 2003-heatwave. In August 2003, high temperatures caused the unavailability of 10 to 15 GW of the 63 GW of nuclear power then installed in France.[1317] This substantial drop in availability, combined with poor performance from other production such as fossil and hydroelectricity and an increased number of incidents on the transportation and distribution networks, brought the supply-demand equilibrium close the brink, resulting in a situation a French Senate report called a "near-miss catastrophe".[1318] The report states:

> Thus, due to environmental constraints as stipulated in the discharge regulations, a potential production shortcoming of up to 16,000 MW has been identified for the week of 18 to 24 August. Over the period 4–24 August, a 4-percent reduction in nuclear energy production has been registered.[1319]

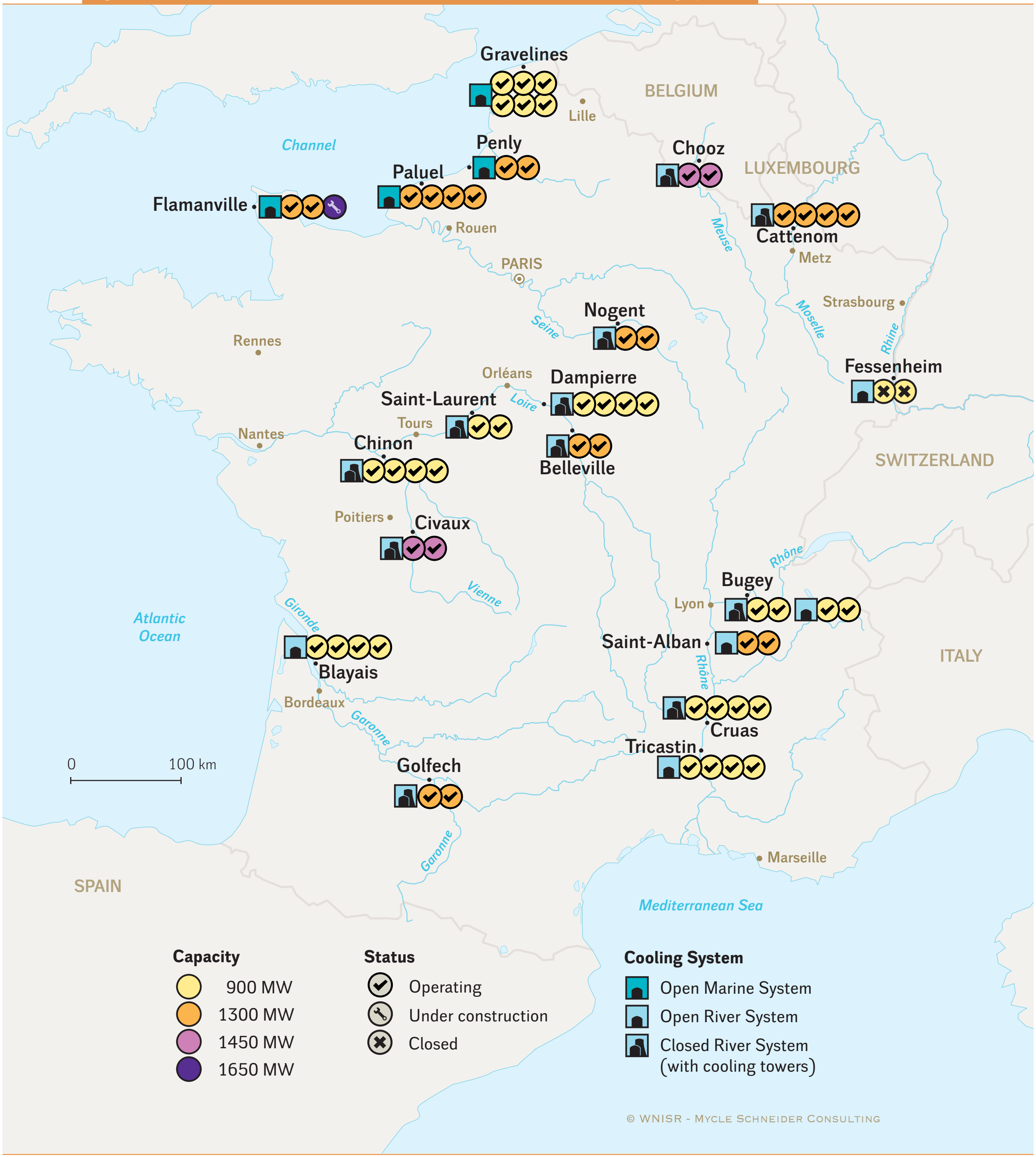
1316 - Callendar, "Nucléaire et climat : Les causes d'indisponibilités climatiques", Forthcoming.

1317 - French Senate, "La France et les Français face à la canicule : les leçons d'une crise—Rapport d'information n°195 (2003-2004)", Filed 3 February 2004 (in French), see https://www.senat.fr/rap/r03-195/r03-195.html, accessed 29 April 2021.

1318 - Ibidem.

1319 - Ibidem.

Figure 60 · Nuclear Power Plant Sites in France with Open and Closed Cooling Systems



Sources: WNISR, based on EDF, RTE, 2021

The 2003 heatwave was a particularly severe example of the impact weather can have on nuclear power, but not an isolated one. Recent incidents, including the unavailability of three out of four 900 MW Blayais reactors in the Bordeaux region on the Atlantic coast in early March 2021 due to an accumulation of foreign matter disabling their pumping stations (fouling)[1320]; a one-month shutdown of the two 1450 MW units in Chooz at the Belgian border caused by the low level of the Meuse river in August–September 2020[1321] and the shutdown of both 1300 MW units of Golfech during the heatwave of July 2019[1322], made it clear that weather can repeatedly bring French nuclear plants to a complete standstill.

Amongst the 56 operating light water reactors, there are 26 reactors with open cooling systems, of which 14 on the seashore and 12 on rivers, and 30 closed systems with cooling towers (all on rivers), (see Figure 60).

Climate-induced Impact on Nuclear Generation in France Since 2015

Duration and production lost

In 2020, the French Transmission System Operator (TSO), RTE, commissioned a study to assess the impact of weather on nuclear power production between 2015 and 2020[1323]. This study was based on data on planned and unplanned unavailability disclosed by EDF under the 2011 European Regulation on wholesale Energy Market Integrity and Transparency (REMIT), available on EDF's transparency platform[1324].

For the purpose of the RTE study, "climate-induced unavailability" was defined as a shutdown or derating of a reactor occurring when a weather phenomenon prevents the continuation of normal operation. This category does not exist in EDF's disclosed data but climate-induced unavailabilities and their probable cause can be identified through natural language processing[1325] of EDF's messages crossed with meteorological and hydrological data—for instance, a shutdown due to "environmental issues" during a heatwave is very likely to be caused by temperature. The results were validated using independent sources including EDF's communication and the IAEA's Operating Experience reports[1326].

1320 - EDF, "Reconnexion de l'unité de production n°1 de la centrale nucléaire du Blayais", 2 March 2021 (in French), see https://www.edf.fr/groupe-edf/nos-energies/carte-de-nos-implantations-industrielles-en-france/centrale-nucleaire-du-blayais/actualites/reconnexion-de-l-unite-de-production-ndeg1-de-la-centrale-nucleaire-du-blayais, accessed 13 August 2021.

1321 - EDF, "Redémarrage de l'unité de production n°2 de la centrale de Chooz", 4 October 2020 (in French), see https://www.edf.fr/groupe-edf/nos-energies/carte-de-nos-implantations-industrielles-en-france/centrale-nucleaire-de-chooz/actualites/redemarrage-de-l-unite-de-production-ndeg2-de-la-centrale-de-chooz, accessed 15 August 2021.

1322 - EDF, "Rapport environnemental annuel relatif aux installations nucléaires du Centre Nucléaire de Production d'Electricité de Golfech 2019", 2020 (in French), p. 38, see https://www.edf.fr/sites/default/files/contrib/groupe-edf/producteur-industriel/carte-des-implantations/centrale-golfech/actualites/Juillet%202020/rase_2019_avec_annexes_compressed.pdf, accessed 16 August 2021.

1323 - Working Group 'référentiel climatique', "Représentation des effets du climat sur le système électrique – Document de cadrage n°4 : Modélisation et évolution de la disponibilité de la production électrique d'origine nucléaire et thermique", Groupe de travail 'référentiel climatique', RTE, 2021 (in French), p. 13, see https://www.concerte.fr/system/files/u12200/2021-03-10-GT_climat_4_nucleaire_v1-min.pdf, accessed 15 August 2021.

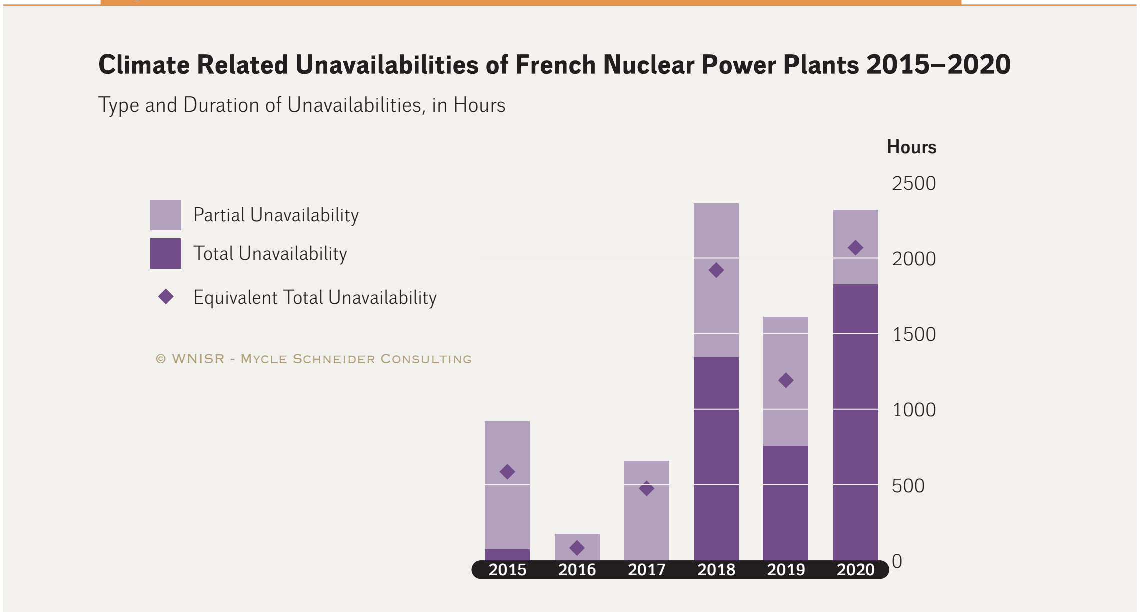
1324 - EDF, "List of Outages and Messages", see https://www.edf.fr/en/the-edf-group/who-we-are/activities/optimisation-and-trading/list-of-outages-and-messages/messages-list.

1325 - Natural language processing (NLP) is a branch of data science that focuses on programing computers to automatically process and analyze large amounts of text.

1326 - IAEA, "Operating Experience with Nuclear Power Stations in Member States—2019 Edition", 50th Edition, 2019, see https://www.iaea.org/publications/13575/operating-experience-with-nuclear-power-stations-in-member-states, accessed 19 May 2021.

According to the RTE study, weather was responsible for 3,994 hours of outages at zero power—a loss of 166 reactor-days of production—and 4,045 hours of derating between 2015 and 2020 (See Figure 61). Climate-induced unavailabilities occurred every year: 2016 was the least affected with just 18 deratings while 2018 was the worst year with 23 full outages and 103 deratings. Over the time period, 26 reactors were affected at least once (including both Fessenheim reactors) and 12 were shutdown (including one Fessenheim unit) at some point.

Figure 61 · Climate Related Unavailabilities of French Nuclear Power Plants 2015–2020



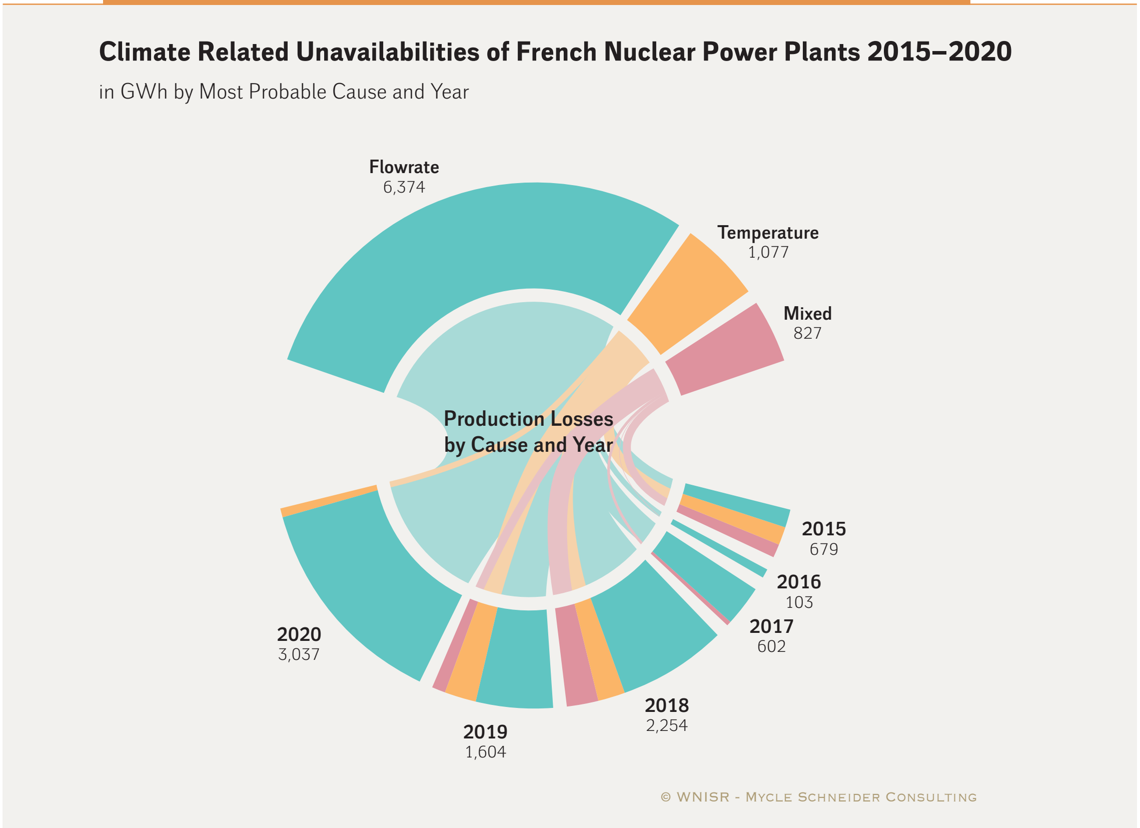
Source: REMIT, compiled by Callendar, 2021

Climate-induced unavailability reduced production by 8.5 TWh over the course of the six years, 1.4 TWh per year on average. This is approximately 0.4 percent of French annual nuclear production, slightly higher than the figures usually reported by EDF.[1327] The discrepancy may be explained by particularly high nuclear generation losses due to climatic impacts in 2020 when approximately 3 TWh fell victim to drought or heat, the highest level since 2003.[1328] (See Figure 62).

1327 - For instance in 2020, "EDF points out that heat has a very limited impact on electricity generation: on average only 0.25% of the fleet's annual production over the last 20 years" as reported in Vincent Collen, "Canicule, sécheresse : le parc nucléaire contraint de s'adapter", *Les Echos*, 8 August 2020 (in French), see https://www.lesechos.fr/industrie-services/energie-environnement/canicule-secheresse-le-parc-nucleaire-contraint-de-sadapter-1229316, accessed 16 August 2021.

1328 - Leila Fernández Thévoz, "Heatwave impact on French nuclear output doubles to 3 TWh", *Montel*, 24 February 2021, see https://www.montelnews.com/fr/story/heatwave-impact-on-french-nuclear-output-doubles-to-3-twh/1198233, accessed 16 August 2021.

Figure 62 · Climate Related Unavailabilities of French Nuclear Plants by Cause and Year



Sources: REMIT, compiled by Callendar, 2021

Table 18 – Causes for Outages and Generation Reductions at French Nuclear Fleet in 2019

Causes	Production Impacts
Other (mostly refueling and maintenance outages)	117.0 TWh
Modulation (production reduction to save fuel)	28.5 TWh
BreakdownTechnical Failures	12.0 TWh
Planned-outage extensions	12.0 TWh
Teil Earthquake*	2.3 TWh
Weather-related Outages	1.4 TWh
Total	**173.2 TWh**

Sources: RTE, 2021[1329]

Notes:

* On 11 November 2019, an earthquake close to the town of Teil triggered the procedure "shutdown for verification" at the Cruas nuclear power plant. The four 900-MW reactors remained offline for several weeks.

While production losses caused by climate-induced unavailability may appear limited in comparison to other unplanned outages, as shown in Table 18, RTE points out that they can be more disruptive as they are less easy to forecast and often concentrated over a relatively short period of the year. In other words, while the cumulated impact on production appears small,

1329 - Working Group "référentiel climatique", "Document de cadrage n°4 : Modélisation et évolution de la disponibilité de la production électrique d'origine nucléaire et thermique", Groupe de travail 'référentiel climatique', RTE, 2021 (in French), p. 13, see https://www.concerte.fr/system/files/u12200/2021-03-10-GT_climat_4_nucleaire_v1-min.pdf, accessed 19 August 2021.

the impacted share of installed capacity can be more significant. During the 2019 heatwave, for example, the capacity unavailable due to extreme temperature and drought simultaneously impacted up to nine reactors or 6.2 GW, approximately 10 percent of the installed nuclear capacity. This situation had a significant impact on the supply-demand balance with spot electricity prices in France quickly climbing from their normal range in summer (30–50€/MWh) to above 70€/MWh[1330].

Most Affected Periods of the Year

From 2015 to 2020, climate-induced unavailabilities were concentrated between July and November, and half of the production losses occurred in the September months (see Figure 63). This is partly due to the Chooz site's 28-day full unavailability in September 2020, but September remains the most affected month even when 2020 is removed.

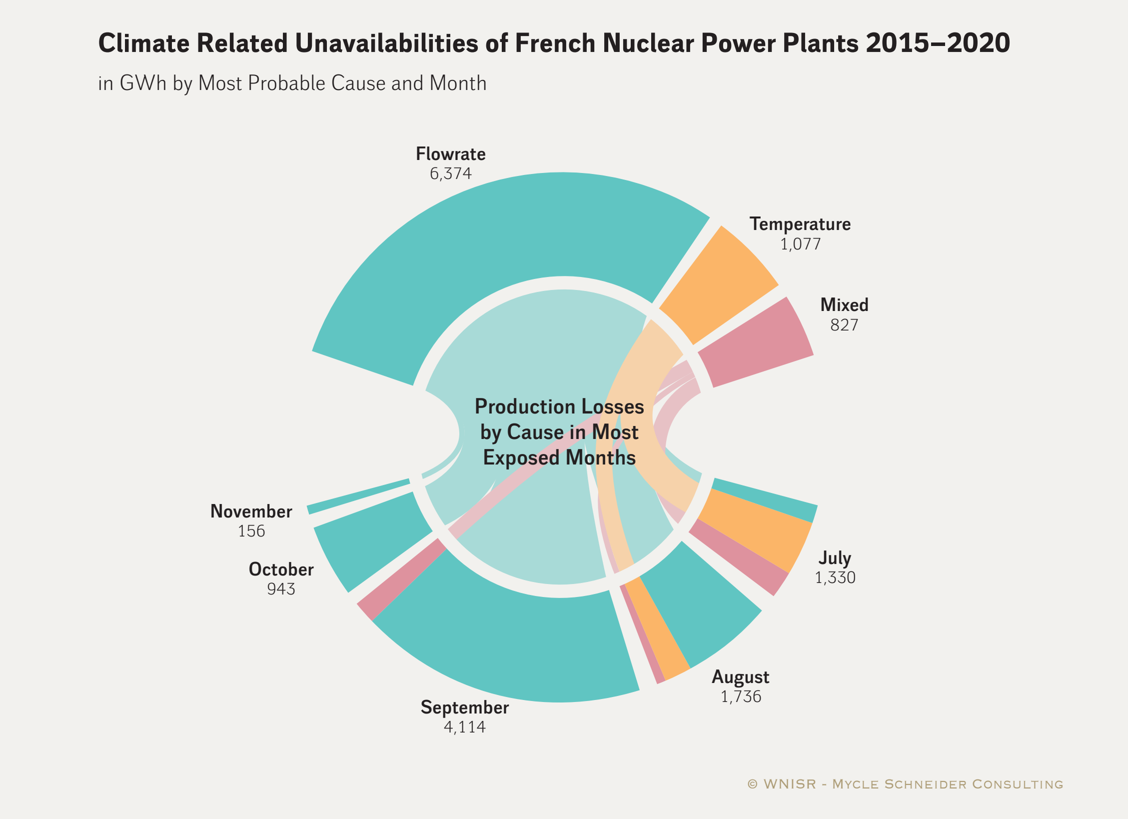
This result was somewhat unexpected as nuclear plant unavailability are typically reported in the general medias in relation to mid-summer heatwaves. Multiple reasons come together to make September the most exposed month:

- **Hydrological conditions.** On average, September is the month with the lowest flow on the Rhône and Meuse rivers, which are used to cool some of the most drought-vulnerable nuclear plants in France.
- **Meteorological conditions.** Water temperature remains high due to river inertia and relatively high air temperature. Late heatwaves, like in 2020 during the third week of September, are also becoming more likely with climate change.
- **Regulatory reasons.** Some plants have different thresholds for thermal discharge in winter and in summer; most noticeably the Bugey site with four 900-MW reactors switches from summer to winter regulation on 15 September which frequently cause unavailability during the second half of the month as the maximum water temperature allowed downstream is reduced by 2°C, from 26°C to 24°C.
- **Operational reasons.** As demand decreases, reactors are often halted in July and August for maintenance or to delay refueling outages, which makes it easier for the remaining reactors to operate under adverse weather conditions by reducing the overall need for water withdrawal and thermal discharge; conversely the probability of climate-induced unavailabilities mechanically increases when load factors increase at the end of the summer.

Besides September with about half of the incidences in the 2015–2020 period, the most affected months were August and July (with 22 percent and 16 percent of electricity production losses respectively). Losses remain significant in October (11 percent) with a tail-end in November (2 percent).

1330 - Thibault Laconde, "The Impact of Climate Change on Nuclear Supply", Callendar, presented at *Montel*, "French Energy Day", Webinar, 15 April 2021.

Figure 63 · Climate Related Unavailabilities of French Nuclear Plants by Cause and Month



Sources: REMIT, compiled by Callendar, 2021

Most Affected Power Plants

The RTE analysis did not identify any climate-induced unavailability for Gravelines, Penly, Paluel and Flamanville, the four French nuclear plant located on the seacoast, although EDF mentions at least one such event in its financial reporting.[1331]

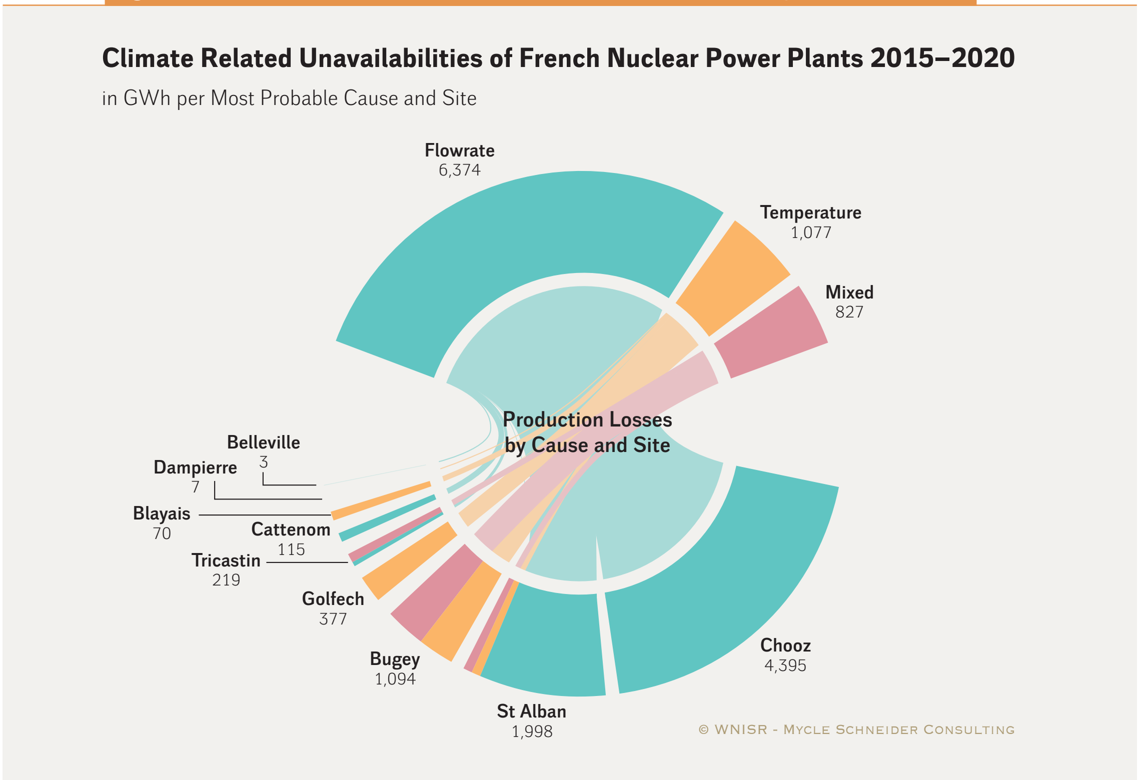
Among the fourteen nuclear plants located inland,[1332] nine experienced climatic unavailability between 2015 and 2020. The two Fessenheim reactors, closed in 2020, were also affected in the past. (See Figure 64).

Three plants lost more than 1 TWh of production: Chooz (4.4 TWh), Saint Alban (2 TWh) and Bugey (1.1 TWh). The Saint Alban plant is the only one to have experienced climate-induced unavailabilities every year since 2015. The Bugey plant experienced unavailabilities every year except in 2020 when its two most vulnerable reactors (Bugey-2 and Bugey-3 equipped with once-through cooling systems) were both offline for refueling and maintenance during the summer. (See Figure 65).

1331 - EDF, "Document d'enregistrement universel 2019", Annual Financial Report, March 2021 (in French), p. 141, see https://www.edf.fr/sites/default/files/contrib/groupe-edf/espaces-dedies/espace-finance-fr/informations-financieres/informations-reglementees/urd/edf-urd-rapport-financier-annuel-2019-fr-3.pdf, accessed 16 August 2021.

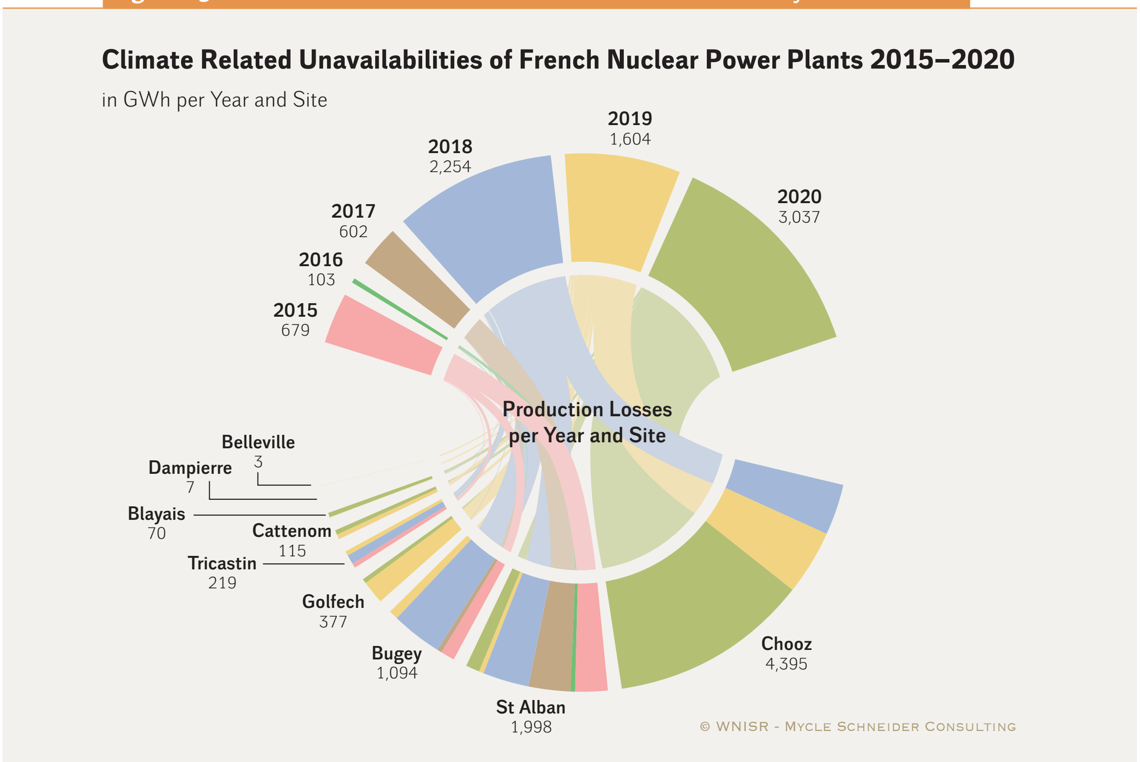
1332 - Although it is located on the Gironde estuary and resembles coastal plants in some aspects (for example the influence of wave and tide), Blayais is regarded here as an inland plant as the estuary is hotter than the sea, which causes frequent heat-induced unavailabilities.

Figure 64 · Climate Related Unavailabilities of French Nuclear Plants per Cause and Site



Source: REMIT, compiled by Callendar, 2021

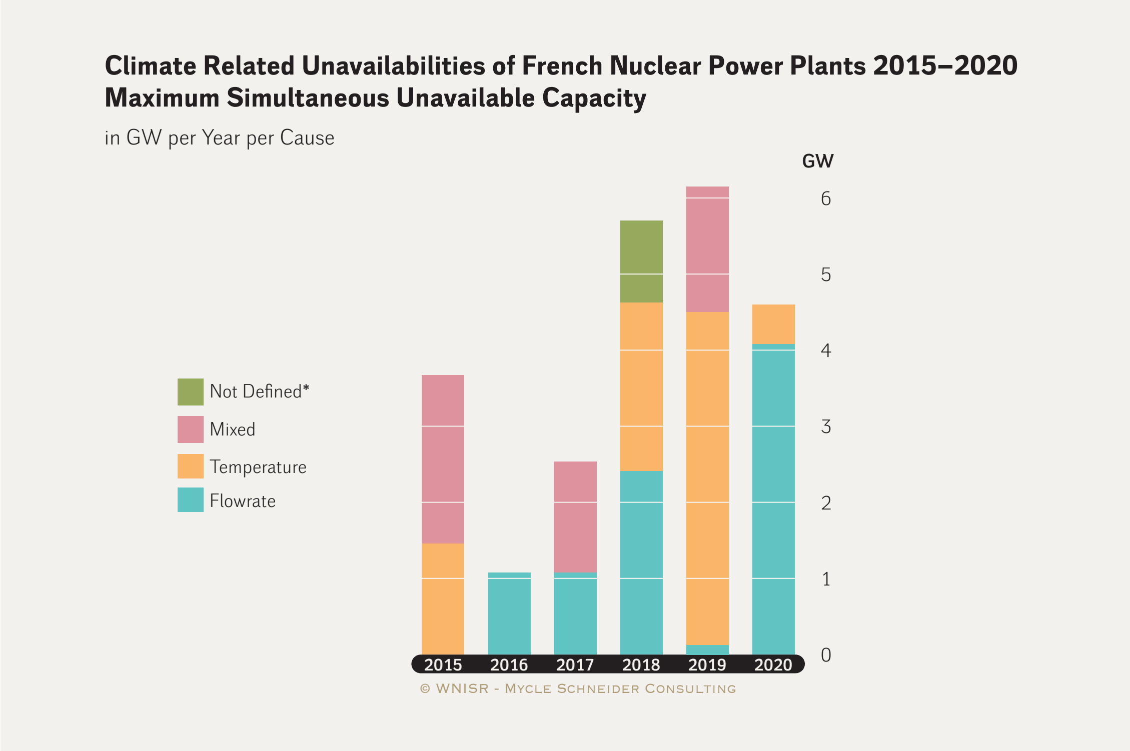
Figure 65 · Climate Related Unavailabilities of French Nuclear Plants by Cause and Year



Source: REMIT, compiled by Callendar, 2021

Figure 66 shows the maximum simultaneous unavailable capacity for each year of the 2015–2020 period, indicating their cause.

Figure 66 · Climate Related Unavailabilities of French Nuclear Plants – Maximum Unavailabilities



Sources: RTE and Callendar, 2021

Note: *No classification provided.

Causes of Climate-Induced Unavailabilities in France

Weather-related disruptions of nuclear power production are often presented as a result of extreme temperatures during summer heatwaves. Empirical data call this common narrative into question and suggest more complex phenomena are at play. The disruptions that happened during the past six years can be classified into three broad categories: summer type (caused by temperature), autumn type (caused by low water flow) and winter type (caused by floods or storms).

Summer-Type Disruptions: Correlated with Heat Waves, Short and Widespread

Even though it is not the most important cause of disruption in terms of energy loss, heatwaves can lead to power plant outages. During sustained periods of heat, the temperature of the water used to cool reactors and turbines increases, making it more and more difficult for a power plant to comply with the regulation on thermal discharge. In extreme cases, indoor air temperature could also become a threat for equipment reliability and performance.

Thermal discharge regulations for French nuclear plants

In France, the regulation of thermal discharge applicable to nuclear plants is set on a case-by-case basis by a decision of the Nuclear Safety Authority, ASN (Autorité de Sûreté Nucléaire) sanctioned by a decree from the Minister in charge of energy. It usually takes two or more of the following forms:[1333]

- A **maximum downstream temperature** after discharged cooling water is mixed with the water body: this type of limit applies to all inland plants with the notable exception of the four sites (Belleville, Chinon, Dampierre, Saint-Laurent-des-Eaux) along the Loire river. The regulation applicable to Bugey was mentioned earlier, Cruas, Golfech, Nogent and Tricastin provide a simpler case with a downstream water temperature limited to 28°C at any time in the year.
- A **maximum increase of temperature** between upstream and downstream after cooling water is mixed: this type of limit is used for inland plants frequently with different thresholds depending on the season or hydrological conditions. For example, the Nogent plant, upstream of Paris, is permitted to warm the Seine River by 3°C and up to 4°C when the flow rate is below 20 m^3/s. By contrast, the Civaux plant is allowed to warm the Vienne River only by 2°C and no additional warming at all is allowed should the river upstream temperature reach 25°C.
- A **maximum discharge temperature** at the point where cooling water is returned to the water body: this type of limit is used mostly for coastal plants and Blayais. The latter, for example, cannot discharge water hotter than 30°C from 16 October to 15 May and 36.5°C from 16 May to 15 October.

In addition, the regulation applicable to some plants contains more lax thresholds that can be used when normal limits cannot be met if the grid operator requires the plant to continue its operation to ensure the security of power supply. In such a case, Golfech, for example, could be allowed to operate with a downstream temperature of up to 30°C (instead of 28°C) but maximum warming between up- and downstream would be reduced to 1.25°C (instead of 1.5°C in summer and 2°C in winter).

Even though the regulation of thermal discharges by nuclear plants is loosely based on a 1978 European Directive[1334] and presents some commonalities with the regulation applicable to other industrial installations using natural water bodies for cooling, the applied case-by-case approach results in a patchwork of thresholds that make it difficult to comprehend why a specific plant had to reduce output or shut down in the past or to forecast future outages.

1333 - Callendar, "Réglementation des rejets et débits pour les centrales nucléaires françaises", Updated 17 November 2020 (in French), see http://callendar.climint.com/wp-content/uploads/2020/12/Reglementation.html.

1334 - European Parliament and Council of the European Union, "Directive 2006/44/EC of 6 September 2006 on the quality of fresh waters needing protection or improvement in order to support fish life", codified September 2006, *Official Journal of the European Union*, see https://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2006:264:0020:0031:EN:PDF; and Council of the European Union, "Council Directive 78/659/EEC of 18 July 1978 on the quality of fresh waters needing protection or improvement in order to support fish life", Official Journal of the European Communities, No. L 22/1, 14 August 1978.

Outages caused by upstream water temperature

During heatwaves, thermal discharge regulations can trigger outages because water temperatures increase with air temperature making it more difficult for nuclear plants to comply with maximum temperature at the discharge point or downstream.

Two slightly different cases exist depending on the cooling system used. Eleven of the 14 inland nuclear plants operating in France are equipped with closed-loop cooling systems, including Bugey which is the only installation with mixed cooling systems: Bugey-4 and -5 use closed-loop while Bugey-2 and -3 use once-through cooling.

With closed-loop cooling, most of the waste heat from the turbine is transferred to the atmosphere through evaporation in a cooling tower. As a result, the impact of the reactor on the temperature of the water body used for cooling is limited, usually less than 0.5°C. This residual warming occurs as water is drained from the cooling circuit to control the concentration in mineral and biological impurities.

As reactors equipped with closed-loop cooling contribute moderately to river temperature, outages usually happen when the upstream temperature is already higher or very close to the maximum temperature allowed downstream. Golfech with two 1300 MW units, along the Garonne river, is the plant most commonly affected by this type of outage: for example, in 2019, from 23–29 July and twice for very short durations in 2020, for 18 hours on 31 July and 1 August and 15 hours on 12 and 13 August.

Coastal plants as well as Blayais, Tricastin (also 4 x 900 MW), Saint-Alban (2 x 1300 MW) and Bugey-2 and -3 use once-through cooling systems. With once-through cooling, water used to cool the turbine is returned directly into the sea or river where it came from. As a result, all the waste thermal energy from the plant is transferred to the water body, and the water is obviously significantly warmer when it is discharged than when it is withdrawn. For example, at Blayais, the increase of water temperature between withdrawal and discharge is on average 8–10°C.[1335] As a result, outages can occur even when the water temperature is significantly lower than the temperature allowed at discharge or downstream: At Blayais, deratings due to excessive water temperature occurred at least 19 times since 2015—in August 2018, July 2019 and August 2020.

Impact of Air Temperature

Many electrical or electronic devices that are important for the safety of a nuclear installation are vulnerable to extreme heat. For example, the reliable operation of emergency generators and pumps can be impaired by excessive temperatures. In case of extreme heat, nuclear plant operation could then be disrupted independently of water temperature.

Heat sensitive equipment usually has one or two temperature thresholds:

- A *nominal* temperature limit ("température de disponibilité") under which they can operate continuously with normal performance;

1335 - EDF, "Rapport environnemental annuel relatif aux installations nucléaires du Centre Nucléaire de Production d'Électricité du Blayais", 2019 (in French), p. 42, see https://www.edf.fr/sites/default/files/contrib/groupe-edf/producteur-industriel/carte-des-implantations/centrale-blayais/surete-et-environnement/rapport_enviro_2019_vdef.pdf, accessed 16 August 2021.

- An *extreme* temperature limit ("température exceptionnelle de tenue des matériels"), higher than the nominal temperature, under which equipment can operate for a limited duration, possibly with impact on their lifespan.

Excessive Indoor Temperatures at Fessenheim During the 2003 Heatwave

In 2003, some electronic equipment at the Fessenheim nuclear plant was qualified to operate only below 50°C. On 31 July 2003, the temperature inside the reactor buildings reached 48.2°C, approaching the authorized temperature limit for the first time in French nuclear history.

To reduce the indoor temperature and avoid a shutdown, the operator decided to use the containment spray system (EAS) of the reactors. This system is designed to be used in the event of an accident to spray water inside the concrete containment of the reactor to reduce pressure and temperature and to trap radioactive iodine. The use of EAS failed to reduce the temperature but may have helped contain it below the 50°C limit. On 4 August 2003, when the spraying stopped, the temperature inside the building was at 48.7°C.[1336] The containment was also sprayed from the outside (see Figure 67).

Figure 67 · The containment of one of the Fessenheim reactors is sprayed with water to cool it down during the heatwave in 2003

Source: France 2, via INA, 4 August 2003.[1337]

EDF was criticized for using an emergency system in this situation and the image of Fessenheim reactors being sprayed also from the outside was arguably a defining moment in the realization that French nuclear plants may be vulnerable to increasing heat under climate change conditions.

1336 - *Le Monde*, "Polémique autour de l'aspersion de la centrale de Fessenheim", 5 August 2003 (in French), see https://www.lemonde.fr/archives/article/2003/08/05/polemique-autour-de-l-aspersion-de-la-centrale-de-fessenheim_329783_1819218.html, accessed 16 August 2021.

1337 - Angela Bolis, "C'était en 2003 : la centrale de Fessenheim arrosée", *Terraeco*, 10 June 2011 (in French), see https://www.terraeco.net/C-etait-en-2003-la-centrale-de,17816.html, accessed 7 May 2021.

Should indoor temperature reach these levels the plant would have to shut down out of precaution. There is no known example of such shutdown in France, but the risk appears credible under warming climatic conditions, as nearly happened in 2003 at Fessenheim (see box above). In addition, EDF's temperature models have been shown to be fallible. During the 2019 heatwave, the assumptions for maximum outside air temperature were exceeded for three nuclear plants (Gravelines, Paluel, Penly), and in other plants, measured indoor temperatures were significantly higher than those anticipated by EDF's building models, despite the outside air temperature being lower and some heat-generating equipment (e.g. certain electrical devices) being shut down.[1338]

Key characteristics of summer outages

Summer-type outages are caused by high temperatures; other factors, such as river flow, play no or minor roles. This leads to some specific characteristics of summer-type outages:

- They are **short**, as they require unusually high temperatures that currently rarely persist for more than one week. As river temperatures have some inertia, outages usually start three to five days after the beginning of the heatwave and cease when temperature decreases, typically lasting a few hours to a few days.
- They happen in a very **limited timeframe**, as they are concentrated around the hottest weeks of the year, usually during the second half of July and the first half of August. This characteristic is often used to dismiss the issue as this is a period of low demand for electricity in France.[1339]
- They are **highly correlated between plants**, as heatwaves frequently hit large parts of the French territory simultaneously. As a result, the operation of multiple power plants can be disrupted simultaneously, even if they are distant from each other and do not share the same cold sink.
- All things being equal, they are **virtually certain to occur more frequently**. While river flow or extreme weather events may in some cases evolve positively with climate change, there is little doubt that summer temperatures will increase significantly in the coming decades leading to more frequent and longer summer outages. This risk can however be reduced by regulatory changes of the downstream temperature limits (at the cost of a higher environmental risk).

Autumn-type Disruptions: Mostly Drought-driven, Long but Localized

As outlined before, weather-related outages are more common in September when heat is receding than during the summer and are still frequent in October and November. These autumnal outages are not caused by temperature but by river flow.

1338 - IRSN, "Avis IRSN n°2020-00010—Réacteurs électronucléaires – EDF – Retour d'expérience de la canicule de l'été 2019", Institute for Radiological Protection and Nuclear Safety, 23 January 2020 (in French), see https://www.irsn.fr/FR/expertise/avis/2020/Documents/janvier/Avis-IRSN-2020-00010_version-commentee_04032020.pdf, accessed 16 August 2021.

1339 - The lowest load day in the summer is around 30 GW or half of the installed nuclear capacity, while the historic winter peak exceeds 100 GW.

River flow rates: a minor constraint for French inland nuclear plants

With the exception of Chooz, technical and regulatory limits depending on the river flowrate have no direct impact on French nuclear plant availability.

Nuclear plants with once-through cooling systems need large quantities of water, e.g. 42 m^3/s per reactor at Tricastin and Bugey-2 and -3 and 57 m^3/s for Saint-Alban.1340 This translates into a minimum river flowrate of 84, 114 and 168 m^3/s for Bugey, Saint-Alban and Tricastin, respectively, at full capacity. Such volumes are provided by the Rhône River with reasonable margins: for Bugey (the most upstream plant), the once in 50 years daily low flowrate is 122 m^3/s, for Saint-Alban it is 190 m^3/s1341.

Stringent Flow Regulation at Chooz

The Chooz nuclear plant is located on the Meuse River less than 10 kilometers upstream of the Belgian border. The water from the Meuse is used in Belgium to produce drinking water for the Namur area and to provide cooling for industries, including the Tihange nuclear plant.

A Franco-Belgian agreement was negotiated to share the water from the river. In practice, this agreement renders the shutdown of one of the two Chooz units mandatory whenever the river flowrate is below 22 m^3/s over a 12-day moving average. Both units have to be put offline when the flowrate is less than 20 m^3/s over a 12-day moving average or if it drops below 14 m^3/s on daily average. This is a much more restrictive framework than those enjoyed by other French nuclear plants. The daily flowrate of the Meuse River dropped below 20 m^3/s five times over the past 15 years.

This rule led to the shutdown of both 1450 MW units from 24 August to 28 September 2020, the shutdown of one reactor in September 2018 (21–25), October 2018 (11–26) and September 2019 (11–30), in addition to 17 partial outages over those past three years.

Plants equipped with closed-circuit cooling systems need much less water, 2.0–2.6 m^3/s per reactor, depending on its capacity, but some are located on rivers with far lower flowrates than the Rhône. For instance, Civaux needs approximately 5 m^3/s at full capacity and is located on a segment of the Vienne River with a once in 50-years low flowrate of 6 m^3/s, Cattenom needs 8 m^3/s for a low flowrate of 9 m^3/s. Even though these plants need less water and operate with a margin, they can be less acceptable to other river users because part of the water is evaporated in the cooling tower, effectively reducing the flowrate of rivers that are already shallow. For

1340 - EDF, "Centrales nucléaires et environnement – Prélèvements d'eau et rejets", April 2014 (in French), see https://www.edp-open.org/images/stories/books/fulldl/guide-EDF_open.pdf, accessed 16 August 2021.

1341 - All flow data from Ministry of Ecological and Solidarity Transition, "Banque Hydro", Undated, see http://www.hydro.eaufrance.fr.

example, in a once in 50-years drought, the four 1300 MW Cattenom reactors could evaporate as much as one third of the Moselle River flow.

Such eventuality obviously makes the regulation of water use by nuclear plants indispensable. However, the regulation in that area is less restrictive than on thermal discharge. Water withdrawals are limited to higher volumes than what plants actually need in normal operation (for instance 140 m³/s for Saint-Alban or 6 m³/s for Civaux). A minimal downstream flow is not always mandated and, where it exists, is set to very low values: the flow downstream of Nogent, for instance, is theoretically allowed to be as low as 8 m³/s, less than half the lower flow observed in that area since public records are available.

For other plants, like Golfech or Dampierre, the regulation gives the administration the ability to restrict water use when river flow reaches a "crisis" level, a very low flowrate value set by regional water management plans or by the regulation itself. It does not seem that these dispositions were ever used.

Low flowrates can still disrupt nuclear production

Despite the current absence of technical limits and mostly lenient regulation, the operations of some French nuclear plants are frequently perturbed by low flowrates. This is because during low flowrate periods, rivers cannot efficiently dilute hot water discharged from the power plant, making it harder to comply with temperature regulations.

The maximum increase of temperature between upstream and downstream is limited for all inland nuclear plants. This temperature increase depends on the quantity of waste energy evacuated to the river (i.e.: plant's rated power, actual load factor and cooling system) but also on the river flow.

All things being equal, the increase of temperature between upstream and downstream is multiplied by two when the river flow is divided by two. As a result, low flowrate periods can make it almost impossible to comply with regulations on maximum temperature increase, regardless of pre-existing ambient air or water temperatures.

This is particularly true for plants equipped with once-through cooling systems without cooling towers as the thermal energy they need to evacuate is approximately two times the electrical power produced. As a consequence, this type of outages occurs frequently in autumn at Saint-Alban and Bugey, and occasionally at Tricastin.

Autumn-type outage characteristics

Autumn-type outages are caused by low flowrates and triggered directly by flow regulation (for Chooz) or indirectly by thermal discharge regulation (mostly for inland plants equipped with once-through cooling). They are the most widespread outages in term of production losses.

Autumn-type outages significantly differ from summer-type outages as:

→ They **last longer**, as a low flowrate period can last for weeks, even months, and cause long-lasting disruptions. These long-term disruptions often take the form of short, daily deratings rather than continuous outages. This is because, in most cases, the temperature increase between upstream and downstream is calculated over a 24-hour period.

Accordingly, the operator can produce at full capacity when demand is high even if it leads to a temporary breaching of the threshold as long as he reduces or shuts down production later in the day to compensate.

- The **period of vulnerability is extended** from August to November, including months where the electricity demand can be high. This was apparent in 2020, when, combined with low availability due to the pandemic, the shutdown of Chooz in September caused France to be a net importer of electricity for a full month for the first time since November 2017.1342
- They are **local** and there is no reason for autumn-type outages to happen at the same time in different watersheds. Even in the same watershed, hydrological conditions can be different depending on the segment of the river, for instance Tricastin which is implanted on the Rhône after the confluence of the Isere is less exposed than Bugey and Saint-Alban upstream.
- While the operator has very little leverage on summer type outages, autumn type disruptions **can be mitigated** (or aggravated) by water management practices and relations with other river users, in particular they pose unique issues for transboundary rivers, e.g. with Belgium being located downstream of Chooz, but also Switzerland upstream of the Rhône power plants.

Winter-type Disruptions:

Higher-Risk / Lower-Frequency Events Caused by Storms or Floods

Between 2015 and 2020, almost all weather-related outages reported by EDF happened between July and November. However, weather can disrupt the operation of nuclear plants during other seasons, especially in winter: the Blayais site was flooded in December 1999; reactors in Cruas and Tricastin were forced to shut down in December 2003 following historically high floods in the Rhône valley; in 2009 after severe rainfalls several tons of algae piled up on pumping station grates in Cruas eventually causing the loss of both feedwater intakes at Unit 4.

These outages were caused by extreme weather events like storm, high wind or torrential rain. Such events can impact nuclear stations in a variety of ways: flooding of essential parts of equipment, direct damage to the plant or its surrounding infrastructures, fouling of the water intakes and sometimes a combination of several effects. The Blayais incident in 1999, for example is recorded as a flooding event but even before the plant was flooded, Units 2 and 4 were shut down because of an electrical surge on their main power lines while the auxiliary lines were unavailable due to treefall; and, even as its basement and emergency pumps were already under water, the Unit 1 was stopped because the cooling system of its turbine was clogged by debris.[1343]

The most common cause of winter outages however appears to be fouling of pumping stations. Pumping stations supply water to cool the turbine via a condenser and the reactor itself via a separate circuit. These pumps have a critical role in ensuring the continuity of electricity production and the safety of the nuclear reactor, but they can be temporarily disabled when

1342 - RTE, "Le mensuel de l'électricité–Analyse du mois de Septembre", September 2020 (in French), p. 4, see https://assets.rte-france.com/prod/public/2020-10/RTE-Mensuel-Electricite-Septembre-2020-V3.pdf, accessed 16 August 2021.

1343 - OPECST, "Rapport sur le contrôle de la sûreté et de la sécurité des installations nucléaires", Parliamentary Office for Evaluation of Scientific and Technological Options, French Parliament, April 2000 (in French), see http://www.assemblee-nationale.fr/rap-oecst/r2331/r2331-1.asp, accessed 16 August 2021.

large amounts of foreign matter gather on their grates. Since 2000, fouling occurred at least in Blayais, Cruas, Flamanville, Paluel, Penly, and Tricastin.[1344]

Such events usually require the combination of two phenomena: the buildup of a stock of foreign matter, such as algae, vegetal wastes or invertebrates, near the plant or upstream and a meteorological event that set it in motion and send it to the pumping station. As the foreign matter involved in fouling is often biological, its proliferation can be amplified by warming waters as well as other phenomena like eutrophication.[1345] The frequency and severity of meteorological events triggering the displacement of matter and the fouling may also evolve with climate change. However, magnitude and direction of this evolution are difficult to anticipate.

Winter Fouling in Blayais

The Blayais nuclear plant, located on the Gironde estuary, is particularly prone to fouling between February and April. The latest example occurred between 28 February and 6 March 2021 when three of the four units had to be shut down due to abnormal presence of sediments in the filtering drums of their pumping stations.[1346]

Fouling risk in Blayais is aggravated by various phenomena, some of them, like high tide, independent from weather. The concentration of biological wastes in the estuary seems to be correlated with autumn drought, when low flowrates contribute to the accumulation of organic matter in the middle course of the Dordogne and Garonne rivers. These wastes are later washed away by winter floods ending their course in the estuary. As climate projections anticipate decreasing river flowrates in that area, the risk of fouling in Blayais may grow in the future even during normal winters.[1347]

Whereas summer and autumn outages are now frequent, with at least a few cases annually, winter disruptions are less regular and less predictable. They can however be more severe. The Blayais flooding in 1999 and the Cruas fouling in 2009, for example, caused significant damage and have serious safety implications. Both were rated Level 2 on the International Nuclear Event Scale (INES).[1348]

1344 - EDF, "Centrales nucléaires et environnement – Prélèvements d'eau et rejets", April 2014 (in French), op. cit.

1345 - Natalie Kopytko, "The Adaptation-Mitigation Dilemma: is Nuclear Power a Practical Solution for Climate Change?", Thesis, Evergreen State College, June 2009, p. 136, see https://www.nrc.gov/docs/ML1206/ML12066A290.pdf, accessed 16 August 2021.

1346 - EDF, "Reconnexion de l'unité de production n°1 de la centrale nucléaire du Blayais", 2 Marcch 2021, see https://www.edf.fr/groupe-edf/produire-une-energie-respectueuse-du-climat/minisite-temporaire/la-centrale-nucleaire-du-blayais/les-actualites-de-la-centrale-nucleaire-du-blayais/reconnexion-de-l-unite-de-production-ndeg1-de-la-centrale-nucleaire-du-blayais, accessed 16 August 2021.

1347 - Ana Fuentes-Cid, Éric De-Oliveira et al., "Apport d'une étude pluridisciplinaire des débris végétaux dans l'estuaire de la Gironde à la compréhension des phénomènes de colmatage du circuit de refroidissement du Centre Nucléaire de Production d'Électricité du Blayais" ["Contribution of a multidisciplinary study of vegetal debris in the Gironde estuary to understand clogging events of the cooling circuit of the Blayais Nuclear Power Plant"], *Hydroécologie Appliquée*, Vol. 18, 2014 (in French), see https://www.hydroecologie.org/articles/hydro/abs/2014/01/hydro140004/hydro140004.html, accessed 16 August 2021.

1348 - See IAEA, "International Nuclear and Radiological Event Scale (INES)", undated, see https://www.iaea.org/resources/databases/international-nuclear-and-radiological-event-scale, accessed 16 August 2021.

MANAGING CLIMATE RISKS IN THE FUTURE

Limited Adaptation Options for the Existing, Ageing Fleet

In response to the 2003 heatwave, EDF put in place a plan to adapt existing nuclear plants, known as Référentiel "Grands Chauds" (Great Heat Guidance). As its name suggests, this plan focuses on the revision of air and water temperature assumptions used to design critical safety equipment and building cooling-systems. The approach adopted is essentially short-term, iterative adaptations to existing nuclear plants. Temperature assumptions must be reevaluated prior to the 10-year comprehensive safety reviews.

The methodology adopted by EDF to evaluate future climate conditions adds to this short-term view. While most adaptation strategies are founded on climate projections, e.g. the simulation of the Earth's future climate based on various scenarios of greenhouse gas concentrations, EDF uses extrapolations. Maximum temperatures are calculated by extending historical observations over a 10-year period.[1349] This implicitly carries a risk of underestimating future temperature variation, especially with the projected nonlinear escalation of climatic effects, particularly after the 1.5°C limit is crossed.[1350]

Similarly, the impact of climate change on reference-flood scenarios is limited to the extrapolation of the mean sea level until the next safety review.[1351] In practice, this leads, for example, for the Blayais and Gravelines power plants, to an increase of 50 centimeters in the reference level for core safety equipment and +20 centimeters for the rest of the installation.[1352] By contrast, projections for sea level, storm surge and wind suggest that sea level could rise more quickly in the Channel, where Gravelines is located, than in the Bay of Biscay where Blayais is situated.[1353]

Little changes were made to guarantee the production during heatwaves or droughts. Adaptation options in that area are indeed very limited for existing plants. Barring a revision of temperature and flow regulations, only minimal gains are possible through improvement of the efficiency of the cooling system, for instance via reinforcement and more frequent cleaning of the condenser.

1349 - Alain Vicaud and Eric Jouen, "Adapter les centrales nucléaires au changement climatique", EDF, in *Revue Générale Nucléaire*, published online December 2015 (in French), see https://www.sfen.org/rgn/adapter-centrales-nucleaires-changement-climatique, accessed 16 August 2021.

1350 - IPCC, "Summary for Policymakers" in "Global Warming of 1.5°C – An IPCC Special Report on the Impacts of Global Warming of 1.5°C Above Pre-Industrial Levels and Related Global Greenhouse Gas Emission Pathways, in the Context of Strengthening the Global Response to the Threat of Climate Change, Sustainable Development, and Efforts to Eradicate Poverty", 2018, see https://www.ipcc.ch/site/assets/uploads/sites/2/2019/05/SR15_SPM_version_report_LR.pdf, accessed 16 August 2021.

1351 - ASN, "Protection of Basic Nuclear Installations Against External Flooding—Guide N°13", French Nuclear Safety Authority, 8 January 2013, see http://www.french-nuclear-safety.fr/References/ASN-Guides-non-binding/ASN-Guide-No.-13, accessed 16 August 2021.

1352 - IRSN, "Réexamen de sûreté des réacteurs de 900 MWe : Foire aux questions", October 2020 (in French), see https://www.irsn.fr/FR/connaissances/Installations_nucleaires/Les-centrales-nucleaires/visites-decennales/Reexamen-900/Pages/5-Reexamen-de-surete-reacteurs-900-MWe-FAQ.aspx#12, accessed 17 August 2021.

1353 - Data from Copernicus. See Copernicus Climate Change Service, "Water Level Change Indicators for the European Coast from 1977 to 2100 Derived from Climate Projections", European Commission, 2021, see https://cds.climate.copernicus.eu/cdsapp#!/dataset/10.24381/cds.b6473cc1.

Factoring Climate Change into New Projects

Extensive modification of the plant design that are required for major adaptations can only be performed for new constructions. The EPR design includes features that will make it less susceptible to some of the weather-related disruptions observed over the past decades; for instance four independent water intakes, instead of two for second generation reactors, will reduce the risk of fouling.[1354] On the other hand, with 67 m^3/s, an EPR with once-through cooling needs significantly more cooling water than any other nuclear reactor ever built in France.[1355]

In any case, adapting the design of new reactors to face past events is insufficient. They should be designed to operate safely and reliably under climatic conditions they will encounter during the second half of the century, or at least be flexible enough to allow future adaptations. The siting decisions also have an important role to play. Reactors cooled by rivers, for instance, would obviously be more vulnerable to an aridification of the climate, and even among inland reactors the Rhône offers a far better margin than smaller rivers.

Finally, the vulnerability of nuclear power production to climate change should be seen through the lens of the wider electricity system. For example, one key uncertainty when assessing the impact of future weather-related disruptions is the increased penetration of air-conditioning. Currently, low electricity consumption in summer is greatly helping the French electricity system to weather short-term drops of availability during heatwaves. It is not obvious that this favorable situation will endure.

Preliminary safety considerations of nuclear-climate interactions

Besides the substantial economic and financial risks related to unplanned power outages, there are implicit nuclear safety risks that can be associated with climate-linked disruptions. While climatic disruptions alone are unlikely, though not impossible, to cause a major nuclear accident, they can be a precursor of a major disaster. Such impact on nuclear safety can take various forms, including the following:

- Even though the adaptability of nuclear energy to adverse climatic conditions has been demonstrated by some plants to some degree, like Palo Verde in the U.S. or Barakah in the UAE, the potential expansion of nuclear power into a variety of climate zones exposed to increasingly intense weather conditions could exacerbate risks under a weak regulatory framework that lacks proper site-suitability studies.[1356]
- Wildfires, severe storms or flooding can directly impact the safety of nuclear power plants, as illustrated notably by the Blayais incident in 1999 mentioned above.

1354 - IRSN, "Refroidissement des installations nucléaires – Une remise à niveau sur l'ensemble des réacteurs depuis 2009", Undated (in French), see https://www.irsn.fr/FR/connaissances/Installations_nucleaires/Les-centrales-nucleaires/source-froide-pompage-refroidissement/Pages/2-Remise-niveau-Source-Froide.aspx?dId=0a389813-b526-4a03-94ba-84dddcaaef14&dwId=a7b334d0-1b79-47c9-a142-5832def01f25, accessed 18 August 2021.

1355 - EDF, "Projet Flamanville 3—Construction d'une centrale électronucléaire 'tête de série EPR' sur le site de Flamanville", Débat Public 2005/06, p. 44, see https://cpdp.debatpublic.fr/cpdp-epr/docs/pdf/dossier_mo/dossier_mo_interactif.pdf, accessed 18 August 2021.

1356 - In fact, there have already been a number of site selections in the past, notably in the Middle East and in Asia, that are based on questionable methodologies and/or oversight.

- A nuclear accident could coincide with an event such as a wildfire, a strong storm or flooding, which could hinder site access during critical periods.[1357] In such a scenario, the emergency safety response could be compromised by unexpected extreme weather events.

Additionally, as mentioned above, projected higher sea level rise is expected to increase the intensity of coastal storms and the chances of flooding in low-lying assets, including coastal nuclear power plants. This could impact the operations and safety of nuclear power plants. For example, the U.K. Office for Nuclear Regulation (ONR) identifies the climate-induced hazards as a source of concern, especially due to the lengthy lifetime of nuclear assets.[1358] However, a recent analysis has highlighted that the U.K. ONR has not quantitatively defined the threshold of climate impacts (sea level rise for example).[1359]

Policy Implications

In an increasingly competitive energy space with focus on affordable and resilient energy systems, the highlighted climate risks can have important policy implications for the future of nuclear energy.

Governments, planning authorities, the nuclear industry itself and civil society need to take climate risks to the nuclear sector more seriously. These risks are yet to appear in any in-depth economic or safety assessments to date. A systemic and comprehensive risk assessment that covers the full spectrum of not only current, but also projected extreme weather conditions, would be essential to future decision-making. The centerpieces of these assessments are weighing of energy policy options in a given geographical, climatic, societal and political framework, open-minded site selection procedures and nuclear technology choices.

In principle, water-cooled nuclear technologies can adopt some adaptation pathways such as shifting to dry cooling (using air-cooled condenser) or relying on better predictive weather models. However, although dry cooling reduces vulnerability to water temperature and availability issues, it could increase vulnerability to air-temperature constraints. Regardless of the adopted mitigation pathway, there will be substantial economic losses. For example, dry cooling lowers the thermal efficiency of the power plant. Advanced reactor concepts that use coolants other than water (such as gases or liquid metals) could be deployed too but these face significant development barriers, deployment challenges and tradeoffs.[1360]

One major difference between nuclear power and most other energy sources is the long (theoretical) lifespan of nuclear assets and the lengthy construction time. While the nameplate lifetime of solar and wind is between 20 to 30 years, nuclear reactors are now designed and built to operate for 60 years, with an average construction time of around 10 years.[1361] This

1357 - This was the case when the access road to the Blayais nuclear power plant was flooded in December 1999. An injured person thus could not be evacuated.

1358 - UK-ONR, "Nuclear Safety Technical Assessment Guide on External Hazards", UK Office for Nuclear Regulation, 2018.

1359 - Paul Dorfman, "Climate Change UK Nuclear", Nuclear Consulting Group, 2021, see https://www.nuclearconsult.com/wp/wp-content/uploads/2021/06/Climate-Change-UK-Nuclear-June-2021.pdf, accessed 2 July 2021.

1360 - M. V. Ramana and Zia Mian, "One size doesn't fit all: Social priorities and technical conflicts for small modular reactors", *Energy Research & Social Science*, Vol. 2, June 2014, see http://www.sciencedirect.com/science/article/pii/S2214629614000486, accessed 26 October 2020.

1361 - Coal-fired power plants also have a long lifetime of 60 years. However, conducting major climate-smart refurbishment within already operating nuclear power plants is likely to take much longer and require higher resources due to the presence of higher levels of regulatory requirements.

limits the prospects of incorporating new technological solutions and interventions in a timely manner in nuclear projects that are either operating or under construction. In fact, any design changes might trigger further delays due to the need to conduct new safety and regulatory assessments.

An interesting example that highlights the complexity of incorporating adaptation measures after the power plant has been built is the Ascó nuclear power plant in Spain, which consists of two reactor units cooled in open circuit by the Ebro River. A few years after startup, regulatory authorities deemed the impact on river temperature as too high. A cooling tower was added, but the reactor and turbine cooling systems were not modified, i.e. the cooling tower is only used to cool the water discharged from the reactors before it is returned to the river, increasing costs and water consumption as now some of the water is evaporated and not returned to the river anymore.[1362] In other cases, operators decided to close reactors rather than to add towers to the plant, e.g. as happened in the case of Indian Point close to New York. The last of three operating units ceased operating at the end of April 2021.

CONCLUSION

The impact of a changing climate on the operation of nuclear power plants is evident. Nuclear power reactors are vulnerable to an array of direct and indirect climate-linked disruptions. This vulnerability is expected to become more pronounced as the frequency and intensity of extreme weather events such as heatwaves, droughts and severe storms increase because of climate change.

In France, so far, weather-related disruptions on the nuclear fleet have usually remained mild, with production loss over the past six years representing <0.5 percent of total. However, short-term impact can reach several percent over several weeks and the capacity loss has reached up to 10 percent of the installed nuclear capacity. It is also worth noting that some past events caused a drop in availability large enough to have an impact on the electricity market and, in rare occasions, nuclear safety was at stake.

As nuclear energy seems bound to remain a disproportionate contributor to French electricity production at least for some time, it will have to face significant uncertainties and risks. Will the unavailability caused by heat, drought and extreme weather events remain manageable under deteriorating climate change conditions? How will they interact with the impact of climate change in other sectors as well as long-term economic, technical and social trends, like more expensive peaker plants, stiffer competition for access to water or increased penetration of air conditioning?

These questions are becoming more pressing as the French nuclear program approaches a tipping point. The currently operating fleet of second-generation reactors is reaching the end of their originally envisaged operational lives. The options are lifetime extensions, new-build or a significant shift in energy policy. All options will be impacted by climate change and the in-depth assessment of the implications should be part of the decision-making process.

1362 - See diagram of Ascó nuclear power plant: anav, "Ascó", Undated, see https://www.anav.es/en/anav-en/diagram/, accessed 28 May 2021.

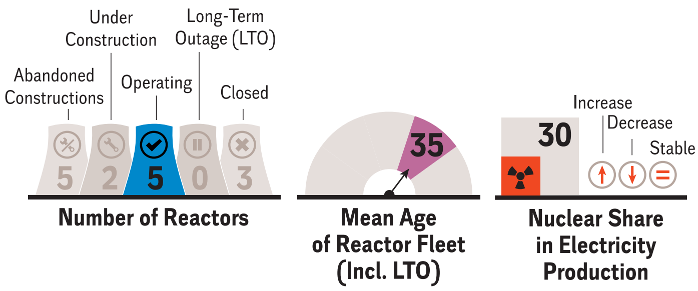
Unfortunately, there is a dearth of research on these topics. When it comes to the impact of future climate change, the scientific literature appears to be far thinner in the case of nuclear power than for renewable energies, such as hydro or wind, or even for transmission systems.[1363]

1363 - Jennifer Cronin, Gabrial Anandarajah and Olivier Dessens, "Climate change impacts on the energy system: a review of trends and gaps", *Climatic Change*, 6 August 2018, see https://link.springer.com/article/10.1007/s10584-018-2265-4.

TABLE OF ANNEXES

ANNEX 1 – OVERVIEW BY REGION AND COUNTRY

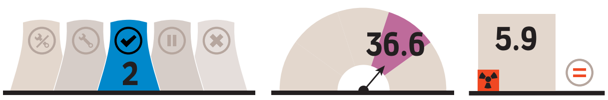
These "quick view" indicators will be used in the country sections throughout the report.



Unless otherwise noted, data on the numbers of reactors operating and under construction and their capacity (as of mid-2021) and nuclear's share in electricity generation in 2020 are from the International Atomic Energy Agency's Power Reactor Information System (IAEA-PRIS) online database.[1364] Historical maximum figures indicate the year that the nuclear share in the power generation of a given country was the highest since 1986, the year of the Chernobyl disaster.

AFRICA

South Africa



Africa's only commercial nuclear power plant consists of two 900 MW reactors located at Koeberg, near Cape Town in South Africa. Both reactors started operating in the mid-1980s. In 2020, they generated 11.6 TWh representing 5.9 percent of the country's power, a decrease of nearly 2 percentage points over the previous year, and down from the historical maximum of 7.4 percent in 1989. 2020 was a landmark year for the South African grid, as variable renewables—namely solar and wind—produced more electricity than the nuclear power plant for the first time.[1365]

The reactors were initially permitted to operate for 40 years and now plan a series of replacement and upgrading work to extend their operational lifetimes.[1366] The decision to replace all six steam generators of the two units was taken in 2010. AREVA was awarded the contract in 2014[1367] , and a lengthy legal battle with competitor Westinghouse followed. In 2018, the Parliament began investigations into the actions of several Eskom officials relating to several issues, including the steam generator contracts. The Parliament committee report

1364 - IAEA-PRIS, "Nuclear Share of Electricity Generation in 2019", see https://pris.iaea.org/PRIS/WorldStatistics/NuclearShareofElectricityGeneration.aspx.

1365 - Remeredzai Joseph Kuhudzai, "Solar & Wind In South Africa Contributed More Than Nuclear For 1st Time Ever In 2020", *CleanTechnica*, 13 March 2021, see https://cleantechnica.com/2021/03/13/solar-wind-in-south-africa-contributed-more-than-nuclear-for-1st-time-ever-in-2020/, accessed 26 June 2021.

1366 - Kevin Brandt, "Koeberg nuclear plant components can run beyond 2045, say experts", *Eyewitness News*, 5 November 2019, see https://ewn.co.za/2019/11/05/koeberg-nuclear-plant-components-can-run-beyond-2045-say-experts, accessed 25 June 2021.

1367 - *NEI*, "AREVA to replace steam generators at Koeberg", 19 August 2014, see https://www.neimagazine.com/news/newsareva-to-replace-steam-generators-at-koeberg-4346550/, accessed 25 June 2021.

concluded that the former chairmen and executives of Eskom "reasonably ought to have known or suspected" that their failure to report the flouting of governance rules relating to some contracts, including those relating to the steam generator replacement "may constitute criminal conduct".[1368]

The plant has been operating at low temperatures to reduce the pace of corrosion in the steam generator tubes. The replacement of the steam generators is scheduled to be carried out in 2021.[1369] Problems with the existing steam generators continue to plague the plant, and in January 2021, Unit 1 was taken offline for several months due to leakage. The unplanned outage of the reactor caused further supply problems for the already struggling Eskom, leading to additional load-shedding (power rationing).[1370]

The state-owned South African utility and Koeberg operator Eskom had considered acquiring additional large PWRs and had made plans to build 20 GW of generating capacity by 2025. However, in November 2008, Eskom scrapped an international tender because the Government was unwilling to provide the loan guarantees demanded by potential financiers, and credit-rating agencies threatened downgrades. In 2011, the Department of Energy (DOE) published an Integrated Resource Plan (IRP) for future power generation investments that contained a 9.6 GW target, or six nuclear units, by 2030. Startup would have been one unit every 18 months beginning in 2022. The total price of the project was estimated to be in the range of US$37-100 billion.[1371]

In April 2017, the Western Cape division of South Africa's High Court ruled in favor of two NGOs, the Southern African Faith Communities Environment Institute (SAFCEI) and Earthlife Africa, in their cases against the Government. This halted a December 2015 decision to procure 9.6 GW of new nuclear capacity and annulled the nuclear co-operation agreements that the Government had signed with Russia, South Korea, and the United States. The court concluded that the lack of public consultation on the decisions "rendered its decision procedurally unfair" and breached its statute.[1372] In May 2017, the Government announced that it would not appeal the court. The 2018 Goldman environmental prize was awarded to grassroots activists Makoma Lekalakala and Liz McDaid for the successful legal challenge in this case.[1373]

In January 2018, future President Cyril Ramaphosa said in Davos that "we have no money to go for major nuclear plant building."[1374] Even the chief financial officer of Eskom stated: "I can't

1368 - Alec Hogg et al., "Three former Eskom chairmen to be criminally probed", *BizNews.com*, 28 November 2018, see https://www.biznews.com/briefs/2018/11/28/eskom-chairmen-criminal-probe, accessed 25 June 2021.

1369 - According to an Eskom spokesperson, personal communication, Anton Eberhard, email dated 13 July 2020.

1370 - *NEI*, "Koeberg 1 closed after steam generator leakage", 11 January 2021, see https://www.neimagazine.com/news/newskoeberg-1-closed-after-steam-generator-leakage-8446258, accessed 26 June 2021.

1371 - *NEI*, "Eskom plans RFP for new reactors by mid-year", 15 March 2017, see https://www.neimagazine.com/news/newseskom-plans-rfp-for-new-reactors-by-mid-year-5761595/, accessed 25 June 2021.

1372 - Phil Chaffee, "Legal: High Court Upends South African Newbuild Plans", *NIW*, 28 April 2017.

1373 - Jonathan Watts, "Goldman prize awarded to South African women who stopped an international nuclear deal", *The Guardian*, 23 April 2018, see https://www.theguardian.com/world/2018/apr/23/goldman-prize-awarded-to-south-african-women-who-stopped-an-international-nuclear-deal, accessed 25 June 2021.

1374 - Alexis Akwagyiram, "South Africa has no money for major nuclear expansion, Ramaphosa says", *Reuters*, 25 January 2018, see https://www.reuters.com/article/davos-meeting-safrica-nuclear/south-africa-has-no-money-for-major-nuclear-expansion-ramaphosa-says-idINKBN1FE2O4, accessed 25 June 2021.

go and commit to additional expenditure around a nuclear program."[1375] In August 2018, the Government published its draft IRP 2018[1376], in which new nuclear is absent in the period up to 2030.[1377]

However, in October 2019, in the updated IRP document, nuclear power was described as a "no regret option". The document stated that due to the expected decommissioning of 24 GW of coal capacity, it was proposed to implement nuclear "at an affordable pace and modular scale" and "at a pace and scale the country can afford".[1378]

In June 2020, the Government issued a "Request for Information" (RfI) to enable an assessment of the potential reactor technologies to "be considered" under a future newbuild program that might encompass both conventional reactors and SMRs. The vendors were expected to supply technical and financial information by 15 September 2020.[1379]

In November 2020, the National Energy Regulator launched a three-month consultation on the draft plan to construct 2.5 GW of new nuclear capacity by 2030 and beyond. Within the consultation announcement, the regulator stated that it "has not yet formulated any opinions on the issues that are raised in this consultation paper but is raising them so that stakeholders can give their opinions".[1380]

Submissions to the consultation highlighted the additional costs of including nuclear power in the power mix. A scenario with additional nuclear and constraint in renewables' expansion was found to cost an additional cumulated R200 billion (US$14 billion) by 2040 compared to a scenario with no nuclear, no increase in coal and unrestricted expansion of renewables.[1381]

1375 - *NIW*, "Weekly Roundup", 2 February 2018.

1376 - Despite there being half a dozen versions of the IRP, only one, the revision of 2011 was 'promulgated' so all the other versions including the August 2018 version have no policy status.

1377 - *NEI*, "South Africa cancels nuclear expansion plans", 30 August 2018, see https://www.neimagazine.com/news/newssouth-africa-cancels-nuclear-expansion-plans-6728356/, accessed 25 June 2021.

1378 - Department of Mineral Resources and Energy, "Integrated Resource Plan (IRP2019)", October 2019, see http://www.energy.gov.za/IRP/2019/IRP-2019.pdf, accessed 25 June 2021.

1379 - Roger Murray and Phil Chaffee, "South Africa: Government RFI Keeps New Nuclear Option Alive", *NIW*, 19 June 2020.

1380 - *NEI*, "South African regulator launches consultation on new nuclear", 26 November 2020, see https://www.neimagazine.com/news/newssouth-african-regulator-launches-consultation-on-new-nuclear-8380496/, accessed 25 June 2021.

1381 - Helen Suzman Foundation, "Comments to NERSA on the ministerial determination of October 2020 regarding the commencement of a process to procure 2 500MW of new nuclear generation capacity", 3 February 2021, see https://hsf.org.za/publications/submissions/comments-by-hsf-to-nersa-on-ministerial-determination-3-february-2021.pdf, accessed 26 June 2020.

THE AMERICAS

Argentina

Argentina has three nuclear reactors that provided 10 TWh of electricity in 2020, an increase of 2 TWh over the previous year, and represented 7.5 percent of the country's electricity generation (up from 5.9 percent in 2019, but down from a maximum of 19.8 percent in 1990). They were all supplied by foreign reactor builders. Atucha-1 and -2 were built by German company Siemens, and the CANDU (CANadian Deuterium Uranium) type reactor at Embalse by Canadian Atomic Energy of Canada Limited (AECL).

In April 2018, the regulatory authority gave a lifetime extension license to enable **Atucha-1**, originally started up in 1974, to continue operating until 2024, which would thus allow for a 50-year working life.[1382]

Embalse, which started operating in 1983, was shut down at the end of 2015 for major overhaul, including replacing hundreds of pressure tubes, to enable it to operate for up to 30 more years. It eventually returned to service in May 2019.[1383]

Atucha-2 was ordered in 1979 and construction was stop/start for the following decades, but finally, grid connection was announced on 27 June 2014. It took until 26 May 2016 to enter commercial operation.[1384]

For the past decade, discussions have been held on the construction of a fourth reactor. In February 2015, Argentina and China ratified an agreement to build an 800 MW CANDU-type reactor at the Atucha site, when Atucha-3 was expected to cost US$5.8 billion.[1385] A framework agreement was also signed in 2015 between the two companies to construct a Hualong One reactor, China's Generation-III design, without a site being specified. In May 2017, a co-operation agreement was signed between Argentina and China, whereby China would help build and mainly finance the construction of the two reactors, with the CANDU-6 starting construction in 2018 and the Hualong reactor in 2020.[1386] However, the site for the Hualong reactor has not been agreed on, as the Governor of Rio Negro—the Government's preferred location—rejected the construction of the reactor in his province, citing a lack of social acceptance for the project.[1387]

Despite this, the Government insisted in October 2017 that construction on both projects would begin in the 2nd half of 2018. The total cost of the Hualong and Atucha-3 projects were

1382 - *WNN*, "Atucha 1 operating licence renewed", 16 April 2018, see http://www.world-nuclear-news.org/RS-Atucha-1-operating-licence-renewed-1604184.html, accessed 7 May 2021.

1383 - WNA, "Nuclear Power in Argentina", January 2021, see https://www.world-nuclear.org/information-library/country-profiles/countries-a-f/argentina.aspx, accessed 7 May 2021.

1384 - *WNN*, "Atucha 2 receives full operating licence", 31 May 2016, see http://www.world-nuclear-news.org/RS-Atucha-2-receives-full-operating-licence-3105165.html, accessed 7 May 2021.

1385 - *WNN*, "Argentina and China sign contract for two reactors", 18 May 2017, see http://www.world-nuclear-news.org/NN-Argentina-and-China-sign-contract-for-two-reactors-1805175.html, accessed 7 May 2021.

1386 - CNNC, "CNNC to build heavy water reactor and HPR 1000 units in Argentina", China National Nuclear Corporation, 19 May 2017, see http://en.cnnc.com.cn/2017-05/19/c_77725.htm, accessed 7 May 2021.

1387 - Phil Chaffee, "Argentina", *NIW*, 29 September 2017.

expected to be US$12.5 billion, (other sources indicate US$15 billion)[1388] financed with a 20-year loan from China at an interest rate of 4.5 percent. In May 2018, the Government announced that it was suspending talks with China regarding the construction of both reactors for at least four years.[1389]

In June 2019, the Argentine Government expressed ongoing support for the project following official meetings with the Chinese, with Argentina's cabinet chief Marcos Pena saying, "there is an intention to move forward."[1390] The President of China National Nuclear Corporation (CNNC) Jun Gu told delegates at an IAEA conference in October 2019 that construction of the reactors would begin in 2020[1391], which did not happen.

There are few indications that the project will proceed, and its prospects are further diminished by the ongoing tension between the U.S. and China, which may affect developments in Argentina as the U.S. Department of Defense has identified 20 Chinese companies, including CNNC, as having ties to the Chinese military. The China-focused U.S.-based news platform SupChina commented: "If Washington decides to pursue sanctions against those firms, that could be the final nail in the coffin of the Argentinian Hualong-1 saga".[1392] This is exactly what happened, and the two main companies that have developed the Hualong One, CNNC and China General Nuclear Power Corporation (CGN), were blacklisted by the U.S. Administration.[1393]

However, in June 2021, the state-owned company Nucleoeléctrica Argentina SA approved its Action Plan for the coming years.[1394] The plan provides for the construction of a Hualong One reactor and the "preservation of the national technology (heavy-water natural-uranium)" through the revival of the CANDU project.[1395] It remains unclear what influence the U.S. blacklistings will have on the plan.

Construction of a prototype 27-MWe PWR, the domestically designed **CAREM-25** (Central Argentina de Elementos Modulares—a pressurized-water SMR) began near the Atucha site in February 2014, with startup initially planned for 2018. The reactor was expected to cost US$446 million.[1396] In 2019, it was rescheduled to begin operating in 2022.[1397] However, late

1388 - *WNN*, "Argentina and China Sign Contract for Two Reactors", May 2017, op. cit.

1389 - Phil Chaffee, "The Fallout From Argentina's Newbuild Retreat", *NIW*, 25 May 2018.

1390 - Cassandra Garrison and Hugh Bronstein, "Argentine official, in China, talks nuclear deal and soymeal", *Reuters*, as published on *SaltWire*, 25 June 2019, see https://www.theguardian.pe.ca/business/argentine-official-in-china-talks-nuclear-deal-and-soymeal-326387/, accessed 7 May 2021.

1391 - *WNN*, "China confident of 'new era' for nuclear, says CNNC president", 9 October 2019, see https://world-nuclear-news.org/Articles/China-confident-of-new-era-for-nuclear-says-CNNC accessed 7 May 2021.

1392 - Álvaro Etchegaray, "Chinese nuclear energy in Argentina is in trouble", *SupChina*, 3 September 2020, see https://supchina.com/2020/09/03/chinese-nuclear-energy-in-argentina-is-in-trouble/, accessed 7 May 2021.

1393 - Bureau of Industry and Security, "Entity List", U.S. Department of Commerce, see https://www.bis.doc.gov/index.php/policy-guidance/lists-of-parties-of-concern/entity-list, accessed 7 July 2021.

1394 - Nucleoeléctrica Argentina S.A., "Impulso al desarrollo nuclear: el Poder Ejecutivo Nacional aprobó el Plan de Acción de Nucleoeléctrica Argentina", 7 July 2021, see https://portal.na-sa.com.ar/es/prensa/impulso-al-desarrollo-nuclear-el-poder-ejecutivo-nacional-aprobo-el-plan-de-accion-de-nucleoelectrica-argentina-230, accessed 29 July 2021.

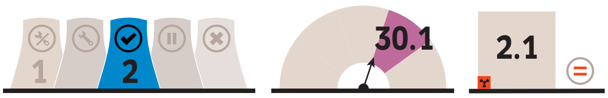
1395 - Nucleoeléctrica Argentina, "Plan de acción para Nucleoeléctrica Argentina", June 2021 (in Spanish), *Mercado Eléctrico*, 30 June 2021, see http://www.melectrico.com.ar/web/index.php?option=com_content&view=article&id=3120:plan-de-accion-para-nucleoelectrica-argentina&catid=1:latest-news, accessed 29 July 2021.

1396 - *WNN*, "Construction of CAREM underway", 10 February 2014, see http://www.world-nuclear-news.org/NN-Construction-of-CAREM-underway-1002144.html, accessed 7 May 2021.

1397 - *Agencia TSS*, "CAREM: Reactor en alta tensión", 21 February 2019, see http://www.unsam.edu.ar/tss/carem-reactor-en-alta-tension/, accessed 26 June 2021.

in 2019, Techint Engineering & Construction, the main contractor, halted work, citing late payment from the Government, unanticipated design changes and late delivery of technical documentation. In April 2020, reports suggested that the dispute had been resolved and that work should begin again in May; there is no indication about the impact this would have on project's timeline.[1398] In an April 2021 interview, Hadid M. Subki, nuclear engineer with the IAEA's Department of Nuclear Energy, stated that "CAREM-25 is approaching prototype operation"; however, there is no other evidence to support this assertion.[1399]

Brazil



Brazil operates two nuclear reactors that provided the country with 13.2 TWh or 2.1 percent of its electricity in 2020, less than half of the maximum of 4.3 percent in 2001. The construction of a third reactor was suspended in late 2015.

The first contract for constructing a nuclear power plant, **Angra-1**, was awarded to Westinghouse in 1970. The reactor eventually went critical in 1981 and is licensed to operate until December 2024. But in October 2020, Westinghouse signed a contract to conduct engineering analyses critical to safety, reliability, and long-term operation to be part of the programme to extend its working life until 2044.[1400]

Angra-2 is a large PWR German designed reactor, with a capacity of 1275 MW and was connected to the grid in July 2000, 24 years after construction started.

Preparatory work for the construction of **Angra-3** started in 1984, although it is unclear how much progress was made. In May 2010, Brazil's Nuclear Energy Commission issued a construction license and the IAEA in the Power Reactor Information System (PRIS) records that construction started on 1 June 2010.

In early 2011, the Brazilian national development bank (BNDES) approved a BRL6.1 billion (US$3.6-billion)-loan for work on the project and in November 2013, Eletrobras Eletronuclear signed a €1.25 billion (US$$_{2013}$1.67 billion) contract with French builder AREVA for the completion of the plant.[1401] Commissioning was planned for July 2016 but was delayed to May 2018 in 2015.[1402] However, by February 2016, a deadline of mid-2019 was "already being reevaluated".[1403]

1398 - Dan Yurman, "Argentina Plans To Revive CAREM-25 SMR", *NucNet*, as published on *Energy Central*, 26 April 2020, see https://energycentral.com/c/ec/argentina-plans-revive-carem-25-smr, accessed 26 June 2021.

1399 - *NEI*, "Prospects for small reactors", Interview with Hadid M. Subki, Nuclear Engineer, SMR Technology Development, Department of Nuclear Energy, IAEA, 28 April 2021, see https://www.neimagazine.com/features/featureprospects-for-small-reactors-8707333/, accessed 7 May 2021.

1400 - Westinghouse, "Westinghouse signs Engineering Contract to extend the life of Angra 1", 5 October 2020, see https://www.westinghousenuclear.com/uknuclear/about/news/view/westinghouse-signs-engineering-contract-to-extend-the-life-of-angra-1, accessed 6 October 2020.

1401 - *WNN*, "Areva contracted to complete Angra 3", 8 November 2013, see http://www.world-nuclear-news.org/C-Areva-contracted-to-complete-Angra-3-081134.html, accessed 7 May 2021.

1402 - *NIW*, "Briefs – Brazil", 9 January 2015.

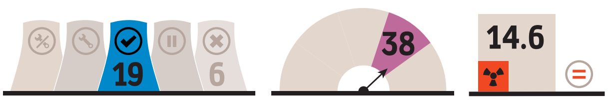
1403 - *NIW*, "Brazil: Politics, Corruption and Finances Grind Angra-3 to a Halt", 19 August 2016.

Over the following years, various government announcements have been made and initiatives launched to re-start the project. In June 2020, the Government approved plans for completing the project, "with or without a partner joining Electronuclear." This is despite the President of Electronuclear suggesting that an additional BRL14.5 billion (US$2.65 billion) of investment would be needed to complete the unit.[1404]

In March 2021, Leonardo Mendes Cabral, director of privatisations at BNDES, said he expects a financing arrangement to finish Unit 3 of the Angra nuclear power plant will be ready by the end of 2022. He said that the Brazilian Government and Electrobras had hired BNDES to develop the project and build it, with an estimated cost of US$3–4 billion.[1405] Meanwhile, Electronuclear has launched a tender with the intention that a contractor will be hired in the second half of 2022, and the nuclear plant is scheduled to come online in November 2026.[1406]

Despite the lack of construction, the project has created political scandals, and even the former Brazilian President Michel Temer has become involved and arrested, along with others, in March 2019, for allegedly diverting BRL1.8 billion (US$475 million) from Eletronuclear's Angra-3 new-build project.[1407] (See also earlier WNISR editions).

Canada



Canada has 19 CANDU (CANada Deuterium Uranium) reactors with a total capacity of 13.5 GW that produced 92.2 TWh and represented 14.6 percent of total electricity generation in 2020. This represents a slight decrease from 94.9 TWh in 2019, or 14.9 percent. Eighteen out of the 19 nuclear reactors are located in the province of Ontario, where nuclear power constituted 33 percent of installed capacity and contributed 60 percent of the electricity generated in 2020.[1408]

Most of Canada's electricity comes from renewable sources. According to Statistics Canada, renewables contributed 66 percent of the total electricity generated in 2020, slightly more than the 2019 share. Renewable electricity is dominated by hydro power, which contributed over 60 percent of all of Canada's electricity generated; of the remaining, wind energy contributed 5.7 percent, and solar energy 0.4 percent.[1409] Over the past decade 2011–2020, Canada's total renewable electricity generating capacity has grown from 82.8 GW to 101.2 GW, with

1404 - Marcela Ayres and Anthony Boadle, "UPDATE 1-Brazil government approves plan to complete third nuclear plant", *Reuters*, 11 June 2020, see https://www.reuters.com/article/brazil-eletrobras-nuclear-idLTAL1N2DN367, accessed 7 May 2021.

1405 - *WNN*, "Brazil to complete Angra 3 finance package in 18 months, says BNDES director", 22 March 2021, see https://www.world-nuclear-news.org/Articles/Brazil-to-complete-Angra-3-finance-package-in-18-m?feed=feed, accessed 22 March 2021.

1406 - *BNAmericas*, "Brazil launches tender to resume Angra 3 nuclear plant works", 26 February 2021, see https://www.bnamericas.com/en/news/brazil-launches-tender-to-resume-angra-3-nuclear-plant-works, accessed 22 March 2021.

1407 - *NIW*, "Brazil: 'Radioactivity' Probe Nets Ex-President; Shoot-Out Near Angra", 22 March 2019.

1408 - IESO, "Power Data – Supply Overview: Transmission-Connected Generation", Independent Electricity System Operator, 2021, see https://ieso.ca/en/Power-Data/Supply-Overview/Transmission-Connected-Generation, accessed 30 May 2021.

1409 - Government of Canada, "Electric power generation, monthly generation by type of electricity", Statistics Canada, Last Modified 7 July 2021, see https://www150.statcan.gc.ca/t1/tbl1/en/tv.action?pid=2510001501, accessed 13 July 2021.

hydropower increasing from 75.4 GW to 80.9 GW, wind from 5.2 GW to 13.6 GW, and solar from 0.5 GW to 3.3 GW.[1410]

Projections by the Canadian Energy Regulator (previously the National Energy Board) expect the nuclear share of total electricity generation decreasing to 10.9 percent in 2040 and to 10.3 percent in 2050 in the reference, or business-as-usual, scenario.[1411] The projection for renewables seems modest, since it foresees wind and solar energy supplying only 13.7 percent of all electricity by 2050 in its reference scenario, despite the rapid increases in these technologies over the past decade. In the "evolving scenario", this fraction goes up to 23.5 percent. Regardless of these percentages, the salient assumption in this projection is that no new reactors are expected to come online and maintaining these fractions will require most of the existing reactors to be refurbished.

There are questions about both of these assumptions, the former because of the ardent promotion of Small Modular Reactor (SMR) technologies (see Chapter on SMRs) by several federal government agencies, and some provincial governments. The assumption about refurbishment will depend on how the current refurbishment projects work out. As of now, only one of the units at the Darlington site (Unit 2) has been refurbished and returned to operational status, albeit with a delay of around four months. The refurbishment of Unit 3 has commenced and, as of May 2021, the feeder tubes in Unit 3 had been removed and preparatory work for the removal of fuel channel assemblies had started.[1412] At the Bruce site, refurbishment of Unit 6 has been ongoing since February 2020, and is "on track" according to Bruce Power.[1413]

A comparison of Ontario's Independent Electricity System Operator (IESO)'s annual planning documents from January 2020 and December 2020 shows a number of delays in projected dates: the refurbishment start date for Darlington-1 has been pushed back from 15 October 2021 to 15 February 2022, and the end date from 15 December 2024 to 18 April 2025; the end date for Darlington-3 is now projected as 2 January 2024, in comparison with the earlier projection of 15 June 2023; and the start date for Darlington-4 from 1 May 2023 to 15 September 2023 and the end date from 31 May 2026 to 16 October 2026.[1414] See Table 19 for details.

Likewise, the projected retirement dates for Pickering-1 and -4 reactors have been delayed from the end of 2022 to the last quarter of 2024 and for Pickering-5 through -8 reactors from the end of 2024 to the end of 2025.[1415] This is despite a major report showing that the Canadian Nuclear

1410 - IRENA, "Renewable Capacity Statistics 2021", International Renewable Energy Agency, March 2021, see https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2021/Apr/IRENA_RE_Capacity_Statistics_2021.pdf, accessed 4 May 2021.

1411 - Canada Energy Regulator/Régie de l'énergie du Canada, "Canada's Energy Futures 2020 Supplement: Electricity", Last Modified 3 March 2021, see https://www.cer-rec.gc.ca/en/data-analysis/canada-energy-future/2020electricity/index.html, accessed 31 May 2021.

1412 - OPG, "Darlington Refurbishment performance update - Q1 2021", Ontario Power Generation, May 2021, see https://www.opg.com/news/darlington-refurbishment-performance-update-q1-2021/, accessed 31 May 2021.

1413 - *WNN*, "Bruce Power marks first year of refurbishment project", 24 February 2021, see https://world-nuclear-news.org/Articles/Bruce-Power-marks-first-year-of-refurbishment-proj, accessed 5 June 2021.

1414 - IESO, "Annual Planning Outlook – Ontario's Electricity System Needs: 2022-2040", December 2020, see https://www.ieso.ca/-/media/Files/IESO/Document-Library/planning-forecasts/apo/Annual-Planning-Outlook-Dec2020.ashx; and IESO, "Annual Planning Outlook – A view of Ontario's electricity system needs", January 2020, see http://www.ieso.ca/-/media/Files/IESO/Document-Library/planning-forecasts/apo/Annual-Planning-Outlook-Jan2020.pdf?la=en, both accessed 1 August 2020.

1415 - Ibidem.

Safety Commission overlooked unexpected results from inspections of the station's pressure tubes that seemed inexplicable, raising safety concerns.[1416]

Table 19 – Status of Canadian Nuclear Fleet - PLEX and Expected Closures

Reactor	Operator	Grid Connection	Refurbishment[(a)]	Planned Closure[(b)]	Licensed to[(c)]
Bruce-1	Bruce	1977	Restarted in 2012	2064	2028
Bruce-2		1976	Restarted in 2012		
Bruce-3		1977	01/01/23–30/06/26		
Bruce-4		1978	01/01/25–31/12/27		
Bruce-5		1984	01/07/26–30/06/29		
Bruce-6		1984	17/01/20–05/11/23		
Bruce-7		1986	01/07/28–30/06/31		
Bruce-8		1987	01/07/30–30/06/33		
Darlington-1	OPG	1990	15/02/22–18/04/25	2055	2025
Darlington-2		1990	10/16–06/20[(d)]		
Darlington-3		1992	30/07/20–02/01/24		
Darlington-4		1993	15/09/23–16/10/26		
Pickering-1	OPG	1971		30/09/2024[(e)]	2028[(f)]
Pickering-4		1973		13/12/2024[(e)]	
Pickering-5		1982		31/12/2025[(e)]	
Pickering-6		1983		31/12/2025[(e)]	
Pickering-7		1984		31/12/2025[(e)]	
Pickering-8		1986		31/12/2025[(e)]	
Point Lepreau	NB Power	1982	03/2008–03/2012	2039–2040[(g)]	2022

Sources: Compiled by WNISR, from IESO, Operators, CNSC, 2021

Notes:

OPG = Ontario Power Generation

(a) - IESO, "Annual Planning Outlook - A view of Ontario's electricity system needs", January 2020, see http://www.ieso.ca/-/media/Files/IESO/Document-Library/planning-forecasts/apo/Annual-Planning-Outlook-Jan2020.pdf?la=en, accessed 1 August 2020,
Updated with IESO, "Annual Planning Outlook - Ontario's electricity system needs: 2022-2040", December 2020, see https://www.ieso.ca/-/media/Files/IESO/Document-Library/planning-forecasts/apo/Annual-Planning-Outlook-Dec2020.ashx, accessed 12 June 2021.

(b) - As announced by operator.

(c) - As listed on Canadian Nuclear Safety Commission's (CNSC) website for each station.
Bruce: https://www.cnsc-ccsn.gc.ca/eng/reactors/power-plants/nuclear-facilities/bruce-nuclear-generating-station/index.cfm;
Darlington: https://www.cnsc-ccsn.gc.ca/eng/reactors/power-plants/nuclear-facilities/darlington-nuclear-generating-station/index.cfm;
Pickering: https://www.cnsc-ccsn.gc.ca/eng/reactors/power-plants/nuclear-facilities/pickering-nuclear-generating-station/index.cfm;
Point Lepreau: https://www.cnsc-ccsn.gc.ca/eng/reactors/power-plants/nuclear-facilities/point-lepreau-nuclear-generating-station/index.cfm.

(d) - Refurbishment of Darlington-2 was completed in June 2020, with the reactor being reconnected to the grid on 2 June 2020. OPG, "Darlington Unit 2 powers on—Refurbishment now complete on first unit", 4 June 2020, see https://www.opg.com/news/darlington-unit-2-powers-on/, accessed 28 July 2020.

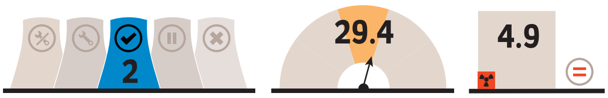
(e) - Pickering Units 1 and 4 are expected to be closed in 2024, and Units 5–8 in 2025. OPG, "The future of Pickering Generating Station", OPG, n.d., see https://www.opg.com/powering-ontario/our-generation/nuclear/pickering-nuclear-generation-station/future-of-pickering/, accessed 12 June 2021.

(f) - The Pickering Power Plan is licensed to 2028 but operation beyond 2024 would require additional authorizations, CNSC, "Pickering Nuclear Generating Station", Updated 14 July 2021, see https://nuclearsafety.gc.ca/eng/reactors/power-plants/nuclear-facilities/pickering-nuclear-generating-station/index.cfm?pedisable=true.

(g) - NB Power, "NB Power's 10-Year Plan - Fiscal Years 2021 to 2030", September 2019, see https://www.nbpower.com/media/1489656/10-year-plan-2021-to-2030.pdf, accessed 13 May 2020, updated with NB Power, "Integrated Resource Plan", November 2020, see https://www.nbpower.com/media/1490323/2020-irp-en-2020-11-17.pdf, accessed July 2021.

1416 - Matthew McClearn, "Canada's nuclear regulator overlooked dubious data when renewing Pickering plant's licence, documents show", *The Globe and Mail*, 23 March 2021.

Mexico



In Mexico, two General Electric (GE) reactors operate at the Laguna Verde power plant, located in Alto Lucero, Veracruz. The first unit was connected to the grid in 1989 and the second unit in 1994. In 2020, nuclear power generation produced a stable 10.9 TWh providing 4.9 percent (+0.4 percentage points) of the country's electricity. The power plant is owned and operated by the state utility Federal Electricity Commission (Comisión Federal de Electricidad - CFE).

CFE has requested that the units be granted a 30-year lifetime extension to enable each unit to operate for a total of 60 years.[1417] It was stated that each 1.4 GW-unit would cost US$7 billion to refurbish.[1418] In March 2019, the IAEA completed a long-term operational safety review of the plant and made recommendations as part of the process to extend the operating lives of the reactors. The license renewal was granted in July 2020 to enable operation of Unit 1 until July 2050.[1419]

Press reports[1420] continually record problems, often age-related, at the Laguna Verde plant, including an emergency shutdown (a scram) in January 2021 and leaks from the diesel generators. Between 2012 and 2020, the Laguna Verde recorded 33 unusual events, according to data from the CFE.[1421]

In December 2019, it was reported that CFE was considering the construction of an additional four reactors, two at the existing site at Laguna Verde—an idea that has been around for years, without any follow-up—and two on the Pacific coast.

United States

See Focus Countries – United States Focus.

ASIA & MIDDLE EAST

China

See Focus Countries – China Focus.

1417 - *NEI*, "IAEA reviews long term operation of Mexico's Laguna Verde", 25 March 2019, see https://www.neimagazine.com/news/newsiaea-reviews-long-term-operation-of-mexicos-laguna-verde-7057990/, accessed 7 May 2021.

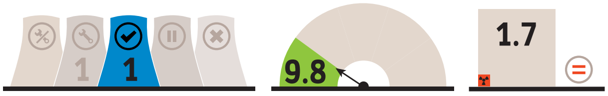
1418 - *Forbes Mexico*, "4 nuclear reactors under consideration by electricity commission", *Mexico News Daily*, 11 December 2019.

1419 - Secretaría de Energía, "La Secretaría de Energía renueva la licencia de operación a Unidad 1 de la Central Nuclear Laguna Verde", 17 July 2020, see http://www.gob.mx/sener/articulos/la-secretaria-de-energia-renueva-la-licencia-de-operacion-a-unidad-1-de-la-central-nuclear-laguna-verde?idiom=es, accessed 7 May 2021.

1420 - *El Universal*, "Laguna Verde: could a nuclear accident put Mexico at risk of becoming the next Chernobyl?", *The Yucatan Times*, 9 April 2021, see https://www.theyucatantimes.com/2021/04/laguna-verde-could-a-nuclear-accident-put-mexico-at-risk-of-becoming-the-next-chernobyl/, accessed 26 June 2021.

1421 - Eddie Corp, "The damage cornered the Laguna Verde nuclear plant | Economy", *Digis Mak*, 1 February 2021, see https://digismak.com/the-damage-cornered-the-laguna-verde-nuclear-plant-economy/, accessed 26 June 2021.

Iran



In 2011, Iran started up the first nuclear power reactor in the Middle East, the 915-MW Bushehr-1, which became operational, 34 years after construction began. Construction on one other reactor, Bushehr-2, has restarted in November 2019.

In 2020, Bushehr-1 generated 5.8 TWh of electricity, this compares with 5.9 TWh in 2019, and is 1.7 percent of the total electricity generated in Iran, compared with 1.8 percent in 2019.

Until Bushehr-2 comes online, the nuclear share is expected to decline as Iran ramps up its capacity of other sources to meet increasing electricity demand. Despite Iran's heavy economic and political investments in the nuclear program, nuclear power contributes less than 2 percent to the country's electricity generating capacity and production.

Compared to other countries in the region, Iran went beyond the mere goal of acquiring nuclear power reactors by investing in nuclear fuel chain activities such as uranium mining, enrichment and fuel manufacturing. Although Iran possesses the capabilities to produce its own enriched uranium, under the restrictions of the Joint Comprehensive Plan of Action (JCPOA) it was not supposed to exceed Low Enriched Uranium (LEU) levels. On 13 April 2021, Iran announced that it was proceeding with plans to enrich uranium to 60 percent (U-235), which exceeds the 20 percent threshold and is classified as Highly Enriched Uranium (HEU).[1422] It remains to be seen what happens now with the agreement following the election of U.S. President Biden and attempts to secure the survival of the JCPOA.

Beyond Bushehr-1, in November 2014, Iran's Nuclear Power Production and Development Co. (NPPD) and Rosatom subsidiary Atomstroyexport signed a contract to restart and complete construction of Bushehr-2 and -3. The Atomic Energy Organization of Iran (AEOI) projected that Units 2 and 3 would be completed within a 10-year timeline and cost around US$10 billion.[1423]

In terms of the second reactor at Bushehr, new basemat concrete for the reactor building was poured on 10 November 2019, according to the AEOI.[1424] Excavation for this foundation started on 31 October 2017. Iranian authorities and Rosatom stated that Bushehr-2 and -3 are to be completed in 2024 and 2026 respectively.[1425]

Unit 2 was part of the original construction work on the Bushehr plant, which started in 1976. In fact, in 1994, the IAEA still listed both Units 1 and 2 as "under construction".[1426] The NPDD-Atomstroyexport contract signed in November 2014, included the design and construction as

1422 - Robert E Kelly, "Why is Iran producing 60 per cent-enriched uranium?", SIPRI, 27 April 2021, see https://www.sipri.org/commentary/essay/2021/why-iran-producing-60-cent-enriched-uranium, accessed 19 July 2021.

1423 - Darrell Proctor, "Iran Expands Plans for Nuclear Power", *POWER Magazine*, 1 May 2019, see https://www.powermag.com/iran-expands-plans-for-nuclear-power/, accessed 13 April 2020.

1424 - AEOI, "Concrete pouring of the Second unit of nuclear power plant held in Bushehr", 11 December 2019, see https://aeoi.org.ir/en/portal/home/?news/45799/69280/294254/concrete-pouring-of-the-second-unit-of-nuclear-power-plant-held-in-bushehr, accessed 19 July 2021.

1425 - *WNN*, "Rosatom committed to Iranian plant project", 9 May 2019, see https://world-nuclear-news.org/Articles/Rosatom-committed-to-Iranian-plant-project, accessed 19 July 2021.

1426 - WNISR, "Iran: Construction Restart of Busheer-2", World Nuclear Industry Status Report, 14 November 2019, see https://www.worldnuclearreport.org/Iran-Construction-Restart-of-Busheer-2.html, accessed 19 July 2021.

well as commencing operations of the two units, each with a capacity of 1057 MW electricity output. The reactor design for Unit 2 is the VVER V-446.

In 2016, Ali Akbar Salehi, Head of the AEOI, mentioned negotiations with China to build two more power plants in Darkhovain and on the Makran coast.[1427] Since then, however, there has been no progress reported on these plans and their schedule, which are likely to be delayed further given the current economic and political environment. It is unclear whether a recent bilateral agreement between China and Iran will eventually lead to additional nuclear plant construction.[1428]

Bushehr Shutdown

On 20 June 2021, the AEOI announced the emergency shutdown of Bushehr-1 due to a technical defect. No further details were provided at that time.[1429] On 22 June 2021, the International Atomic Energy Agency (IAEA) announced that it had been informed by the AEOI that a technical problem occurred in the electrical generator of the plant, and after resolving it, the plant will be reconnected to the national electricity grid.[1430] On 23 June 2021, the *Noor News* website, which is close to Iran's National Security Council, reported a "sabotage operation" against one of Iran's nuclear energy buildings.[1431] Iran's *Press TV* network quoted a security source as "The sabotage attack on a building of the Atomic Energy Organization of Iran has been thwarted."[1432]

The director of the AEOI, Ali Akbar Salehi, noted on 26 June 2021 that because of U.S. sanctions imposed on Iran after the U.S. withdrew from the JCPOA, Iran has not been able to pay Russia 500 million euros [US$$_{2021}$597 million] it owes for two other power plants under construction and the fuel for the Bushehr power plant but that it would be paid.[1433]

The shutdown of Bushehr occurred when electricity demand was exceeding supply capacity by about 11,000 MW, forcing Tehran to impose unannounced power cuts for hours at a time when the need for air conditioning soars amid temperatures hitting close to 50 degrees Celsius on a daily basis.[1434]

1427 - *Tasnim News Agency*, "China to Build 2 Nuclear Power Plants in Iran: AEOI Chief", 19 January 2016, see https://www.tasnimnews.com/en/news/2016/01/19/975906/china-to-build-2-nuclear-power-plants-in-iran-aeoi-chief, accessed 19 July 2021.

1428 - Farnaz Fassihi and Steven Lee Myers, "China, With $400 Billion Iran Deal, Could Deepen Influence in Mideast", *The New York Times*, 27 March 2021, see https://www.nytimes.com/2021/03/27/world/middleeast/china-iran-deal.html, accessed 19 July 2021.

1429 - AEOI, "[illegible]", Press Release, 20 June 2021, see https://www.aeoi.org.ir, accessed 19 July 2021.

1430 - IAEA, "Iran says temporary shutdown of Bushehr NPP due to technical problem in electrical generator", 22 June 2021, see https://www.iaea.org/newscenter/pressreleases/iran-says-temporary-shutdown-of-bushehr-npp-due-to-technical-problem-in-electrical-generator, accessed 19 July 2021.

1431 - Cyrus Yaqubi, "Iran: What Is Behind Bushehr Nuclear Power Plant Shutdown? – OpEd", *Eurasia Review*, 24 June 2021, see https://www.eurasiareview.com/24062021-iran-what-is-behind-bushehr-nuclear-power-plant-shutdown-oped/, accessed 19 July 2021.

1432 - Ibidem.

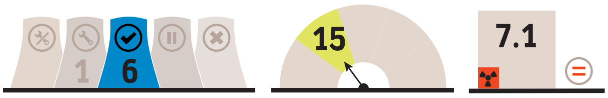
1433 - *Iran International*, "Iran Ready To Pay 500 Million Euro Debt To Russia For Nuclear Reactor", 27 June 2021, see https://iranintl.com/en/world/iran-ready-pay-500-million-euro-debt-russia-nuclear-reactor, accessed 19 July 2021.

1434 - Aresu Eqbali and Claudia Carpenter, "Iran's summer of power cuts could be worst yet with new capacity on hold", *S&P Global*, 14 July 2021, see https://www.spglobal.com/platts/en/market-insights/latest-news/oil/071421-feature-irans-summer-of-power-cuts-could-be-worst-yet-with-new-capacity-on-hold, accessed 19 July 2021.

On 3 July 2021, state-run power company TAVANIR announced that Bushehr-1 had restarted.[1435]

Saudi Arabia has in the past raised concerns that potential radioactive leakage from the Bushehr plant could endanger the Gulf, including air, food and water supplies. Saudi Arabia, the UAE and other Gulf Cooperation Council (GCC) states have voiced their concerns about Bushehr's safety on various occasions, especially after earthquakes.[1436] In March 2020, Kazem Gharibabadi, Iran's ambassador to the Vienna-based international organizations, dismissed the Saudi concern as an attempt to politicize technical issues and maintained that the plant is meeting international safety standards.[1437] Gharibabadi pointed to the IAEA's Integrated Regulatory Review Service (IRRS) mission at Bushehr in February and March 2020, the result of which was "satisfactory", adding that the IAEA delegation concluded that "Iran's nuclear safety system has the competence and capability to monitor nuclear activities".[1438]

Pakistan



Pakistan operates six nuclear reactors with a combined capacity of 2.3 GW. This includes Kanupp-2, which was connected to the grid in March 2021 and is the first Hualong-One reactor to become operational outside of China.[1439] The sister unit, Kanupp-3, is scheduled for operation in the first quarter of 2022.[1440] Nuclear electricity production in Pakistan has increased slightly from 2019 to 2020, from 9 TWh to 9.6 TWh, with the share of electricity from nuclear power plants increasing from 6.6 percent to 7.1 percent. Both values are new records for Pakistan.

Kanupp-2 and Kanupp-3 are supplied by the China National Nuclear Corporation (CNNC) on a turnkey basis and will be operated by the Pakistan Atomic Energy Corporation (PAEC).[1441] Costs of these two reactors have been reported as being around US$10 billion.[1442] These have contributed to Pakistan's major debt problem, which has in turn afflicted the country's power sector.[1443]

1435 - *Reuters*, "Iran restarts Bushehr nuclear power plant after overhaul-state media", 3 July 2021, see https://www.reuters.com/world/middle-east/iran-restarts-bushehr-nuclear-power-plant-after-overhaul-state-media-2021-07-03/, accessed 19 July 2021.

1436 - Elizabeth Dickinson, "UAE and Saudi Arabia call on Iran to allay nuclear plant fears", *The National*, 7 June 2013, see https://www.thenational.ae/world/mena/uae-and-saudi-arabia-call-on-iran-to-allay-nuclear-plant-fears-1.478749; and Amir Taheri, "Iran Earthquake Raises Concern over Nuclear Plant", *Asharq AL-awsat*, 16 November 2017, see https://english.aawsat.com/home/article/1085541/iran-earthquake-raises-concern-over-nuclear-plant, both accessed 19 July 2021.

1437 - *Tehran Times*, "Iran dismisses Saudi claims over safety at Bushehr plant", 10 March 2020, see https://www.tehrantimes.com/news/445953/Iran-dismisses-Saudi-claims-over-safety-at-Bushehr-plant, accessed 19 July 2021.

1438 - Ibidem.

1439 - WNISR, "Grid Connection of Chinese Reactor in Pakistan", World Nuclear Industry Status Report, 20 March 2021, see https://www.worldnuclearreport.org/Grid-Connection-of-Chinese-Reactor-in-Pakistan.html, accessed 29 May 2021.

1440 - *The News*, "PM Imran Khan inaugurates 1,100 MW Chinese-built nuclear power plant", 21 May 2021, see https://www.thenews.com.pk/latest/837916-pm-imran-khan-inaugurates-1100-mw-chinese-built-nuclear-power-plant, accessed 24 May 2021.

1441 - WNISR, "Grid Connection of Chinese Reactor in Pakistan", March 2021, op. cit.

1442 - Ayaz Gul, "Pakistan's China-Built Nuclear Reactor Starts Operation", *Voice of America*, 19 May 2021, see https://www.voanews.com/south-central-asia/pakistans-china-built-nuclear-reactor-starts-operation, accessed 24 May 2021.

1443 - Vaishali Basu Sharma, "As Pakistan's Energy Crisis Worsens, Have Chinese Investments Failed Islamabad?", *The Wire*, 2 June 2020, see https://thewire.in/south-asia/pakistan-energy-crisis-cpec, accessed 24 May 2021.

PAEC appears to be exploring the possibility of building further Hualong One reactors at Chashma, the second nuclear power plant site in the country.[1444] This site already hosts four Chinese designed CNP-300 reactors. The longer-term goal is to expand nuclear energy to reach a total capacity of 8.8 GW by 2030.

In parallel, Pakistan has been rapidly expanding its renewable energy capacity. Over the past decade, total renewable capacity in Pakistan has grown from 7 GW in 2011 to just under 12.4 GW in 2020. Wind and solar capacity have grown from around 0.06 GW and 0.02 GW in 2011 to 1.2 GW and 0.7 GW respectively in 2020. Although 2020 saw very little increase in capacity, Prime Minister Imran Khan has called for the country to produce 60 percent of its electrical power from renewable sources by 2030.[1445]

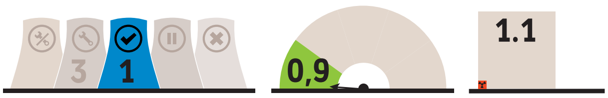
South Korea

See Focus Countries – South Korea Focus.

Taiwan

See Focus Countries – Taiwan Focus.

United Arab Emirates



The United Arab Emirates (UAE) was the first Arab country to establish a nuclear power program. The Emirates Nuclear Energy Corporation (ENEC) was founded in 2009 and, in December of that year, signed a US$20 billion contract with the Korea Electric Power Corporation (KEPCO) to build four APR-1400 reactors at Barakah, in the Al Dhafra region of Abu Dhabi.[1446] The four units have a total generation capacity of 5.6 GW. Nawah Energy company, the nuclear energy plant operator in UAE, was established in 2016; ENEC owns 82 percent of the company while KEPCO owns the remaining 18 percent. On behalf of Nawah, ENEC applied for operating licenses for the first two units for Barakah in 2015.

According to plans from 2010, construction was to start in 2012 at a rate of one reactor per year, and for the four units to start commercial operations at a rate of one reactor per year starting in 2017.[1447] But, as has been the case with nuclear projects around the world, the project has been delayed, and that despite the UAE's immense financial resources and access to global expertise. The first nuclear unit entered commercial operation only in April 2021, four years

1444 - *APP*, "PAEC to enhance nuclear energy share to 8,800 MW by 2030", *The Nation*, 12 June 2020, see https://nation.com.pk/12-Jun-2020/paec-to-enhance-nuclear-energy-share-to-8-800-mw-by-2030, accessed 24 May 2021.

1445 - Zofeen T. Ebrahim, "Pakistan faces an unexpected dilemma: too much electricity", *Reuters*, 24 February 2021, see https://www.reuters.com/article/us-pakistan-energy-climate-change-featur-idUSKBN2AO27C, accessed 24 May 2021.

1446 - *WNN*, "Construction under way at Barakah", 19 July 2012, see https://www.world-nuclear-news.org/Articles/Construction-under-way-at-Barakah, accessed 1 August 2021.

1447 - WNISR, "Barakah, UAE: Grid Connection of First Commercial Reactor in the Arab World", 21 August 2021, see https://www.worldnuclearreport.org/Barakah-UAE-Grid-Connection-of-First-Commercial-Reactor-in-the-Arab-World.html, accessed 1 August 2021.

later than planned.[1448] It had earlier been connected to the grid in August 2020 and reached full power in December 2020.[1449]

As discussed in earlier WNISR editions, the delays are due to four main factors: challenges in establishing and training a domestic workforce; the discovery of voids in the containment buildings of Units 2 and 3; delays in commissioning reactors in South Korea; and quality assurance scandals within South Korea's nuclear industry. Construction of Unit 2 was completed in July 2020 and a 60-year operating license was issued for the unit in March 2021.[1450] As of that date, construction of Units 3 and 4 are said to be 94 percent and 87 percent complete, respectively.[1451]

The Barakah project is financed through a joint venture agreement between KEPCO and ENEC. The 2009 announcement by ENEC included the statement that the "value of the contract for the construction, commissioning and fuel loads for four units equaled approximately US$20 billion, with a high percentage of the contract being offered under a fixed-price arrangement".[1452] By 2018, as the project was getting seriously delayed, the cost estimate went up to US$24.4 billion.[1453] There is no publicly available revision of the full cost following the first unit getting completed.

Construction of the Barakah nuclear plant has raised a number of different concerns for the region.[1454] In December 2017, a Houthi rebel group from Yemen claimed to have launched a missile at Barakah; the claim has not been supported by evidence and UAE officials have denied the news.[1455] A different concern was expressed in a 2019-letter from Qatar's Foreign Affairs ministry to the IAEA Director General Yukiya Amano: "Qatar believes that the lack of any international co-operation with neighboring states regarding disaster planning, health and safety and the protection of the environment pose a serious threat to the stability of the region and its environment".[1456]

1448 - *WNN*, "UAE's first nuclear unit starts commercial operation", 6 April 2021, see https://www.world-nuclear-news.org/Articles/UAE-s-first-nuclear-unit-starts-commercial-operati, accessed 12 April 2021.

1449 - *WNN*, "First UAE nuclear reactor reaches full power", 7 December 2020, see https://www.world-nuclear-news.org/Articles/First-UAE-nuclear-reactor-reaches-full-power.

1450 - *WNN*, "UAE completes construction of Barakah 2", 15 July 2020, see https://www.world-nuclear-news.org/Articles/UAE-completes-construction-of-Barakah-unit-2; and *WNN*, "UAE regulator issues second Barakah operating licence", 9 March 2021, see https://www.world-nuclear-news.org/Articles/UAE-regulator-issues-second-operating-licence, both accessed 1 August 2021.

1451 - *WNN*, "UAE Regulator Issues Second Barakah Operating Licence", 9 March 2021, see https://world-nuclear-news.org/Articles/UAE-regulator-issues-second-operating-licence, accessed 1 August 2021.

1452 - ENEC, "UAE Selects Korea Electric Power Corp, as Prime Team as Prime Contractor for Peaceful Nuclear Power", Emirates Nuclear Energy Corporation, 27 December 2009, see https://www.enec.gov.ae/news/uae-selects-korea-electric-power-corp-as-prime-team-as-prime-contractor-fo/, accessed 22 April 2018.

1453 - *Reuters*, "UAE's first nuclear reactor delayed until 2019", as published on *Gulf Business*, 22 March 2018, see http://gulfbusiness.com/uaes-first-nuclear-reactor-delayed-2019/, accessed 23 March 2018.

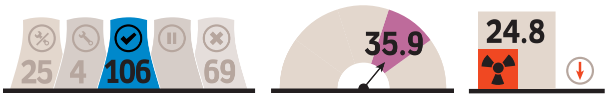
1454 - Patricia Sabga, "Nuclear Gulf: Experts sound the alarm over UAE nuclear reactors", *Al Jazeera*, 15 July 2020, see https://www.aljazeera.com/ajimpact/nuclear-gulf-experts-sound-alarm-uae-nuclear-reactors-200628194524692.html, accessed 14 July 2020.

1455 - Ali Ahmad, "A Yemeni rebel claim highlights the risk of nuclear power in the Middle East", *Bulletin of the Atomic Scientists*, 12 August 2017, see https://thebulletin.org/2017/12/a-yemeni-rebel-claim-highlights-the-risk-of-nuclear-power-in-the-middle-east/.

1456 - Geert De Clercq, "Exclusive: Qatar asks IAEA to intervene over 'threat' posed by UAE nuclear plant", *Reuters*, 20 March 2019, see https://www.reuters.com/article/us-qatar-emirates-nuclearpower-exclusive/exclusive-qatar-asks-iaea-to-intervene-over-threat-posed-by-uae-nuclear-plant-idUSKCN1R120L, accessed 9 April 2019.

Meanwhile, UAE has been increasing its renewable generation capacity rapidly. Total capacity went from 0.6 GW in 2018 to 2.5 GW in 2020, almost entirely composed of solar energy.[1457] This is expected to rise to 9 GW by the end of 2025.[1458] According to UAE's "Energy Strategy 2050", the country aims to increase the contribution of low-carbon energy in the country's primary energy mix to 50 percent, out of which 44 percent to be derived from renewables and 6 percent from nuclear power.[1459]

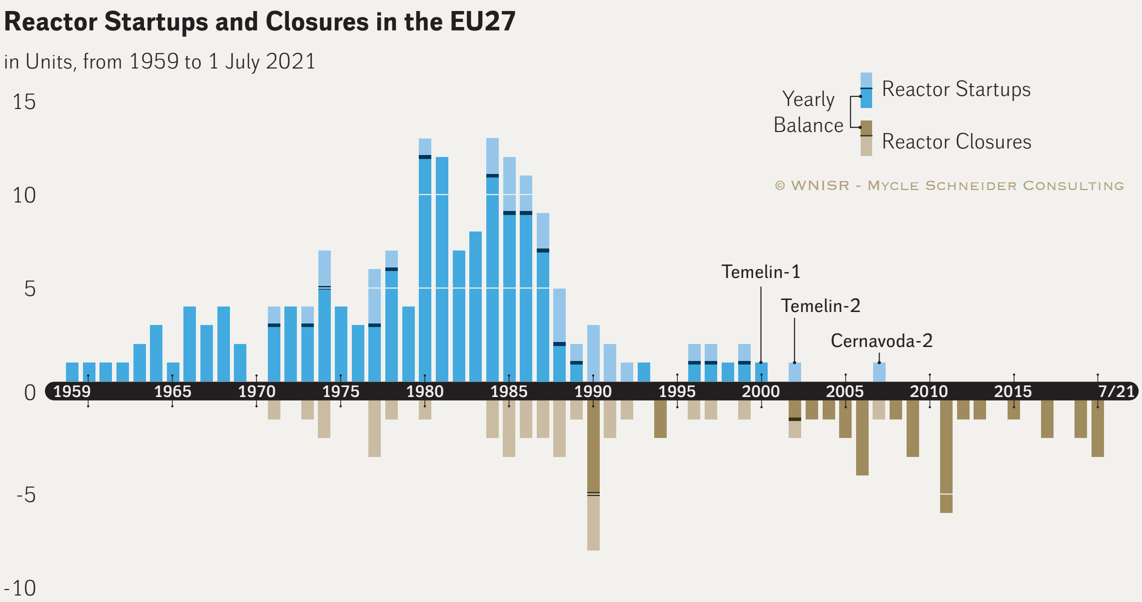
EUROPEAN UNION (EU27)



The EU27 member states have gone through three nuclear construction waves (see Figure 68)—two small ones in the 1960s and the 1970s and a larger one in the 1980s (mainly in France).

But since then, in thirty years, only 14 reactors were connected to the EU27-grid, half of them in France, the rest in Eastern and Central Europe. Only two reactors were started-up over the past 20 years, all in Eastern Europe (one each in the Czech Republic and Romania). Since Cernavoda-2 was connected to the grid in Romania in 2007, no other reactor was started up, but 20 reactors were permanently closed.

Figure 68 · Nuclear Reactors Startups and Closures in the EU27 1959–1 July 2021



Sources: WNISR, with IAEA-PRIS, 2021

1457 - IRENA, "Renewable Capacity Statistics 2021", International Renewable Energy Agency, March 2021, see https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2021/Apr/IRENA_RE_Capacity_Statistics_2021.pdf, accessed 4 May 2021.

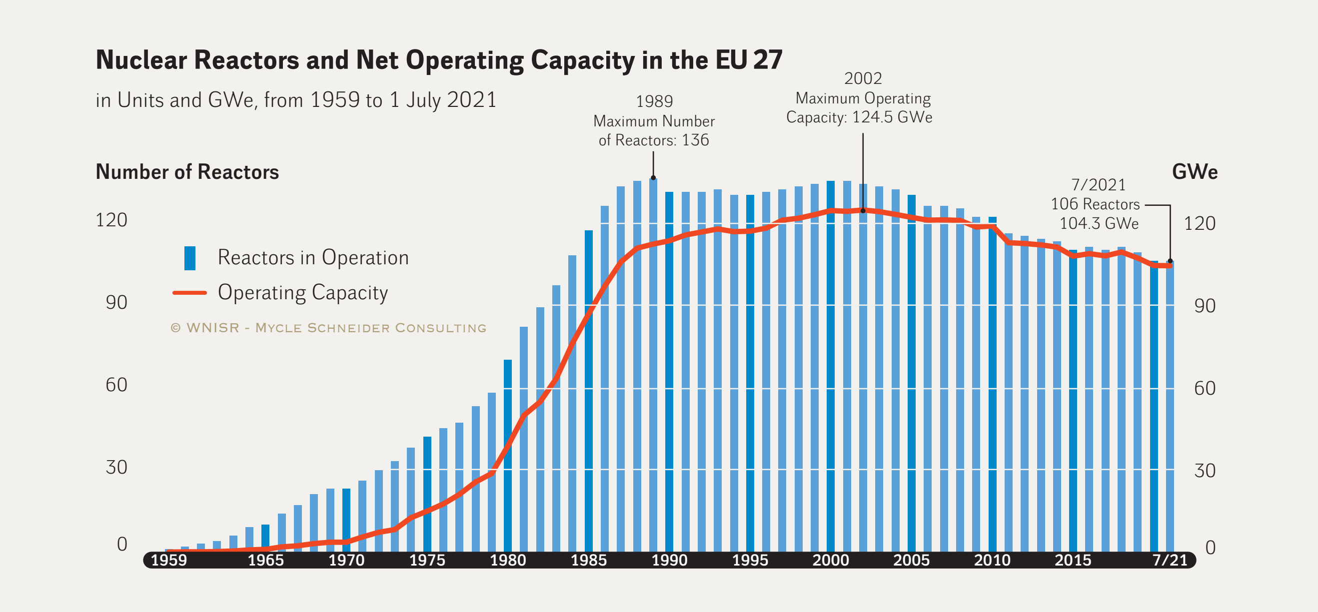
1458 - Rystad Energy, "It's raining solar panels in the UAE: Renewable capacity set to increase fourfold to 9 GW by end-2025", Press Release, 9 February 2021, see https://www.rystadenergy.com/newsevents/news/press-releases/its-raining-solar-panels-in-the-uae-renewable-capacity-set-to-increase-fourfold-to-9-gw-by-end-2025/, accessed 8 May 2021.

1459 - United Arab Emirate Government, "UAE Energy Strategy 2050", 1 May 2021, see https://u.ae/en/about-the-uae/strategies-initiatives-and-awards/federal-governments-strategies-and-plans/uae-energy-strategy-2050, accessed 10 May 2021.

There are only four reactors under construction, two in Slovakia (since 1985) and one each in France (since 2007) and Finland (since 2005).

As Figure 69 shows, 106 reactors are operating in the EU27 as of 1 July 2021, thirty less than the historic maximum of 136 units in 1989. The vast majority of the operating facilities, 87 units or over 80 percent, are located in seven of the western countries—with 56 units, over half, in France alone—and only 19 in the six newer member states with nuclear power.

Figure 69 · Nuclear Reactors and Net Operating Capacity in the EU27



Sources: WNISR, with IAEA-PRIS, 2021

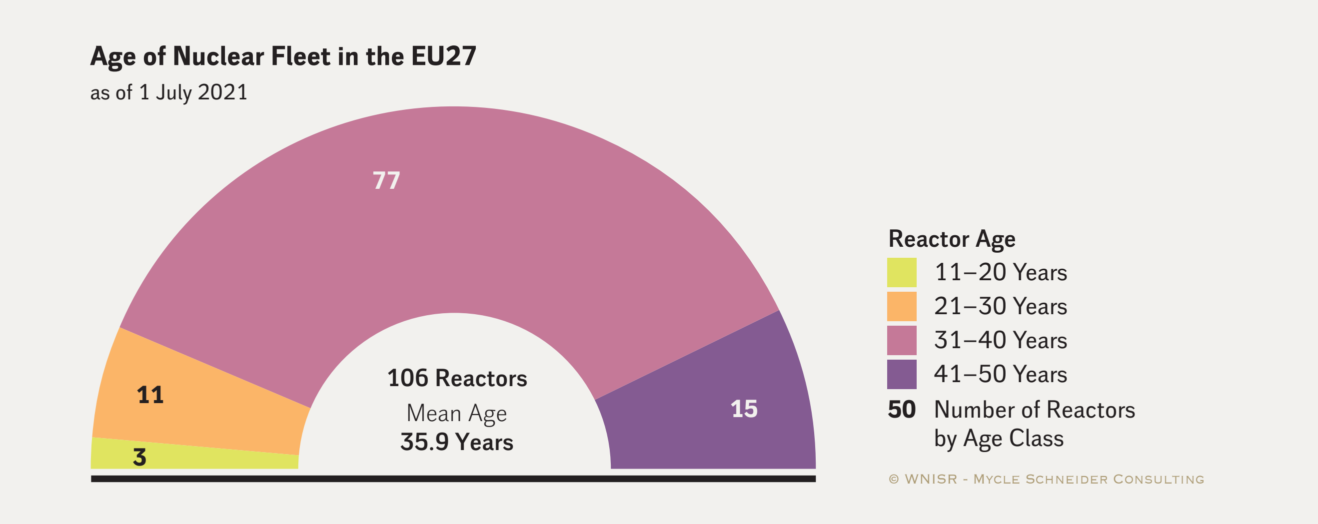
In the EU27, in 2020, nuclear plants have generated 652 TWh, an 11-percent decrease compared to the previous year. While the nuclear share in net power production is not yet available from IAEA-PRIS or Eurostat, BP indicates a 24.8 percent share in gross generation (26.4 percent in 2019).[1460]

In the absence of any significant delivering new-build program, the average age of nuclear power plants keeps increasing and at mid-2021 stands at 36 years (see Figure 70). The age distribution shows that now over 86 percent—92 of 106—of the EU's operating nuclear reactors have been in operation for 31 years and beyond.

The closure of Ringhals-1, in December 2020, brings the number of permanently closed reactors in the EU27 to 69 (60 in Western Europe, of which half in Germany).

1460 - BP, "Statistical Review of World Energy – Statistical Workbook", July 2021, op. cit.

Figure 70 · Age Distribution of the EU27 Reactor Fleet



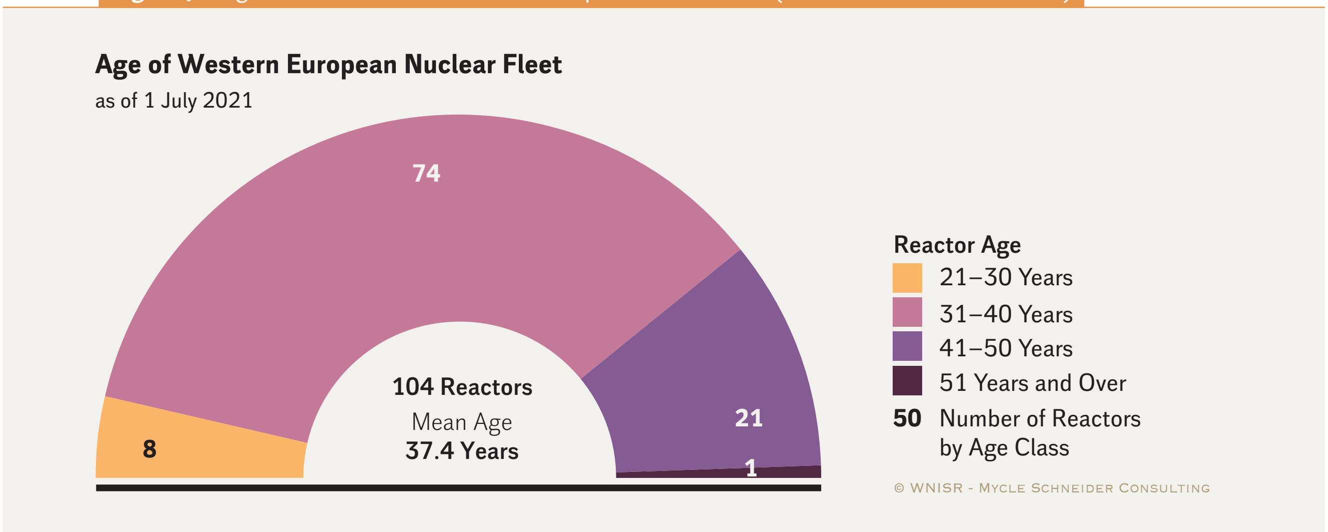
Sources: WNISR, with IAEA-PRIS, 2021

WESTERN EUROPE

As of 1 July 2021, 104 nuclear power reactors operated in Western Europe (including U.K. and Switzerland), 56 units fewer than in the peak years 1988/89. In WNISR2020, the U.K. had three reactors in LTO: one was restarted since and two have been permanently closed. One reactor was closed in the EU27, Ringhals-1 in Sweden in the second half-year of 2020.

With the U.K. and Switzerland operating respectively four and three reactors over 41 years old— one of which the 51-year-old Beznau reactor—the average age of operating reactors in Western Europe reaches 37.4 years (see Figure 71).

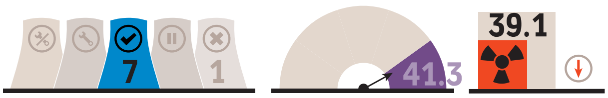
Figure 71 · Age Distribution of the Western European Reactor Fleet (incl. Switzerland and the U.K.)



Sources: WNISR, with IAEA-PRIS, 2021

Four reactors are currently under construction, two in the U.K (Hinkley Point C-1 and C-2) and one each in Finland (Olkiluoto-3) and France (Flamanville-3). All are European Pressurized Water Reactors (EPR) and all are many years behind their initial schedule and billions of Euros over budget (details are discussed in other chapters of the report).

Belgium



In 2020, nuclear electricity generation continued the fluctuations it has been undergoing over the past decade, dropping 21 percent after recovering with a 52-percent increase in 2019 after a particularly poor performance in 2018. In the first half of 2021, availability of nuclear has increased by half over the first semester 2020. Thus, the oscillating pattern seems to continue.

Belgium operates seven pressurized-water reactors that have generated 32.8 TWh in 2020, about one third below the maximum of 46.7 TWh reached in 1999. Nuclear power contributed 39.1 percent of Belgium's electricity in 2020, a drop of 8.5 percentage points over 2019, while the maximum was 67.2 percent in 1986.

The average age of the Belgian fleet is 41.3.

Legally the country remains bound to a nuclear phase-out target of 2025. In January 2003, legislation was passed that requires the closure of all of Belgium's nuclear plants after 40 years of operation, so based on their startup dates, plants would be closed progressively between 2015 and 2025 (see Table 20). Practically, however, after lifetime extension to 50 years was granted for three reactors, five of the seven reactors would go offline in the single year of 2025. This represents an increasingly challenging policy goal.

The Belgian government confirmed the nuclear phase-out date when on 30 March 2018 it presented the federal energy strategy.

Table 20 – Belgian Nuclear Fleet (as of 1 July 2021)

Reactor	Net Capacity (MW)	Grid Connection	Operating Age (as of 1 July 2021)	End of License (Latest Closure Date)
Doel-1	433	28/08/1974	46.8	10-year lifetime extension to 15 February 2025
Doel-2	433	21/08/1975	45.9	10-year lifetime extension to 1 December 2025
Doel-3	1 006	23/06/1982	39.0	1 October 2022
Doel-4	1 038	08/04/1985	36.2	1 July 2025
Tihange-1	962	07/03/1975	46.3	10-year lifetime extension to 1 October 2025
Tihange-2	1 008	13/10/1982	38.7	1 February 2023
Tihange-3	1 038	15/06/1985	36.0	1 September 2025

Sources: WNISR, 2021; Belgian Law of 28 June 2015; Electrabel/GDF-Suez, 2015[1461]

1461 - *Moniteur Belge*, "Loi modifiant la loi du 31 janvier 2003 sur la sortie progressive de l'énergie nucléaire à des fins de production industrielle d'électricité afin de garantir la sécurité d'approvisionnement sur le plan énergétique", N.174, Second Edition, 6 July 2015 (in French and Dutch), see http://www.ejustice.just.fgov.be/mopdf/2015/07/06_2.pdf.
• For Doel-1&-2, see Electrabel, GDF Suez/Engie, "Note de Presse—Sécurité d'approvisionnement et transition énergétique—Accord sur la prolongation de Doel 1 et Doel 2", Press Release,1 December 2015 (in French) and Engie Electrabel, "Doel Nuclear Power Plant—Profile of the 4 units", Updated 7 August 2017, see http://corporate.engie-electrabel.be/local-player/nuclear-3/doel;
• For Tihange-1, see Engie/Electrabel, "Tihange", Undated, see http://corporate.engie-electrabel.be/local-player/nuclear-3/tihange; all accessed 23 June 2019.

National Energy and Climate Plan (PNEC)

The National Energy and Climate Plan (Plan National Énergie-Climat or PNEC) was passed in late 2019 and defines the strategy of compensation for the 6 GW of nuclear power that will be closed by the end of 2025. A capacity market shall attract the necessary investments into other generation capacity and flexibility options. The renewable energy target is set at 40 percent by 2030. The interconnection with neighboring countries, already on a high level, will be further improved.

In its assessment of the PNEC, the European Commission notes: "On energy security, Belgium has largely addressed the recommendation to specify the measures supporting the energy security objectives. In particular, the final plan better outlines the reform of the electricity market linked to the phase-out of the nuclear fleet. It also indicates that Belgium will implement the reforms in its market reform plan under the Electricity Regulation in a timely manner. (…) To replace 6 GW of nuclear capacity, the energy production mix is expected to make use of flexible capacity, storage and renewable energy sources." However, the Commission also stated "An increase in the country's energy dependence is expected after this phase-out."[1462]

Lifetime Extensions

In summer 2012, the operator identified an unprecedented number of hydrogen-induced crack indications in the pressure vessels of Doel-3 and Tihange-2, with respectively over 8,000 and 2,000—which later increased to over 13,000 and over 3,000—previously undetected defects. In spite of widespread concerns, and although no failsafe explanation about the negative initial fracture-toughness test results was given, on 17 November 2015, the Federal Agency for Nuclear Control (FANC) authorized the restart of Doel-3 and Tihange-2 (see previous WNISR editions for details).

The Belgian government did not wait for the outcome of the Doel-3/Tihange-2 issue and decided in March 2015 to draft legislation to extend the lifetime of Doel-1 and Doel-2 by ten years to 2025. The law went into effect on 6 July 2015. On 22 December 2015, FANC authorized the lifetime extension and restart of Doel-1 and -2.

On 6 January 2016, two Belgian NGOs filed a complaint against the 28 June 2015 law with the Belgian Constitutional Court, arguing in particular that the lifetime extension had been authorized without a legally binding public enquiry. In a 22 June 2017 pre-ruling decision, the Court addressed a series of questions to the European Court of Justice (ECJ), in particular concerning the interpretation of the Espoo and Aarhus Conventions, as well as the European legislation.

On 29 July 2019, the ECJ stated that the lifetime extension of a reactor

> must be regarded as being of a comparable scale, in terms of risks of environmental impact, to the initial commissioning of those power stations. Consequently, it is mandatory for such

1462 - European Commission, "Assessment of the final national energy and climate plan of Belgium", Commission Staff Working Document, SWD(2020) 900 final, 14 October 2020.

> a project to be the subject of an environmental impact assessment provided for by the EIA directive.[1463]

In addition, as the Doel-1 and -2 reactors are particularly close to the Belgian-Dutch border, "such a project must also be subject to the transboundary assessment procedure". The judgement permitted though to delay the implementation of the order, if a national court considers it is

> justified by overriding considerations relating to the need to exclude a genuine and serious threat of interruption to the electricity supply in the Member State concerned, which cannot be addressed by other means or alternatives, inter alia in the context of the internal market. That maintenance may only last for the amount of time strictly necessary in order to remedy that illegality.[1464]

On 5 March 2020, the Belgian Constitutional Court nullified the lifetime extension legislation in its entirety but gave the government until the end of 2022 "at the latest" to carry out an appropriate Environmental Impact Assessment (EIA) and a transboundary consultation.[1465]

The Belgian government argued that the lifetime extension "plays a vital role in securing its supply of electricity until 2025" and sent a notification for consultation to a number of European governments inviting them to comment on the "project" (that is the well engaged lifetime extension of Doel-1 and -2).[1466]

The Belgian precedent will have significant consequences on the lifetime extension projects in European Union Member States that now will all have to carry out full-scale EIAs and organize transboundary consultations prior to granting permission for lifetime extensions.

In the meantime, Electrabel had signaled that it wished to extend the lifetime of two or three units beyond 2025 and warned that it would need legislation to be adapted by the end of the year 2020.[1467] This did not happen and Engie decided "to stop preparation works that would allow for the 20-year extension of two nuclear units beyond 2025".[1468]

Part of the nuclear phase-out strategy is the buildup of offshore wind capacities. As of mid-2021, Belgium reaches 2.3 GW installed capacity and outranks Denmark as 4th offshore wind energy operator worldwide behind the U.K., Germany, and China. Capacity increased by 45 percent in 2020 alone. In 2020, offshore wind farms covered 8.4 percent of the Belgian

1463 - ECJ, "The Belgian law extending the operating life of nuclear power stations Doel 1 and Doel 2 was adopted without the required environmental assessments being carried out first", Press Release, 29 July 2020.

1464 - Ibidem.

1465 - Cour constitutionnelle, "La Cour annule la loi qui prolonge l'activité des centrales nucléaires de Doel 1 et 2, en l'absence d'études préalables d'incidences environnementales, mais en maintient les effets jusqu'au plus tard le 31 décembre 2022" , Press Release, 5 March 2020 ; for the text of the judgement see Cour constitutionnelle, "Arrêt 34/2020", 5 March 2020 (in French), see https://www.const-court.be/public/f/2020/2020-034f.pdf, accessed 8 August 2020.

1466 - Marie-Christine Marghem, Letter dated 13 August 2020, Ministry of Energy, Environment and Sustainable Development, Belgium.

1467 - *Montel*, "Electrabel réitère son appel à prolonger le nucléaire belge", 28 January 2020, see http://www.montelnews.com/fr/story/electrabel-ritre-son-appel-à-prolonger-le-nuclaire-belge/1082410, accessed 8 August 2020.

1468 - Engie, "2020 Management Report and Annual Consolidated Financial Statements", March 2021, see https://www.engie.com/sites/default/files/assets/documents/2021-02/ENGIE_2020_Management_report_and_annual_consolidated_financial_statements.pdf, accessed 1 August 2021.

electricity consumption, and they are supposed to increase their share to 10 percent over a full year of operation.[1469]

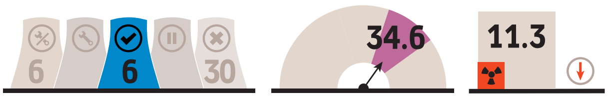
Finland

(See Focus Countries – Finland Focus.)

France

(See Focus Countries – France Focus.)

Germany



Germany's nuclear fleet generated 61 TWh net in 2020, a 14 percent decline over the rather stable past three years, and only 37.5 percent of the peak generation of 162.4 TWh in 2001. Nuclear plants provided 11.3 percent of Germany's electricity generation, representing little more than one-third of the historic maximum of 30.8 percent in 1997.

One more reactor, the 1400-MWe Philippsburg-2 PWR, was closed at the end of 2019, according to the nuclear phase-out legislation that will see three of the six remaining reactors closed by the end of 2021 and the other by the end of 2022 (see Table 21 for details). While the nuclear phase-out has proceeded smoothly so far, independent experts are warning that the challenge with six large reactors leaving the grid within one year has not been compensated. "For renewables to be able to cover the nuclear power volumes that will soon be eliminated, more renewables must be quickly added", stresses Agora Energiewende.[1470]

Germany decided immediately after 3/11 to close eight of the oldest[1471] of its then 17 operating reactors and to phase out the remaining nine by the end of 2022, effectively reactivating a "consensus agreement" negotiated a decade earlier. This choice was implemented by a conservative, pro-business, and, until the Fukushima disaster, very pro-nuclear Government, led by physicist Chancellor Angela Merkel, with no political party dissenting, which makes it virtually irreversible under any political constellation. On 6 June 2011, the Bundestag passed a seven-part energy transition legislation almost by consensus and it came into force on 6 August 2011 (see earlier WNISR editions for details).

With the near completion of the nuclear power phase-out, the question about the fate of facilities other than nuclear reactors gains ground. There is an operating uranium enrichment facility in Gronau and fuel fabrication in Lingen. The Ministry for the Environment, Nature Protection and Nuclear Safety, released an official statement on the tenth anniversary of the beginning of the Fukushima disaster asking for the closure of both facilities "in order to

1469 - BOP, "First offshore wind energy zone in the Belgian North Sea fully and on time completed", Belgian Offshore Platform, 3 January 2021, see https://www.belgianoffshoreplatform.be/en/news/first-offshore-wind-energy-zone-in-the-belgian-north-sea-fully-and-on-time-completed/, accessed 1 August 2021.

1470 - Patrick Graichen and Fabian Hein, "10 years after Fukushima: consequences of the nuclear phase-out for the energy transition", Agora Energiewende, March 2021.

1471 - Including the Krümmel and Brunsbüttel reactors that by then had not generated power for almost two and four years respectively.

terminate the unbearable situation that foreign old nuclear power plants close to the border are operated with fuel assemblies of German production".[1472]

In addition, the German Government wishes to team up with other non-nuclear or nuclear phase-out countries to actively promote nuclear phase-out in the EU, eliminate lifetime extensions of operating reactors, and oppose the use of EU funds for nuclear projects.[1473]

Renewables generated 251 TWh or 45.4 percent of gross national electricity in 2020. More than half of this is from wind power with 131 TWh, which, since 2017, outgenerates nuclear power.[1474]

To put this into perspective, provisional figures for 2020 show respective shares of 19.3 percent for German renewables,[1475] for the first time exceeding the 16.8 percent for French nuclear of final energy consumption.[1476] As renewables accelerate their expansion beyond the power sector throughout the German economy, their share in final energy has increased by 7.6 percentage points since 2010, while the French nuclear share remained stable (16.9 percent in 2010). However, both figures indicate how modest the contribution of the respective technologies to the overall energy sector remains, with oil remaining the dominant primary source in both countries.

Coal-based electricity generation in Germany dropped by large margins over the period 2015-2020—hard coal by 63.9 percent and lignite by 40.7 percent, while natural gas generation increased by 47.4 percent. In 2020, renewables were again by far the largest contributor to the power mix (gross) and supplied twice as much as lignite (16 percent) and hard coal (7.4 percent) together, while natural gas combustion for power was at an all-time high and contributed 16 percent.

The move away from nuclear and coal did not have any major adverse effects on the wholesale power prices. Agora Energiewende notes: "In recent years, the electricity exchange price in Germany has always been lower than in France, the country with the most nuclear power plants."[1477]

In 2017, Germany's net power exports hit a record at 55 TWh. But by 2020, net exports had dropped again to 21 TWh.

Figure 72 summarizes the main developments of the German power system between 2010—the last year prior to the post-3/11 closure of the eight oldest nuclear reactors—and 2019.

1472 - Bundesministerium für Umwelt, Naturschutz und nukleare Sicherheit, "12 Punkte für die Vollendung des Atomausstiegs – die Position des Bundesumweltministeriums", 11 March 2021.

1473 - Ibidem.

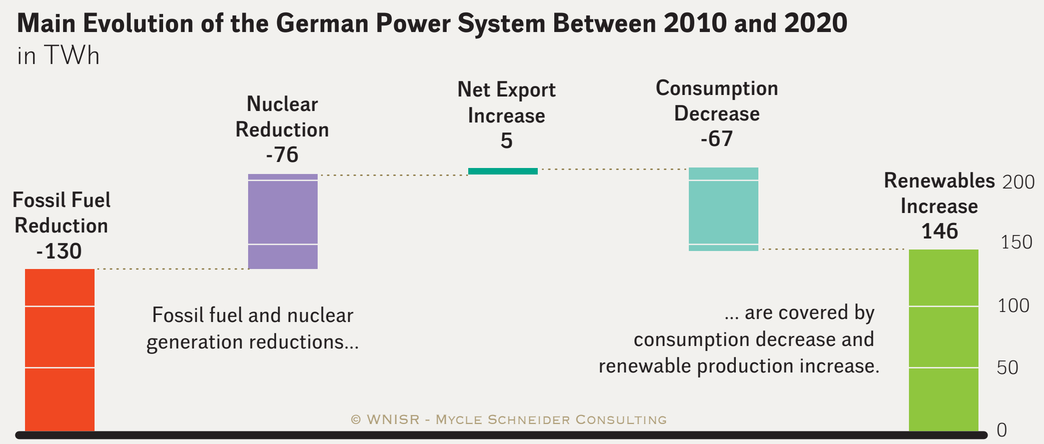
1474 - Federal Ministry for Economic Affairs and Energy, "Development of Renewable Energy Sources in Germany in the year 2020", February 2021, see https://www.erneuerbare-energien.de/EE/Redaktion/DE/Downloads/development-of-renewable-energy-sources-in-germany-2020.pdf, accessed 3 August 2021.

1475 - Share calculated according to EU-Directive 2009/28/EC. The share calculated according to German Energiekonzept is 19.6 percent, see Federal Ministry for Economic Affairs and Energy, "Development of Renewable Energy Sources in Germany in the year 2020", op. cit.

1476 - General Commission for Sustainable Development, "Bilan énergétique de la France en 2020–Données provisoires", French Ministry for the Ecological and Inclusive Transition, April 2021.

1477 - Patrick Graichen and Fabian Hein, "10 years after Fukushima: consequences of the nuclear phase-out for the energy transition", op. cit.

Figure 72 · Main Developments of the German Power System Between 2010 and 2020



Sources: WNISR based on AG Energiebilanzen (AGEB), 2021

It illustrates that Germany is making rapid progress on the double phase-out of nuclear power *and* coal. Renewable electricity generation (+146 TWh) and the reduction in domestic consumption (–67 TWh) were more than sufficient to compensate for the reduction of nuclear generation (76 TWh), and a dramatic reduction in power generation from fossil fuels (–130 TWh). Within the fossil-fuel generating segment:

- Lignite peaked in 2013 and then declined—especially in 2019–20— to 37 percent below the 2010 level;
- Hard coal also peaked in 2013 then dropped to 64 percent below the 2010-level;
- Natural gas fluctuated since 2010 and peaked in 2020 at 2.6 percent above the 2010-level;
- Oil was insignificant and dropped further to 52 percent below the 2010-level representing 0.7 percent of gross power generation.

Due to the COVID-19 pandemic, the 2020-results are not fully representative. In the first half of 2021, fossil fuel use was back up. Consumption of the most polluting resource (lignite) was up by about one third compared to the first half of 2020. However, the increase is mainly due to the exceptionally low wind-power output, which remained 20 percent below the performance during the same period in 2020. In the longer trend, lignite consumption continues to fall as it remains 12 percent below the 2019 first half-year result.

Table 21 – Legal Closure Dates for German Nuclear Reactors 2011–2022

Reactor Name (Type, Net Capacity)	Owner/Operator	First Grid Connection	End of License (latest closure date)
Biblis-A (PWR, 1167 MW)	RWE	1974	6 August 2011
Biblis-B (PWR, 1240 MW)	RWE	1976	
Brunsbüttel (BWR, 771 MW)	KKW Brunsbüttel[a]	1976	
Isar-1 (BWR, 878 MW)	PreussenElektra	1977	
Krümmel (BWR, 1346 MW)	KKW Krümmel[b]	1983	
Neckarwestheim-1 (PWR, 785 MW)	EnBW	1976	
Philippsburg-1 (BWR, 890 MW)	EnBW	1979	
Unterweser (BWR, 1345 MW)	PreussenElektra	1978	
Grafenrheinfeld (PWR, 1275 MW)	PreussenElektra	1981	31 December 2015 (closed 27 June 2015)
Gundremmingen-B (BWR, 1284 MW)	KKW Gundremmingen[c]	1984	31 December 2017
Philippsburg-2 (PWR, 1402 MW)	EnBW	1984	31 December 2019
Brokdorf (PWR, 1410 MW)	PreussenElektra/Vattenfall[d]	1986	31 December 2021
Grohnde (PWR, 1360 MW)	PreussenElektra	1984	
Gundremmingen-C (BWR, 1288 MW)	KKW Gundremmingen	1984	
Isar-2 (PWR, 1410 MW)	PreussenElektra	1988	31 December 2022
Emsland (PWR, 1329 MW)	KKW Lippe-Ems[e]	1988	
Neckarwestheim-2 (PWR, 1310 MW)	EnBW	1989	

Sources: German Atomic Energy Act/Atomgesetz, 31 July 2011, Atomforum Kernenergie May 2011; WNISR with IAEA-PRIS, 2021[1478]

Notes:

Krümmel and Brunsbüttel were officially closed in 2011 but had not been providing electricity to the grid since 2009 and 2007 respectively

PWR=Pressurized Water Reactor; BWR=Boiling Water Reactor; KKW=Nuclear Power Plant (Kernkraftwerk); RWE=Rheinisch-Westfälisches Elektrizitätswerk Power AG; EnBW=Energie Baden-Württemberg AG.

a - Vattenfall 66.67%, E.ON 33.33%

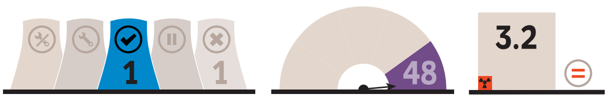
b - Vattenfall 50%, E.ON 50%.

c - RWE 75%, E.ON 25%.

d - E.ON 80%, Vattenfall 20%.

e - RWE 87.5%, E.ON 12.5%.

Netherlands



The Netherlands operates a single, 48-year-old 480 MW PWR at Borssele that provided 3.9 TWh (3.7 TWh in 2019) and a stable 3.2 percent of the country's electricity in 2020, with a historic maximum of 6.2 percent back in 1986. In late 2006, the operator and the Government reached an agreement to allow operation of the reactor to continue until 2033.[1479]

The conservative-liberal ruling governing party VVD (People's Party for Freedom and Democracy) announced in January 2019 that it was developing new ideas for nuclear power in Netherlands. The options under consideration were further extension of operations at Borssele, construction of a new plant, or realizing new nuclear power plants in a European context. At the time the energy industry in the Netherlands dismissed the government initiative to develop a new nuclear plant as wholly unrealistic. The operator of Borssele in May 2019 stated that any new nuclear plant would "never happen" without government financing. Developments during

1478 - German Bundestag, "Dreizehntes Gesetz zur änderung des Atomgesetzes", Signed into Law on 31 July 2011, *Bundesgesetzblatt*, Nr. 43, 5 August 2011; and "Atomforum Kernenergie", May 2011,

1479 - WNA, "Nuclear Power in the Netherlands", Updated February 2017, see http://www.world-nuclear.org/info/inf107.html, accessed 14 July 2021.

the last year show that Elektriciteits Produktiemaatschappij Zuid-Nederland (EPZ) have made considerable progress towards that state financing.[1480]

EPZ explained in a parliamentary hearing in November 2020 its thinking both in terms of the future of the 48-year-old Borssele reactor and any new nuclear plant. In terms of lifetime extension, EPZ proposed that together with government it explore the technical-economic preconditions for operating Borssele for 10–20 years beyond its current license which expires in 2033.

As for new reactors, EPZ stated that it supported the construction of two 1500 MW reactors, with European Pressurized Water Reactor (EPR) and Advanced Pressurized Water Reactor (APR), which they described as "already licensed and in operation elsewhere. EPR and APR units are also under construction. They are proven safe and reliable means of production."[1481] The site under consideration would be the existing Borssele site with the preferred option being construction of both reactors simultaneously with phased delivery, with anticipated costs of a new Generation-III reactor "between 8 and 10 billion euros [US$$_{2020}$9.3–11.6 billion] and the construction time is approximately 8 years."[1482]

In language reflecting the significant costs and risks of new nuclear and in mirroring that used by EDF in the U.K. over the financing of the Hinkley Point C EPRs, EPZ indicated that any new reactors (and Borssele life extension decisions) would require active support from the Dutch government, including financial mechanisms. EPZ said that the government's role would be indispensable because "if the design is changed during construction (which takes 8 to 10 years) due to changing requirements, the costs and construction time increase disproportionately."[1483]

EPZ de facto admitted that nuclear power cannot compete with renewables in the current electricity market, stating that renewable "incentives" disrupt the functioning of the market, "as a result of which sustainable energy is marketed far below system costs… Government control and/or guarantees are indispensable to be able to operate a nuclear power plant in this capricious market. Certainties are needed with regard to the payback of the (commercial) investment in a new nuclear power plant."[1484]

In what appears to be a direct response to the calls from EPZ for government support for nuclear power, on 7 July 2021, KPMG released a report on nuclear energy market consultation, which discusses the conditions under which market parties would be prepared to invest in new nuclear plant in the Netherlands.[1485] The report was authorized following a resolution by the Dutch House of Representatives. In confirming that the cost of nuclear power was not possible to finance without direct government intervention, the KPMG report concluded that, "that private financing is impossible or difficult to achieve without far-reaching guarantees from the

1480 - Ibidem.

1481 - EPZ, "Vision EPZ on nuclear energy in the Netherlands after 2033", November 2020 (in Dutch), see https://www.epz.nl/app/uploads/2021/04/Visie-EPZ-op-kernenergie-in-Nederland-na-2033.pdf, accessed 30 June 2021.

1482 - Ibidem.

1483 - Ibidem.

1484 - Ibidem.

1485 - Government of the Netherlands, "KPMG marktconsultatie kernenergie" ["KPMG nuclear energy market consultation"], 7 July 2021 (in Dutch), see https://www.rijksoverheid.nl/documenten/rapporten/2021/07/07/kpmg-marktconsultatie-kernenergie, accessed 14 July 2021.

government… a large NPP is too big for many private investors and has too long a horizon."[1486] As cited in *Nuclear Engineering International* (*NEI*), the various financing structures assessed by KPMG include price guarantees (Contract for Difference, 'CfD', or Power Purchase Agreement, 'PPA') or certainty of power purchase (Mankala model). Market parties indicate that they prefer the Regulated Asset Based (RAB) model although it is untested in nuclear energy. Looking at the Mankala model (for example Hanhikivi in Finland) a substantial part of the financing is provided by the supplier during construction of nuclear technology (through equity or subordinated loans), possibly in combination with export financing but "this model appears to be less applicable in the Netherlands, partly due to the lack of sufficient participants (i.e. large consumers)".[1487] With respect to a PPA or CfD model, KPMG says that, in addition to security of turnover, it is expected that financiers will request various guarantees from the government.

KPMG reported market parties indicating that the Netherlands should opt for a Generation III+ reactor and in due course a Generation IV reactor after the technology has been proven. The preferred technology providers cited were EDF (Olkiluoto, Flamanville, Hinkley Point C), Westinghouse (Vogtle), KEPCO (Barakah), and Rosatom (Ostrovets, Akkuyu, Hahnikivi, Paks II).

The option to develop new reactors with Rosatom, as well as Chinese technology, has been excluded on request from the Dutch Ministry of Economic Affairs. A final choice is expected to be made between 2021 and 2023. KPMG believes that the designs of these Generation III+ reactors are "mature" and knowledge and expertise are being built up in Europe, "costs will be expected to be lower." Due to the lack of current commercial SMRs, KPMG projects that possible construction would "be possible only after 2027–2033."[1488]

In response to the KPMG report, the Dutch government announced to study the use of nuclear power to at least 2050.[1489] The government reported that the province of Zeeland, which hosts the Borssele reactor, is positive about the construction of a new nuclear power plant. State Secretary Dilan Yeşilgöz-Zegerius stated that, "We do not have the luxury of excluding a sustainable energy source. The Netherlands wants to emit less CO2 and generate more sustainable energy. To achieve our climate goals, we will have to pull out all the stops, including nuclear energy if it is profitable and safe. That is why I also want to look at how we can maintain and strengthen the nuclear knowledge we have in the Netherlands. We must keep all options open."[1490]

The government also cited the KPMG report that the existing nuclear power plant in Borssele should remain open longer, according to the companies involved, "because the power plant is

1486 - As cited in *NEI*, "KPMG looks at feasibility of new build in Netherlands", 12 July 2021, see https://www.neimagazine.com/news/newskpmg-looks-at-feasibility-of-newbuild-in-netherlands-8893831, accessed 13 July 2021.

1487 - Ibidem.

1488 - Government of the Netherlands, 7 July 2021, op. cit.

1489 - Ibidem.

1490 - Government of the Netherlands, "Staatssecretaris Yeşilgöz-Zegerius gaat toekomstige rol kernenergie onderzoeken" ["Secretary of State Yeşilgöz-Zegerius will investigate the future role of nuclear energy"], 7 July 2021, see https://www.rijksoverheid.nl/actueel/nieuws/2021/07/07/staatssecretaris-yesilgoz-zegerius-gaat-toekomstige-rol-kernenergie-onderzoeken, accessed 14 July 2021; and *Netherland News Live*, "Secretary of State Yeşilgöz-Zegerius investigates future role of nuclear energy", 8 July 2021, see https://netherlandsnewslive.com/secretary-of-state-yesilgoz-zegerius-investigates-future-role-of-nuclear-energy/194098/, accessed 30 July 2021.

economically profitable and nuclear knowledge is thus preserved." The current Dutch Nuclear Energy Act does not permit lifetime extension; however, Yeşilgöz-Zegerius reported that they are currently exploring how the Nuclear Energy Act can be amended to extend the license of Borssele which is scheduled to close in 2033.[1491]

Spain

Spain operates seven reactors that provided a stable 55.8 TWh in 2020, compared to 55.9 TWh in 2019, representing 22.2 percent of the country's electricity, compared to 21.4 percent in 2019 and a maximum of 38.4 percent in 1989. Spain's reactors have a mean operating age of 36.4 years as of 1 July 2021. License extensions have been approved for three reactors during the past year, still in line with the government's nuclear phase-out plans.

In late January 2019, Spain's coalition government agreed a nuclear phase-out plan with utilities Endesa, Iberdrola and Naturgy. The agreement was part of the overall Integrated National Energy and Climate Plan (INECP) which was approved by the Cabinet meeting on 22 February 2019.[1492] The details of the reactor closure-dates were published in February 2019 by newspaper *Cinco Días*.[1493] All of Spain's reactors would be closed by 2035; however, the policy also secured lifetime extension for all reactors beyond 40 years, in contrast to previous governing Socialist Party (PSOE) policy. On 3 March 2019, Teresa Ribera, Minister for the Ecological Transition, confirmed that an agreement had been reached with Iberdrola, Endesa and Naturgy that in effect extends operation of their reactors.[1494]

In March 2020, the government updated the INECP 2021–2030.[1495] The 2030 target of 161 GW of total installed power generating capacity is to include 50 GW of wind, 39 GW of solar PV, 27 GW of CCGTs (Combined Cycle Gas Turbines), 16 GW hydro, 9.5 GW pumped hydro, 7 GW thermo- solar, and 3 GW nuclear (1.9 percent).[1496]

A major point of tension between the utilities was over the amortization time of their reactors. Iberdrola had accounted for the nuclear plants' operating until 40 years, whereas Endesa had planned for 50-year operation in its accounts. Iberdrola said that it also has no financial incentive to continue nuclear operations if the business continues to lose money.[1497] Iberdrola and Naturgy had put forward plans for extension of the Almaraz reactors to 2027, of which they jointly share ownership together with Endesa, on the condition that they would be able to

1491 - Ibidem.

1492 - Carmen Monforte, "El Gobierno cierra el calendario con las fechas de clausura de cada central nuclear", *CincoDías, El País Economía*, 11 February 2019 (in Spanish), see https://cincodias.elpais.com/cincodias/2019/02/08/companias/1549647160_807281.html, accessed 8 July 2021.

1493 - Ibidem.

1494 - *Público*, "La ministra Ribera afirma que es necesario prolongar la vida de las centrales nucleares", 3 March 2019 (in Spanish), see https://www.publico.es/politica/energia-nuclear-prolonga-vida-centrales-nucleares.html, accessed 8 July 2021.

1495 - *Renewables Now*, "Spain raises ambitions in new 2030 NECP - more emission cuts, wind, solar", 13 April 2020, see https://renewablesnow.com/news/spain-raises-ambitions-in-new-2030-necp-more-emission-cuts-wind-solar-694786/, accessed 8 July 2021.

1496 - Massimo Schiavo, Pierre Georges et al., "The Energy Transition And What It Means For European Power Prices And Producers: Midyear 2020 Update", *S&P Global*, 8 June 2020, see https://www.spglobal.com/ratings/en/research/articles/200608-the-energy-transition-and-what-it-means-for-european-power-prices-and-producers-midyear-2020-update-11509932, accessed 8 July 2021.

1497 - *NW*, "Spain's Endesa to apply to renew all reactor licenses in 2019, 2020", *Platts*, 7 March 2019.

withdraw if there was a requirement to make further investments. Endesa, which was not in favor of reactor closure before 50 years, set no conditions.

On 22 March 2019, Iberdrola confirmed that it had reached agreement for the extension of the Almaraz-1 and -2 reactors to operate until 1 November 2027 and 31 October 2028 respectively, and that it had applied for license extension.[1498] The agreement is based on the condition that Iberdrola will spend no more than €600 million (US$677 million) during the remaining operational life of the reactors.[1499]

On 7 May 2020, the Plenary of the Nuclear Safety Council (CSN) announced that it had decided to approve a technical assessment on the request for license renewal for the two Almaraz reactors.[1500] As a result, CSN recommended to the Government to authorize the 39-year-old Almaraz-1 to operate until 1 November 2027 and Almaraz-2, connected to the grid in October 1983, to operate until 31 October 2028. The approval by CSN set safety and compliance conditions, including the requirement, as noted above, to invest up to €600 million (US$677 million).[1501] The Ministry for the Ecological Transition granted the license extensions for the Almaraz plant in July 2020.[1502]

The Almaraz plant is located adjacent to the Tagus River in an area of significant seismic risk and 110 kilometers from the Portuguese border.[1503] For this reason the continued operation of the plant has been opposed by Portuguese environmental groups, political parties, and governments. The decision of the CSN prompted the Portuguese government to demand that Almaraz be subject to an environmental impact assessment.[1504] In July 2020, a complaint was filed by a Portuguese parliamentary member of the Pessoas-Animais-Natureza (PAN) party against the Almaraz decision.[1505] The filing was to the United Nations Economic Commission for Europe, citing contravention of the Espoo Convention, which requires an environmental impacts assessment and the Arhus Convention, which obliges Madrid to “inform and consult” neighboring Portugal before making any decision on license renewal.

1498 - Iberdrola, “Iberdrola finalises the Almaraz renewal agreement, which guarantees economic activity and employment at the plant for the next 25 years”, 22 March 2019, see https://www.iberdrola.com/press-room/news/detail/iberdrola-finalises-almaraz-renewal-agreement-which-guarantees-economic-activity-employment-plant-next-years, accessed 8 July 2021.

1499 - Isla Binnie, “Power firms agree on route to close Spain’s oldest nuclear plant”, *Reuters*, 22 March 2019, see https://www.reuters.com/article/us-spain-energy-nuclearpower/power-firms-agree-on-route-to-close-spains-oldest-nuclear-plant-idUSKCN1R325G, accessed 8 July 2021.

1500 - CSN, “El CSN informa favorablemente la renovación de la autorización de explotación de la central nuclear Almaraz (Cáceres)”, 7 May 2020 (in Spanish), see https://www.csn.es/-/el-csn-informa-favorablemente-la-renovacion-de-la-autorizacion-de-explotacion-de-la-central-nuclear-almaraz-caceres-, accessed 8 July 2021.

1501 - *elEleconomista*, “El CSN autoriza a la central nuclear de Almaraz a operar hasta octubre de 2028”, 7 May 2020 (in Spanish), see https://www.eleconomista.es/empresas-finanzas/noticias/10529185/05/20/El-CSN-autoriza-a-la-central-nuclear-de-Almaraz-a-operar-hasta-octubre-de-2028.html, accessed 8 July 2021.

1502 - Ministerio para la Transición Ecológica y el Reto Demográfico, “Orden TED-773-2020 , de 23 de julio, por la que concede la renovación de la autorización de explotación de la Central Nuclear de Almaraz, Unidades I y II”, 2020, see https://www.csn.es/documents/10182/27922/Orden%20TED-773-2020%20,%20de%2023%20de%20julio,%20por%20la%20que%20concede%20la%20renovaci%C3%B3n%20de%20la%20autorizaci%C3%B3n%20de%20explotaci%C3%B3n%20de%20la%20Central%20Nuclear%20de%20Almaraz,%20Unidades%20I%20y%20II, accessed 11 August 2020.

1503 - *Jornal Económico*, “Spanish nuclear power plant in Almaraz authorized to operate until 2028”, 8 May 2020, see https://jornaleconomico.sapo.pt/en/news/Spanish-nuclear-power-plant-in-Almaraz-authorized-to-operate-until-2028-586165, accessed 8 July 2021.

1504 - *Notícias ao Minuto*, “Governo quer que extensão de funcionamento de Almaraz seja avaliada”, 5 May 2020 (in Portuguese), see https://www.noticiasaominuto.com/pais/1483078/governo-quer-que-extensao-de-funcionamento-de-almaraz-seja-avaliada, accessed 8 July 2021.

1505 - *Portugal Resident*, “Almaraz nuclear risks: PAN lodges complaint against Spain to UN”, 30 July 2020, see https://www.portugalresident.com/almaraz-nuclear-risks-pan-lodges-complaint-against-spain-to-un/, accessed 7 July 2021.

Asociación Nuclear Ascó-Vandellós II, known as ANAV, the operator of Vandellos-2, applied for 10-year license renewal taking it to 2030.[1506] Under the recently agreed Integrated Energy and Climate Plan, Vandellos-2 is scheduled to operate until 2034, and therefore a further license extension may be sought prior to 2030. On 24 June 2020, the CSN approved a ten-year extension for Vandellos-2 until 2030.[1507] The reactor is scheduled for closure in 2034.[1508]

On 18 March 2021 ministerial approval was granted for license extension for the Cofrentes reactor until 30 November 2030,[1509] at which time Spain's only remaining commercial BWR is expected to close.[1510]

The Plenary of CSN announced on 8 July 2021 that it had begun the analysis for license renewal for the Ascó Unit 1 and Unit 2 PWRs for nine and ten years respectively.[1511] Unit 1 was connected to the grid on 13 August 1983 and Unit 2 was connected to the grid on 23 October 1985. Both reactors have operational licenses until September 2021 and are scheduled for closure in 2029 and 2030 respectively.

The one reactor yet to apply for a license extension is Trillo Unit 1, which currently has a license until November 2024, and is scheduled to close in 2035.

The Spanish government on 21 June 2021 approved new draft legislation to curb a recent increase in energy prices for end-consumers while promoting clean energies, with a fresh cut of one billion euros in utilities' remuneration.[1512] The government is attempting to control rising CO2 prices that increase energy prices for consumers and cap windfall profits of utilities operating hydropower (above 10 MW) and nuclear plants. The new regulation will not be ready for approval before year-end.

Utilities are already complaining that continued nuclear operation is unfavourable due to high taxation on nuclear generation and low electricity market prices. Cited in the International Energy Agency (IEA)'s "Spain 2021 Energy Policy Review", Endesa told IEA that current nuclear generation costs are well over €50/MWh, around 40 percent of which are taxes and fees for radioactive waste management.[1513] Endesa told the IEA that it operates its reactors at an economic loss under the prevailing MIBEL (Iberian power market or Mercado Ibérico de Electricidad) market price, "which has dropped due to the impacts of the COVID-19 pandemic.

1506 - *Platts Nuclear News Flashes*, "Operator of Spain's Vandellos-2 applies for 10-year license renewal", 28 March 2019.

1507 - CSN, "El Pleno del CSN informa favorablemente la solicitud de renovación de autorización de explotación de la central nuclear Vandellós II (Tarragona)", 24 June 2020 (in Spanish), see https://www.csn.es/-/el-pleno-del-csn-informa-favorablemente-la-solicitud-de-renovacion-de-autorizacion-de-explotacion-de-la-central-nuclear-vandellos-ii-tarragon-1, accessed 8 July 2021.

1508 - *Platts Nuclear News Flashes*, "Spain approves 10-year license extension for Vandellos-2 reactor", 25 June 2020.

1509 - *NEI*, "Spanish government approves renewal of operating licence for Cofrentes NPP", 23 March 2021, see https://www.neimagazine.com/news/newsspanish-government-approves-renewal-of-operating-licence-for-cofrentes-npp-8618722, accessed 8 July 2021.

1510 - Gianluca Baratti, "Spain's nuclear regulator approves Cofrentes license renewal", *S&P Global*, 18 February 2021, see https://www.spglobal.com/platts/en/market-insights/latest-news/electric-power/021821-spains-nuclear-regulator-approves-cofrentes-license-renewal, accessed 8 July 2021.

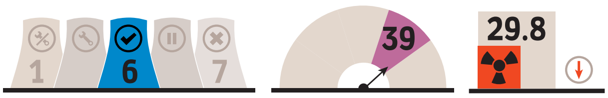
1511 - CSN, "The CSN begins the analysis of the application for renewal of the operating authorization of the Ascó nuclear power plant", 8 July 2021 (in Spanish), see https://www.csn.es/en/noticias-csn/2021/-/asset_publisher/jMixvJv7q15q/content/el-csn-inicia-el-analisis-de-la-solicitud-de-renovacion-de-autorizacion-de-explotacion-de-la-central-nuclear-asco, accessed 8 July 2021.

1512 - Jesús Aguado and Belén Carreño, "UPDATE 2-Spain approves energy legislation to promote clean energy, curb prices", *Reuters*, 21 June 2021, see https://www.reuters.com/article/spain-power-regulation-idINL5N2NJ2UU, accessed 8 July 2021.

1513 - IEA, "Spain 2021 Energy Policy Review", May 2021, see https://iea.blob.core.windows.net/assets/bf2b75f3-224f-45bd-9dc2-83eb86388636/Spain2021.pdf, accessed 7 July 2021.

Indeed, average MIBEL prices were around €40/MWh or less during the third quarter of 2020, much lower than the nuclear generation cost."[1514]

Sweden



Sweden's nuclear fleet of seven reactors generated 47.4 TWh in 2020, a 26.5 percent drop over the previous year, and 29.8 percent of the country's electricity production, a decline of 4.2 percentage points over 2019. This is the first time since the early 1980s that the share of nuclear power drops below the 30-percent mark. It had peaked in 1996 at 52.4 percent.

On 1 January 2021, it was announced that the Ringhals-1 had been shut down permanently after 46 years of operation.[1515] This followed the closure of Ringhals-2 on 30 December 2019.[1516] The country has six remaining operating reactors. State-owned utility Vattenfall co-owns five units,[1517] while OKG (Oskarshamns Kraftgrupp AB)[1518] owns the sixth, Oskarshamn-3.

The past year has seen a continuation of efforts by right-of-center opposition parties to overturn the decision in 2016 on shutting down all nuclear reactors in Sweden by 2040. On 10 December 2019, the Moderate Party and the Christian Democrats announced their withdrawal from the June 2016 energy policy agreement.[1519] This was when the ruling Red-Green coalition and three opposition parties, including the Center Party, had reached a "traditional Swedish compromise" on future energy policy,[1520] which fixed a 2040 target for a 100-percent renewable electricity mix.

Following the closure of Ringhals-2 in December 2019, attempts were made by politicians to reverse the decision and scrap plans for closure of Ringhals-1. A parliamentary motion on 22 January 2020 attempted to reverse the closure of the Ringhals reactors but failed by one vote. The motion was put forward by the far-right Sweden Democrats party, and backed by the Moderates, the Liberals and the Christian Democrats, and was opposed by the Social Democratic Party and Green Party coalition-government.

Despite these efforts, the closure of Ringhals is under Swedish law, final, with confirmation by the Swedish Radiation Safety Authority (SSM) on 20 January 2021, that as far as Ringhals-1

1514 - Ibidem.

1515 - Vattenfall, "The Ringhals 1 reactor has reached the finish line", 1 January 2021, see https://group.vattenfall.com/se/nyheter-och-press/pressmeddelanden/2021/reaktorn-ringhals-1-har-gatt-i-mal, accessed 18 July 2021.

1516 - Vattenfall, "Ringhals 2 nuclear plant shuts down", Press Release, 19 December 2019, see https://group.vattenfall.com/press-and-media/ news--press-releases/newsroom/2019/ringhals-2-nuclear-plant-shuts-down; and *Svenska Dagbladet*, "Ringhals 2 tystnade: 'Vemod'", 30 December 2019 (in Swedish), see https://www.svd.se/medelalders-elforsorjare-tystnar, both accessed 18 July 2021.

1517 - Ringhals-1–4 (Vattenfall 70.4%, E.ON 29.6%), Forsmark-1–3 (Forsmarks Kraftgrupp FKG, Vattenfall 66%, Mellansvensk Kraftgrupp 25.5%, E.ON 8.5%)

1518 - OKG is owned by Uniper Sverige (formerly Sydkraft), an E.ON spinoff, for 54.5% and Fortum for 45.5%.

1519 - *Svenska Dagbladet*, "M och KD lämnar – vill ha svar om kärnkraften", 10 December 2019 (in Swedish), see https://www.svd.se/m-och-kd-ratar-energioverenskommelsen, accessed 16 June 2020.

1520 - Government Offices of Sweden, "Agreement on Swedish energy policy—Framework agreement between the Swedish Social Democratic Party, the Moderate Party, the Swedish Green Party, the Centre Party and the Christian Democrats", 16 June 2016, see https://www.government.se/articles/2016/06/agreement-on-swedish-energy-policy/, accessed 1 August 2020.

is concerned, "under the regulations of the Act on Nuclear Activity means that electrical production may not be resumed".[1521]

As reported in WNISR2019, the efforts to stop the closure of Ringhals conflicts with the position of the reactor owners. Vattenfall's decision to close the reactors was due to the reactors being uneconomic, safety concerns over containment aging, the requirement for major investment in many upgrades, as well as the need for new licensing.[1522] On 28 November 2019, the head of the company's generation department, Torbjörn Wahlborg, said that Vattenfall never intended to operate Ringhals-1 and -2 longer than into the mid-2020s. He added that although electricity prices are higher now (at the end of 2019) than they were in 2015 when the company took the decision to close the reactors, "there is so much renewable energy in the [electricity] system that there is no place in the market for these reactors."[1523]

For more than four decades phasing out nuclear power has been on the agenda in Sweden. A 1980 public referendum decided to end nuclear power by 2010. Sweden retained the 2010 phase-out date until the middle of the 1990s, but an active debate on the country's nuclear future continued and led to a new inter-party deal to start the phase-out earlier but abandon the 2010 deadline. The first reactor (Barsebäck-1) was closed in 1999 and the second one (Barsebäck-2) in 2005. In June 2010, the parliament voted by a tight margin (174–172) to abandon the phase-out legislation. As a result, theoretically, a new plant could again be built— but only if an existing plant is closed.

On 22 December 2016, the 40-year-old Oskarshamn-2 was officially closed, followed on 17 June 2017 with the closure of the 46-year-old Oskarshamn-1.[1524]

To operate reactors into the 2040s, owners need to win approval following ten-year periodic safety reviews. The first to do so under the new 2016 policy were the 39-year-old Forsmark-1 and 38-year-old Forsmark-2, which secured approval on 18 June 2019 from SSM to operate for 10 more years until 2028.[1525] The SSM approved continued operation for the reactors, while also finding "deficiencies regarding the containment and aging of concrete structures deemed as small in the current situation, but it may increase in the long term if the deficiencies are not remedied since serious degradations… may occur in the reactor containment and other building structures of importance for radiation safety."[1526] This could mean significant refurbishment work may be indispensable in the coming years.

1521 - SSM, "Notification regarding the permanent closure of Ringhals 1", 20 January 2021, see https://www.stralsakerhetsmyndigheten.se/en/press/news/2021/notification-regarding-the-permanent-closure-of-ringhals-1, accessed 15 July 2021.

1522 - Birgitta Forsberg, "Vattenfalls vd: Mer kärnkraft inte lösningen", *Svenska Dagbladet*, 20 May 2019 (in Swedish), see https://www.svd.se/vattenfalls-vd-mer-karnkraft-inte-losningen; and Lars Larsson, "Kärnkraftsförespråkare förlorade om Ringhals", *Svenska Dagbladet*, 22 January 2020 (in Swedish), see https://www.svd.se/riksdagen-rostar-om-ringhals, accessed 15 July 2021.

1523 - Ariane Sains, "Swedish parliament to debate continued operation of Ringhals reactors", *NW*, 2 January 2020.

1524 - Ibidem.

1525 - SSM, "Forsmark har förutsättningar att fortsätta driva F1 och F2 strålsäkert till 2028s", 24 June 2019 (in Swedish), see https://www.stralsakerhetsmyndigheten.se/press/nyheter/2019/forsmark-har-forutsattningar-att-fortsatta-driva-f1-och-f2-stralsakert-till-2028/, accessed 25 June 2019.

1526 - SSM, "Återkommande helhetsbedömning / Forsmarks Kraftgrupp AB / Forsmark 1 och 2", 18 June 2019 (in Swedish), see https://www.stralsakerhetsmyndigheten.se/contentassets/6b998f90ef4c4dda8a5914ce3c3ca982/granskning-av-aterkommande-helhetsbedomning-av-forsmark-1-och-2.pdf, accessed 24 June 2019.

Major construction work at all of Sweden's reactors—with significant impact on production—was completed during 2020. This relates to the requirement that all reactors operating beyond 2020 have in place Independent Core Cooling Systems (ICCS).[1527] The new system is a consequence of the stress tests following the Fukushima accident and the SSM requirements for an independent core cooling system designed to withstand extreme external hazards. On 18 December 2020, SSM confirmed that the reactors at Forsmark, Ringhals and Oskarshamn predominantly meet the set conditions and requirements.[1528]

The 2016 policy agreement also allowed for the building of new reactors, but, as in the previous agreement, only for replacement and not in addition to existing units. The agreement also stipulates: "Central Government support for nuclear energy, in the form of direct or indirect subsidies, cannot be assumed".[1529] While Vattenfall CEO Hall stated in May 2019 that "the disadvantage of nuclear power is that it has become so expensive to build that it is difficult to motivate to build new nuclear power,"[1530] the company has indicated during the past year that it is open to operating reactors beyond the 2040 deadline.[1531] "We will consider the possibility of driving them longer," said Torbjörn Wahlborg, production manager at Vattenfall.[1532]

Currently, all six remaining Swedish reactors are scheduled for 60-year operation into the 2040s, with closure of the last reactor in 2045,[1533] when Sweden plans to have 100 percent of its electricity generated by renewable energy.

In May 2021, the operators of Sweden's reactors posted an urgent message via power exchange Nord Pool that the Clab temporary spent fuel waste storage site is reaching full capacity and the government has still yet to give its approval to a final repository. Consequently, the operators warned, Forsmark-4 faces potential closure in 2024, followed by Forsmark-3 and Ringhals-3 and -4 the next year, with Forsmark-1 in 2028.[1534] The companies called on the government to make a decision on where to store spent fuel by the end of August 2021 to avoid exceeding the storage allowance at the temporary site in Oskarshamn. "We have ongoing contact with government representatives, but a decision before the end of August this year is necessary in

1527 - Ministry of the Environment, "Sweden's Eighth National Report under the Convention on Nuclear Safety—Sweden's Implementation of the Obligations of the Convention", Swedish Government, Ds 2019:16, August 2019, see https://www.regeringen.se/4adae6/contentassets/c8c431c94efb4c4abefb38ca36272b5a/swedens-eighth-national-report-under-the-convention-on-nuclear-safety-ds-201916.pdf, accessed 16 June 2020.

1528 - SSM, "Forsmark, Ringhals and OKG meet the requirements for independent core cooling", 18 December 2020 (in Swedish), see https://www.stralsakerhetsmyndigheten.se/press/nyheter/2020/forsmark-ringhals-och-okg-uppfyller-kraven-pa-oberoende-hardkylning/, accessed 15 July 2021.

1529 - Government Offices of Sweden, "Framework agreement between the Swedish Social Democratic Party, the Moderate Party, the Swedish Green Party, the Centre Party and the Christian Democrats", 16 June 2016.

1530 - Op. cit. Birgitta Forsberg, 20 May 2019.

1531 - Lovisa Åkesson, "Vattenfall öppnar för kärnkraft efter 2040", *Expressen*, 24 November 2019 (in Swedish), see https://www.expressen.se/nyheter/klimat/vattenfall-oppnar-for-karnkraft-efter-2040-/, accessed 15 July 2021.

1532 - *svt Nyheter*, "Ringhals ägare öppnar för ny kärnkraft", 23 November 2019 (in Swedish), see https://www.svt.se/nyheter/inrikes/ringhals-agare-oppnar-for-nya-karnkraftverk, accessed 15 July 2021.

1533 - Vattenfall, "Asset Management At Nuclear Power Plants—With International Standards And Principles", IAEACN-246-14, Presented at the 4th International Conference on NPP Life Management, IAEA, 23–27 October 2017, see https://www.iaea.org/NuclearPower/Downloadable/Meetings/2017/2017-10-23-10-27-NPTDS/054_Frojd_Presentation.pdf, accessed 15 July 2021.

1534 - Industry Europe, "Swedish Nuclear Reactors Risk Closure Due To Waste Storage Issues", 6 May 2021, see https://industryeurope.com/sectors/energy-utilities/swedish-nuclear-reactors-risk-closure-due-to-waste-storage-issues/, accessed 15 July 2021.

order not to endanger electricity production at our nuclear production units," Vattenfall said in a statement to *Reuters*.[1535]

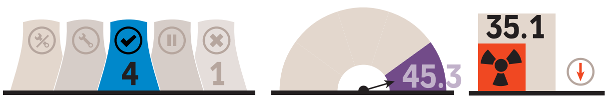
The decision on the repository was described by Environment Minister Per Bolund as "one of the biggest environmental questions ever in Sweden".[1536] The government stated that while the issue was a high priority there was a chance the process would not be completed before Clab reaches full capacity, and therefore there was the possibility of deciding on the Clab interim facility separately from the repository in order to avoid a situation where there is no storage capacity in Sweden.[1537] Barring intervention to prevent the extension of the capacity of Clab, early closure of Sweden's reactors due to this issue is unlikely.

New emergency planning zones and emergency planning distances were announced in June 2020 for Swedish nuclear power plants.[1538] The sites will be surrounded by a Precautionary Action Zone (PAZ) and an Urgent Protective action planning Zone (UPZ) as well as an Extended Planning Distance (EPD), extending approximately 5, 25 and 100 kilometers respectively. SSM stated:

> An inner and an outer emergency planning zone extending approximately 5 and 25 kilometers respectively will be introduced around each of Sweden's nuclear power plants. Within these emergency planning zones, iodine tablets will be pre-distributed, warnings for the public in the event of a nuclear accident will be pre-planned, and plans for evacuation and sheltering will be put in place. (…) For the extended planning distance [out to 100 km], planning will be put in place for relocation based on input from measurements of ground deposition, sheltering, and limited distribution of iodine tablets. (…) The new emergency planning zones and distances are to be implemented in Swedish contingency planning no later than 1 July 2022.[1539]

The reorganization of emergency planning will likely have significant cost implications for nuclear operators.

Switzerland



Prior to the U.K. leaving the EU on 31 January 2020, Switzerland has been the only non-EU Western European country generating nuclear power. Swiss nuclear output has declined by 9 percent from 25.3 TWh in 2019 to 23 TWh in 2020, mainly due to the closure of the Mühleberg reactor in late 2019. As total national electricity generation dropped in the first COVID-19 year by 3.4 percent, nuclear still generated 35.1 percent of the country's electricity, 2.2 percentage

1535 - Nora Buli and Simon Johnson, "Five Swedish reactors risk closure by 2028 due to tardy nuclear waste decision", *Reuters*, 5 May 2021, see https://www.reuters.com/world/europe/five-swedish-reactors-risk-closure-by-2028-due-tardy-nuclear-waste-decision-2021-05-05/, accessed 15 July 2021.

1536 - Ibidem.

1537 - Ibidem.

1538 - SSM, "New emergency and planning zones are introduced around Swedish nuclear power plants", Strålsäkerhetsmyndigheten, see https://www.stralsakerhetsmyndigheten.se/en/press/news/2020/new-emergency-and-planning-zones-are-introduced-around-swedish-nuclear-power-plants/, accessed 30 July 2021.

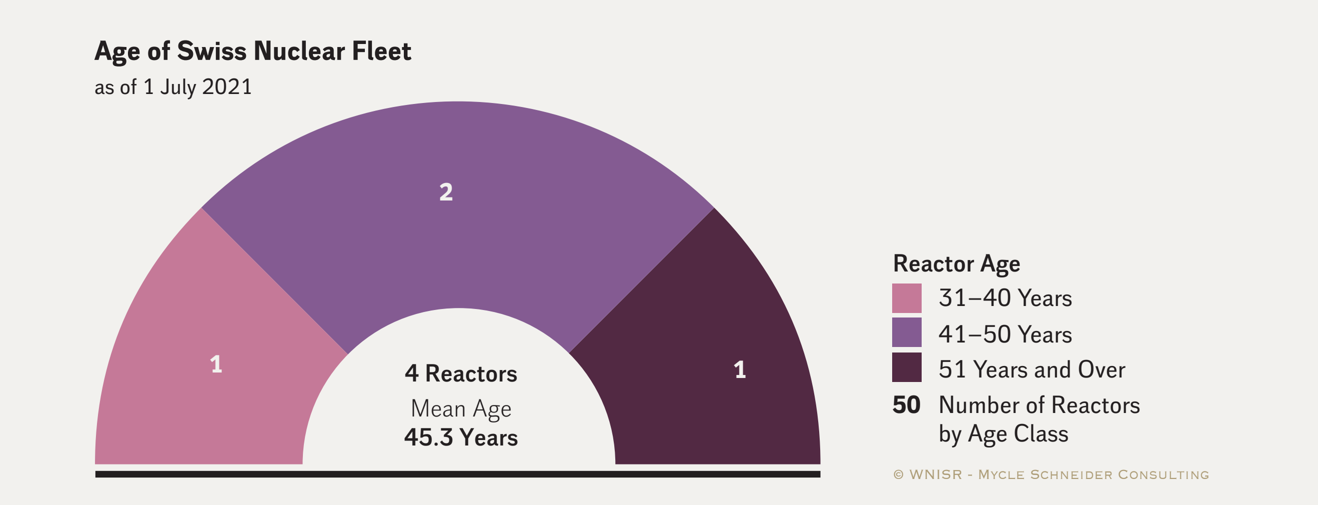
1539 - Ibidem.

points down from the previous year.[1540] With an average age of 45.3 years (see Figure 73), Switzerland operates the second oldest nuclear fleet and—with Beznau-1, age 52 since grid connection—the third oldest commercially operating reactor in the world.

In early July 2021, it was reported that the Federal Energy Office has engaged in talks with the operators of the remaining four reactors about the potential lifetime extension to 60 years.[1541] However, in Switzerland, there is no time limit on licenses. Nuclear reactors can operate as long as they are deemed safe by the safety authorities. The Swiss Energy Foundation has called the lifetime extensions "an unnecessary and dangerous game to gain time".[1542]

In October 2013, operator BKW announced that it would close its Mühleberg reactor in 2019, due to "indefinable and unquantifiable… technical, economic and political uncertainties [that] could increase the economic risks of long-term operation."[1543] In March 2016, BKW communicated that Mühleberg would be disconnected from the grid as of 20 December 2019.[1544] The closure date of the Mühleberg nuclear unit was respected with Swiss precision and the reactor was disconnected from the grid on the target date.

Figure 73 · Age Distribution of the Swiss Nuclear Fleet



Sources: WNISR, with IAEA-PRIS, 2021

On 21 May 2017, 58 percent of Swiss voters agreed to the Energy Strategy 2050 that provides a long-term policy framework based on the dynamic development of energy efficiency and renewable energies. The strategy does not fix any closure dates for nuclear power plants and aims to keep the existing reactors operating "as long as they are safe". However, it prohibits

1540 - SFOE/BFE, "Schweizerische Elektrizitätsstatistik 2020/Statistique Suisse de l'Électricité 2020", Swiss Federal Office of Energy, June 2021 (in German and French), see https://www.bfe.admin.ch/bfe/de/home/versorgung/statistik-und-geodaten/energiestatistiken/elektrizitaetsstatistik.exturl.html/aHR0cHM6Ly9wdWJkYi5iZmUuYWRtaW4uY2gvZGUvcHVibGljYX/Rpb24vZG93bmxvYWQvMTAwODY=.html, accessed 3 August 2021. The official national figures vary slightly from the IAEA-PRIS statistics.

1541 - Michel Sutter, "Laufzeitverlängerung der Kernkraftwerke sorgt für Diskussionen", *Energate Messenger*, 5 July 2021.

1542 - Ibidem.

1543 - *NIW*, "Switzerland—Briefs", 1 November 2013.

1544 - BKW, "Kernkraftwerk Mühleberg geht am 20. Dezember 2019 definitiv vom Netz—Endgültige Einstellung des Leistungsbetriebs", Press Release, 2 March 2016.

the construction of new nuclear power plants and the reprocessing of spent fuel. The "totally revised energy legislation" entered into force on 1 January 2018.[1545]

The legislation is comprehensive, providing a framework for grid development regulation, renewable energy incentives, auto-consumption, energy efficiency and the "organic phase-out" of nuclear power. The efficiency targets are ambitious, with reduction of per-capita energy consumption levels—compared to the 2000 baseline—by 16 percent by 2020 and 43 percent by 2035, while per-capita electricity consumption was to decrease by 3 percent by the end of 2020 and 13 percent by 2035.

According to the "Energy Strategy 2050 Monitoring Report 2020", final energy consumption per capita (weather-adjusted) had decreased by 18.1 percent as of the end of 2019, while per-capita power consumption had decreased by 8 percent (weather-adjusted)—both indicators exceeding the 2020 targets.[1546] In addition, per-capita power consumption decreased by another 0.8 percent in 2019, so Switzerland has again demonstrated that significantly more ambitious targets would be achievable.

Domestic production of non-hydro renewable-energy based electricity was to reach a modest target of 4.4 TWh by 2020, which, after an increase of 17.2 percent over the previous year, was achieved in 2020 with 4.7 TWh, but still represents only 5 percent of the net power generated in the country.[1547]

The request to significantly increase the targets for renewables is therefore a logical point of public demand in the ongoing debate around a new energy bill. The government has decided to liberalize the electricity market and adapt the energy legislation accordingly. It has stated that a key goal of the reform would be to stimulate distributed renewable energies, including collective auto-consumer and energy-coop schemes.[1548]

In particular the safety of Beznau-1, the eldest of the Swiss reactors, continues to raise concerns.[1549]

Meanwhile, Switzerland struggled with the implementation of a credible independent national nuclear regulator. On 24 June 2020, Martin Zimmermann resigned from his position as Chairman of the Board of the national safety authority ENSI as of the end of the month. His decision was "triggered by accusations of a lack of independence that have been expressed in

1545 - SFOE, "Wichtigste Neuerungen im Energierecht ab 2018", Swiss Federal Office of Energy, 2 November 2017 (in German), see https://www.newsd.admin.ch/newsd/message/attachments/50166.pdf, accessed 12 July 2018.

1546 - SFOE, "Energy Strategy 2050—Monitoring Report 2019", Abridged Version, Swiss Federal Office of Energy, November 2019, see https://www.bfe.admin.ch/bfe/en/home/supply/statistics-and-geodata/monitoring-energy-strategy-2050.html; and SFOE, "Stratégie Énergétique 2050—Rapport de Monitoring 2019/Energiestrategie 2050—Monitoring-Bericht 2019", November 2019 (in French and German).

1547 - SFOE, "Schweizerische Elektrizitätsstatistik 2020/Statistique Suisse de l'Électricité 2020", op. cit.

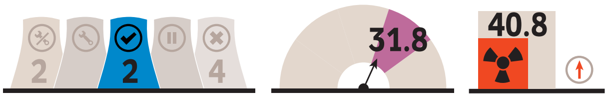
1548 - UVEK, "Bundesrat will einheimische erneuerbare Energien stärken und Strommarkt öffnen", 3 April 2020, see https://www.uvek.admin.ch/uvek/de/home/uvek/medien/medienmitteilungen.msg-id-78665.html, accessed 3 August 2020.

1549 - Simone Mohr and Christian Küppers, "Materialfehler im hochverspröden Reaktordruckbehälter des Kernkraftwerks Beznau Block 1— Stellungnahme zum Sicherheitsbericht der Axpo, zum Review des ENSI und zum Assessment des IRP bezüglich des Sicherheitsnachweises des Reaktordruckbehälters von Beznau 1", commissioned by Greenpeace Switzerland and SES, 28 June 2019; also Simon Banholzer, "Öko-Institut zweifelt am Sicherheitsnachweis von Beznau I", SES, 6 November 2019 (in German), see https://www.energiestiftung.ch/medienmitteilung/oeko-institut-zweifelt-am-sicherheitsnachweis-von-beznau-i.html, accessed 10 August 2020.

the media as well as in procedural requests", according to a statement by the ENSI Board[1550] (see WNISR2020 for details). On 1 November 2020, Marc Kenzelmann took over the ENSI Board Chair position. Kenzelmann, a professor for public economic law, has been a board member since September 2019. On the day of the 10th anniversary of the beginning of the Fukushima disaster, ENSI Board President Andreas Abegg stated that "the ENSI Board will continue to carry out its duties both vigilantly and independently, while ensuring the clear separation of ENSI's regulatory safety function on the one hand from economic and political interests on the other".[1551]

CENTRAL AND EASTERN EUROPE

Bulgaria



In Bulgaria, nuclear power provided 16 TWh or 41 percent of the country's electricity in 2020, down from a maximum of 47.3 percent in 2002, which is produced by two VVER-1000 reactors at Kozloduy.

Originally, there were six reactors on site, but the oldest four (VVER-440 v230) were closed as part of an agreement by the G7 in Munich in 1992, implemented in the agreement to join the European Union in 2007. The two VVER-1000 (V-320) reactors (Units 5 and 6), that started up in 1987 and 1991 respectively, are undergoing a relicensing program intending to try and extend their operating lifetimes for up to 60 years, compared to their initial 30-year license. In 2017, Unit 5 was awarded an additional 10-year operating lifetime, to enable it to continue operating until 2027, and in October 2019, Unit 6, was granted a license to operate until 2029. Reportedly, the total cost of the two-unit extension program was BGN292 million (US$163 million).[1552] In December 2019, the Russian fuel company TVEL announced that it had signed a five-year fuel-supply contract until 2025. This is despite previous requests from the EU for diversification of nuclear fuel supply in Bulgaria.[1553]

There have been ongoing attempts to build another nuclear power plant at Belene in Northern Bulgaria. Construction started in 1987 but was halted in 1990 and suspended indefinitely in 1991. Work officially resumed in 2008 but was abandoned again in 2012. In March 2019, the Government announced that it was preparing to select a single strategic investor for the project and started a tender procedure, which officially started after publication in the *EU Official Journal*. Initial interest has been expressed by China National Nuclear Corporation (CNNC) and Rosatom.

1550 - ENSI, "Martin Zimmermann to stand down as Chairman of the ENSI Board at the end of June 2020", 25 June 2020, see https://www.ensi.ch/en/2020/06/25/martin-zimmermann-to-stand-down-as-chairman-of-the-ensi-board-at-the-end-of-june-2020/, accessed 6 August 2020.

1551 - Andreas Abegg, "Ten years on from Fukushima, the ENSI Board still holds that safety has priority over political or economic interests", ENSI, 11 March 2021, see https://www.ensi.ch/en/2021/03/11/ten-years-on-from-fukushima-the-ensi-board-still-holds-that-safety-has-priority-over-political-or-economic-interests/, accessed 10 August 2021.

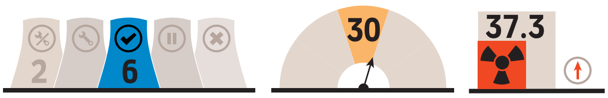
1552 - *WNN*, "Kozloduy unit 6 clear to operate for another 10 years", 2 October 2019, see https://www.world-nuclear-news.org/Articles/Kozloduy-unit-6-clear-to-operate-for-another-10-ye, accessed 4 April 2021.

1553 - *NEI*, "Russia to supply fuel to Kozloduy NPP until 2025", 5 December 2019, see https://www.neimagazine.com/news/newsrussia-to-supply-fuel-to-kozloduy-npp-until-2025-7541032/, accessed 4 April 2021.

In December 2019, during a visit from Prime Minister Boyko Borisov to the U.S., conversations were held with President Trump about the construction of Belene, including the supply of turbines by American firms. The same month, the Bulgarian Government announced that five companies had been shortlisted for negotiations, namely CNNC, Korea Hydro & Nuclear Power (KHNP) and Rosatom's subsidiary Atomenergoprom, although Russia very much sees the project as its own. Two companies, Framatome and General Electric (GE), were shortlisted to supply either the project turbine island (GE) or I&C—Instrumentation and Control systems—(Framatome) rather than the whole reactor. The finalists were expected to submit binding bids by the end of January 2020. The Government announced that investors would be able to negotiate electricity purchases with companies seeking to acquire minority stakes in Belene

However, in January 2021, the Government appeared to abandon the plans for construction of a reactor at Belene and this was reported in the English language press as "this third suspension is likely to end the Belene nuclear project forever".[1554] Nevertheless this was not officially the end of nuclear new-build, with suggestions that attention should once again be focused on building a 7th reactor at Kozloduy, which would include the movement of equipment from Belene.[1555]

Czech Republic



The Czech Republic has six Russian-designed reactors in operation at two sites, Dukovany and Temelín. The former houses four VVER-440 v213 reactors, the latter two VVER-1000 v320 units. In 2020, nuclear plants generated 28.4 TWh, similar to previous years, representing a record 37.3 percent share in electricity production.

The Dukovany units were started up during 1985–87 and have already undergone a lifetime-extension upgrading-program under the expectation they would operate until 2025. In March 2016, the state regulator extended the operating license of Dukovany-1 indefinitely[1556], with an expectation from the operator that the plant will operate until 2037 with the possibility of extension until 2047.[1557]

Over the past two decades the Government and industry have announced new initiatives to build additional reactors. In May 2018, it was reported that the government had postponed a decision saying it needed more time to evaluate the impact on its budget and find out EU views on state aid for such a project.[1558] On 13 November 2019, the Czech parliamentary committee for the construction of new nuclear resources approved the construction of the Dukovany II

1554 - Krassen Nikolov, "Bulgaria puts end to Belene nuclear project", *Euractiv.bg*, 21 January 2021, see https://www.euractiv.com/section/politics/short_news/bulgaria-puts-end-to-belene-nuclear-project/, accessed 4 April 2021.

1555 - *NEI*, "Bulgaria considers using Belene reactors to expand Kozloduy plant", 25 January 2021, see https://www.neimagazine.com/news/newsbulgaria-considers-using-belene-reactors-to-expand-kozloduy-plant-8472288/, accessed 4 April 2021.

1556 - *NucNet*, "Dukovany-2 And -3 To Undergo Extended Checks On Pipe Welds", 13 May 2016, see https://www.nucnet.org/all-the-news/2016/05/13/dukovany-2-and-3-to-undergo-extended-checks-on-pipe-welds, accessed 9 April 2021.

1557 - ČEZ, "NPP Dukovany", CEZ GROUP, n.d., see http://www.cez.cz/en/energy-generation/nuclear-power-plants/dukovany, accessed 10 May 2021.

1558 - Jan Lopatka, "Czechs put off decision on building new nuclear plants", *Reuters*, 17 May 2018, see https://www.reuters.com/article/uk-czech-nuclearpower-idUKKCN1II2SD, accessed 9 April 2021.

nuclear plant.[1559] Subsequently, Prime Minister Andrej Babis said that they would start construction in 2029 with first power in 2036. This would require holding a tender in 2021 and select a vendor by the end of 2022, two years ahead of the previous tentative schedule.[1560]

Minister of Industry Karel Havlicek told reporters in February 2020 that by the end of 2022 the supplier should be selected.[1561] In March 2020, ČEZ submitted an application to the State Office for Nuclear Safety (SÚJB) for permission to construct two new 1200 MW units at the Dukovany site. In June 2020, the government announced that it had agreed a financing model whereby the government would provide a loan covering 70 percent of the project's approximate US$6 billion price tag, while ČEZ will have to front the remaining 30 percent. The government said then it was their intention to launch a tender later in 2020.[1562]

The government is expected to prepare draft contracts with ČEZ and its project company subsidiary that would establish a long-term (30-40 years) offtake agreement from the prospective newbuild, in order to give the project greater financial security. It is also suggested that the Government is prepared to guarantee the project's legislative and regulatory risks, so that if a subsequent government were to phase out nuclear power, it would be committed to buy the project and reimburse the investor's expenses.[1563] It is not clear how the contracts between the state and ČEZ will be drawn up to provide such guarantees to ČEZ and minority shareholders.

The choice of vendor for the project is controversial and could even threaten the whole project. Initially five designs were said to be in the running, including Korea Electric Power Co's (KEPCO's) "APR1000+", a revised EPR from EDF ("EPR1200"), both of which are yet to be built anywhere, an AP1000 from Westinghouse, and reactors from China General Nuclear Power Corporation (CGN) and Rosatom of Russia. However, in early 2021, CGN was ejected from the process—due to security concerns—and the Czech Parliament delayed a final decision as the opposition demanded the Rosatom design also be removed.[1564] Subsequently, the government unanimously approved the resolution and Deputy Prime Minister Karel Havlícek said that security assessment will only be given to suppliers from France, South Korea and the U.S.[1565]

The Government remains determined to proceed with the project and to keep the power purchase agreement (PPA) competitive with €50-€60 (US$61–73/kWh). However, this can only be achieved by significantly increasing the state liabilities through providing 100-percent state-lending, a 60-year rather than 30-year PPA and keeping construction costs to €4,500–5,000 (US$5300–6100/kW). Initially, the Government had hoped to launch the tender

1559 - *NEI*, "Czech Republic approves new unit for Dukovany", 18 November 2019, see https://www.neimagazine.com/news/newsczech-republic-approves-new-unit-for-dukovany-7513325/, accessed 9 April 2021.

1560 - *NIW*, "Briefs – Czech Republic", 15 November 2019.

1561 - *NEI*, "ČEZ applies to build new nuclear units at Dukovany", 30 March 2020, see https://www.neimagazine.com/news/newscez-applies-to-build-new-nuclear-units-at-dukovany-7844971/, accessed 9 April 2021.

1562 - Gary Peach, "Prague Announces 70% Financing for Dukovany", *NIW*, 5 June 2020.

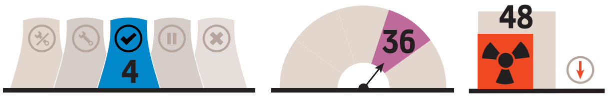
1563 - Phil Chaffee, "Newbuild: Prague AdvancesDukovany Plans", *NIW*, 1 May 2020.

1564 - *NIW*, "Czech Parliament Delays Dukovany", 12 February 2021.

1565 - *NIW*, "Prague Excludes Rosatom From Dukovany II", 23 April 2021.

before the Autumn 2021 elections, but later said that the decision would be taken by the next government.[1566]

Hungary



Hungary has one operating nuclear power plant, at Paks, where four VVER-440 v213 reactors provided a stable 15 TWh or 48 percent of the country's electricity in 2020. The nuclear share in the national power mix is down from 53.6 percent in 2014. The reactors started operation 1982–7 and have been the subject of engineering works to enable their operation for up to 50 years (compared to their initial 30-year license). The first unit received permission to operate for another 20 years in 2012, the second unit in 2014, the third in 2016 and the fourth in December 2017, enabling operation until the mid-2030s.

For over a decade plans have been discussed and developed to build a new nuclear power plant. In March 2009, the Parliament approved a government decision-in-principle to build additional reactors and a tender was prepared according to European rules. In 2014, the Paks II project was suddenly awarded to Rosatom without reference to the public tender, with Russia financing 80 percent of the project in loans. In February 2017, during a visit to Hungary, Russia's President Putin confirmed that it was even willing to fund 100 percent of the estimated €12 billion (US$12.9 billion) investment.[1567] The original Russian-Hungarian bilateral financing agreement consisted of a €10 billion (US$11.3 billion) loan to the Hungarian state, to be repaid starting in 2026, irrespective whether the project would be online at that time. Hungary itself will have to invest 20 percent or €2 billion (US$2.3 billion) into the project. Then in April 2021, the loan terms were revised so that Hungary would start repaying the loan in 2031, five years later than originally agreed.[1568]

In November 2016, the European Commission cleared the award of the contract to Rosatom of any infringement on its procurement rules, and in March 2017, it also approved the financial package for Paks II.[1569] However, in February 2018 the Austrian Government challenged the validity of the decision, which, as of mid-2021, was still under review by the European Court of Justice.[1570] The legal challenge has subsequently been supported by the Luxembourg Government.

The plant was granted an environmental license in September 2016, and in March 2017 the Hungarian Atomic Energy Authority (HAEA) approved the site license for the new

1566 - *BNE Intellinews*, "Tender for Czech nuclear power plant Dukovany to be left to new government", 29 March 2021, see https://www.intellinews.com/tender-for-czech-nuclear-power-plant-dukovany-to-be-left-to-new-government-206633/, accessed 10 May 2021.

1567 - *NIW*, "Briefs – Hungary", 3 February 2017.

1568 - *WNN*, "Hungary gets agreement to delay Paks II loan repayment", 30 April 2021, see https://www.world-nuclear-news.org/Articles/Hungary-gets-agreement-to-delay-Paks-II-loan-repay, accessed 1 May 2021.

1569 - European Commission, "State Aid—Hungary—SA.38454 (2015/C) (ex 2015/N)— Possible aid to the Paks nuclear power station", Official Journal of the European Union, 12 January 2016, see https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A32017D2112, accessed 10 April 2021.

1570 - *WNN*, "Austria takes EC to court over Paks decision", 23 February 2018, see https://www.world-nuclear-news.org/NP-Austria-takes-EC-to-court-over-Paks-decision-2302184.html#:~:text=Austria%20has%20launched%20a%20lawsuit,the%20Paks%20nuclear%20power%20plant., accessed 10 April 2021.

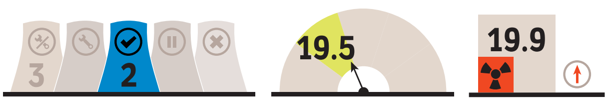
construction.[1571] However, since then, there have been increasing concerns over the impact of hotter summers on the cooling water availability due to higher water temperatures from the Danube River, especially if both Paks I and II are in operation. Within the EIA process the solution to this problem was to reduce output from the plants when cooling water availability was limited, which would affect the economics of the project and the demand-supply grid balance.[1572]

In June 2019, a ceremony was held with representatives of Rosatom to mark the start of the erection of buildings at the site and in October 2019, Rosatom handed in the project technical documents. On 30 June 2020, Paks II Ltd. submitted the construction license application to the HAEA. The regulatory procedure started its assessment the next day and HAEA has 12 months to make known its views.[1573] That period could be—and has been—extended by an additional three months.[1574] If all did go according to plan, site preparation would take an additional 18 months, therefore formal construction is to start in mid-2022, some six years after the Hungarian and Russian Government signed the corresponding intergovernmental agreements.

Power production is therefore likely to be in 2030, rather than the 2025 originally envisaged. It has been noted that the government has ceased pressing for the project to proceed. Russia, where the economy is suffering, awarded the project a fixed price contract that "might no longer be favorable", while in Hungary cheaper solar deployment is rapidly highlighting the high costs of Paks II, which would be borne by the taxpayers.[1575]

In May 2021, the Austrian Federal Environmental Agency published a report which found that the Dunaszentgyörgy-Harta seismic fault passes through the Paks II site and is both an active and a capable fault. The assessment concludes that "The Paks II site should therefore be deemed unsuitable". The Hungarian authorities, responding to the publication of the Austrian report, stated that the licensing process had not found any issues that indicated that the site was unsuitable.[1576]

Romania



Romania has one nuclear power plant at Cernavoda, where two Canadian-designed CANDU reactors are in operation. In 2020, they provided a stable 10.6 TWh or 20 percent of the country's electricity, compared to 18.5 percent in 2019.

1571 - *NIW*, "Briefs – Hungary", 31 March 2017.

1572 - Gary Peach, "Five Years on, Hungary's Paks Expansion Stumbles Along", *NIW*, 8 February 2019.

1573 - HAEA, "Paks II. Ltd. submitted the construction license application to the HAEA", Hungarian Atomic Energy Authority, 30 June 2020, see http://www.oah.hu/web/v3/HAEAportal.nsf/web?OpenAgent&article=news&uid=5B9108F378B8DFBCC1258597003BF3DE, accessed 10 April 2021.

1574 - Hungarian Atomic Energy Authority, "Hirdetmény közzététele az ügyintézési határidő meghosszabbításáról a paksi telephelyen létesítendő 5. és 6. atomerőművi blokkok létesítési engedélyezési eljárásában", 19 May 2021 (in Hungarian), see https://www.haea.gov.hu/web/v3/oahportal.nsf/web?OpenAgent&article=news&uid=4346A8D52E23910EC12586DA0023F45A, accessed 24 May 2021.

1575 - Gary Peach, "Hungary: Exorbitant Costs, Solar Energy Remove Luster From Paks II", *NIW*, 22 May 2020.

1576 - Eszter Zalan, "Hungary's nuclear power plant expansion unnerves Austria", *EUobserver*, 7 June 2021, see https://euobserver.com/climate/152035, accessed 19 June 2021.

The reactors are the only CANDU reactors operating in Europe. Construction started between 1982 and 1987, initially on five reactors. Unit 1 was completed in 1996, and Unit 2 started up in 2007, 14 and 24 years after construction started. The two units were partly funded by the Canadian Export Development Corporation, the second also partly by the Euratom Loan Facility. As with other CANDU reactors, major refurbishment will be needed after longer operation, and in January 2020 a US$10.8 million contract was signed with Candu Energy, part of the Canadian SNC-Lavalin Group, to undertake engineering analysis and assessments on the fuel channels to enable Unit 1 to operate until a large-scale refurbishment expected in 2026.[1577]

Various foreign companies have been involved in the attempts to revive the construction of Units 3, 4 and 5. In November 2013 the Cernavoda operator, state-owned electricity producer Societatea Nationala Nuclearelectrica (SNN) and China General Nuclear (CGN) signed a letter of intent. This was followed in November 2015 with the signing of a Memorandum of Understanding (MoU) between Nuclearelectrica and CGN for the construction, operation and decommissioning of Units 3 and 4. The MoU also included agreements on investments, and remarkably, CGN was to be the majority share owner of the project with at least 51 percent of the shares.[1578] In January 2016, the Romania Government formally expressed support for the project. The cost of the completion of two reactors with 720 MW each was expected to be US$7.8 billion.[1579] However, in January 2020 the Government announced that it would cancel the deal and Prime Minister Ludovic Orban stated that “the partnership with the Chinese company is not going to work”.[1580]

The Government claims it has not abandoned the project but rather would be looking for additional partners. It is suggested that one of the reasons why the partnership with China has been abandoned is the signing of a nuclear co-operation agreement with the U.S. signed in August 2019. In October 2020, Adrian Zuckerman, the U.S. ambassador to Romania, said in a speech at the initialing of an intergovernmental agreement. “Now we have a great clean American company, Aecom, leading this $8 billion project, with assistance from clean Romanian, Canadian and French companies.”[1581] Shortly following this, Romania and France signed a declaration of intent for a partnership on the construction of Units 3 and 4 and the upgrade of reactor 1.[1582]

1577 - *NEI*, “Romania cancels China deal on Cernavoda but proceeds with life extension”, 24 January 2020, see https://www.neimagazine.com/news/newsromania-cancels-china-deal-on-cernavoda-but-proceeds-with-life-extension-7653710, accessed 10 April 2021.

1578 - *Romania Insider*, “Romania and China seal deal for Cernavoda nuclear plant expansion”, 9 May 2019, see https://www.romania-insider.com/index.php/romania-china-seal-deal-nuclear-plant, accessed 10 April 2021.

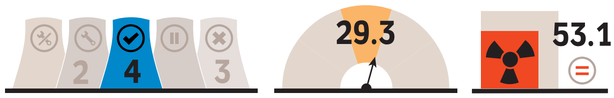
1579 - *WNN*, “Romania expresses support for China’s role at Cernavoda”, 25 January 2016, see https://www.world-nuclear-news.org/NN-Romania-expresses-support-for-China-role-at-Cernavoda-25011601.html, accessed 10 April 2021.

1580 - *NEI*, “Romania Cancels China Deal on Cernavoda but Proceeds with Life Extension”, 24 January 2020, see https://www.neimagazine.com/news/newsromania-cancels-china-deal-on-cernavoda-but-proceeds-with-life-extension-7653710, accessed 29 July 2021.

1581 - *NIW*, “Aecom to Lead $8 Billion Completion of Romania’s Cernavoda-3 and -4”, 9 October 2020, see https://www.energyintel.com/pages/articlesummary/1086555/aecom-to-lead--8-billion-completion-of-romania-s-cernavoda-3-and--4.

1582 - *NEI*, “Romania and France to partner on Cernavoda expansion”, 29 October 2020, see https://www.neimagazine.com/news/newsromania-and-france-to-partner-on-cernavoda-expansion-8206702/, accessed 10 April 2021.

Slovakia



In Slovakia, the state utility Slovenské Elektrárne (SE) operates two nuclear sites, Jaslovské Bohunice, which houses two operating VVER-440 v213 units, and Mochovce, which has two similar reactors. In 2020, their production was a stable 14.4 TWh or 53 percent of the country's electricity.

The country has three permanently closed reactors at the Bohunice site. The A-1, a small 92 MW unit which started operation in 1972, was closed in 1977 following several accidents. The other two VVER-440 v230 reactors were closed in 2006 and 2008, as part of the agreement to join the European Union in 2004.

Units 1 and 2 at the Mochovce plant were started up in 1998 and 1999 respectively. Modernization and upgrading of the units began in August 2020, increasing their output from 471 MWe to 500 MWe. In October 2004, the Italian national utility ENEL (Ente Nazionale per l'Energia Elettrica) acquired a 66 percent stake in SE and, as part of its bid, proposed to invest nearly €2 billion (US$2.7 billion) in new nuclear generating capacity, including completion of the third and fourth blocks of Mochovce, whose construction originally began in January 1985.

In February 2007, SE announced that it was proceeding with the completion of Mochovce-3 and -4 and that ENEL had agreed to invest €1.8 billion (US$$_{2007}$2.6 billion). According to the IAEA's PRIS, construction restarted in June 2009, and, at the time, the units were expected to generate power in 2012 and 2013 respectively.

Towards the end of 2014, ENEL announced it was seeking to sell its share in SE and had received several non-binding bids. In December 2015, Czech holding EPH (Energeticky a Prumyslovy Holding) was revealed as the bid winner, with a preliminary price of €750 million (US$812 million). Under the deal, ENEL got €150 million (US$171 million) in the first stage, in which EPH received a share of 33 percent in the company, the remaining share and final price to be agreed one year after Mochovce is completed.

The construction project continues to be plagued by problems, and by May 2016, the estimate for the total costs of completion of Units 3 and 4 had risen to €5.1 billion (US5.7_{2016}$ billion), with startup at the end of 2016/early 2017.[1583] In March 2017, SE announced a considerable further delay in the project, with operation expected only at the end of 2018 and 2019. This is an additional two years of construction, while the officially expected cost increase was only €300 million (US$333 million).[1584] As of early 2018, completion of the projects was still expected at the end of 2018 and 2019.[1585]

In April 2019, Mochovce-3 completed "hot testing" in preparation for fuel loading in the summer, although the regulatory process could at that time still take eight months. A new delay was reported to add an estimated €270 million (US$305 million) to the cost, representing

1583 - *Spravy Pravda*, "Ďalšie peniaze na Mochovce? Žiga nemá oficiálnu informáciu" ["Additional money for Mochovce ?"], 5 May 2016 (in Slovak), see http://spravy.pravda.sk/ekonomika/clanok/392783-dalsie-peniaze-na-mochovce-ziga-nema-oficialnu-informaciu/, accessed 10 April 2021.

1584 - *WNN*, "Slovak utility increases Mochovce expansion budget", 31 March 2017, see http://www.world-nuclear-news.org/NN-Slovak-utility-increases-Mochovce-expansion-budget-31031701.html, accessed 10 April 2021.

1585 - *NIW*, "Briefs—Slovakia", 31 January 2020.

a 5 percent increase and bringing the total to €5.4 billion (US$6.1 billion).[1586] However, in September 2019, it was announced that the Nuclear Regulatory Authority (ÚJD) would require further modifications prior to fuel loading.[1587] In January 2020, the nuclear regulator reported two deficiencies in Unit 3 following a second round of hot testing. SE had to submit a plan for corrective action.[1588]

Fuel loading has been further delayed, and prior to the COVID-19 pandemic, it was expected at the beginning of the summer of 2020. "In the worst case, it will be the end of 2020" said Branislav Strýček, CEO of SE.[1589] In June 2020, the regulator announced a six month "extension of the period for decision in the administrative proceeding for authorization for commissioning of nuclear installation of the Unit 3".[1590] Furthermore, the regulator found "insufficient documentation of compliance with quality requirements, i.e. the permit holder has yet to complete, supplement or specify documentation proving the quality of certain equipment and work performed".[1591]

In December 2020, an additional loan agreement was made between ENEL and SE for a maximum of US$570 million, to enable the completion of both units. This brings the expected construction cost to US$6.2 billion (US$7,000/kWe), with fuel loading at Unit 3 then expected by April 2021—it did not happen—and at Unit 4 in 2023.[1592]

In May 2021, ÚJD finally issued permits allowing operation as well as related permits for radioactive waste and used fuel management.[1593] The permits are subject to a public comment period, which started on 4 June 2021, with a 15-day window for appeals. The Austrian Government has objected to the licensing and asked for an independent assessment.[1594] The startup of Unit 3 is expected later in 2021.

On 15 April 2019, the Slovak anti-corruption police raided several SE offices, including those at Mochovce, and arrested the former CEO of SE, Paolo Ruzzini, and Nicola Cotugno, former Mochovce director and Ruzzini's successor at SE on corruption charges. Both were involved in the privatization of SE to ENEL in 2004 and responsible for the restart of the Mochovce-3 and -4

1586 - *WNN*, "Mochovce 3 completes commissioning test", 16 April 2019, see https://www.world-nuclear-news.org/Articles/Mochovce-3-completes-commissioning-test, accessed 10 April 2021.

1587 - *NEI*, "Hot testing of Mohovce 3 revealed the need for further modifications", 18 September 2019, see https://www.neimagazine.com/news/newshot-testing-of-mohovce-3-revealed-the-need-for-further-modifications-7413902/, accessed 10 April 2021.

1588 - *NIW*, "Briefs—Slovakia".

1589 - SE, "Mochovce 3: Nuclear authority issued a draft decision on fuel loading", Slovenské Elektrárne, Press Release, 18 February 2020, see https://www.seas.sk/article/mochovce-3-nuclear-authority-issued-a-draft-decision-on-fuel-loading/409, accessed 10 April 2021.

1590 - ÚJD SR, "Announcement of the Nuclear Regulatory Authority of the Slovak Republic on the extension of the period for decision in the administrative proceeding for authorization for commissioning of nuclear installation of the Unit 3 - NPP Mochovce", Press Release, 16 June 2020, see https://www.ujd.gov.sk/ujd/www1.nsf/$All/4188834860C1B178C125858B002981AB, accessed 10 April 2021.

1591 - *NEI*, "Slovakia's Mohovce 3 commissioning slowed by insufficient documentation", 3 September 2020, see https://www.neimagazine.com/news/newsslovakias-mohovce-3-commissioning-slowed-by-insufficient-documentation-8116778, accessed 7 January 2021.

1592 - *WNN*, "Mochovce new-build project receives loan boost", 24 December 2020, see https://www.world-nuclear-news.org/Articles/Mochovce-new-build-project-receives-loan-boost, accessed 10 April 2021.

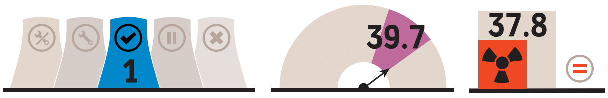
1593 - *NEI*, "Slovak regulator issues permit for commissioning of Mochovce 3", 17 May 2021, see https://www.neimagazine.com/news/newsslovak-regulator-issues-permit-for-commissioning-of-mochovce-3-8749322, accessed 5 July 2021.

1594 - Christoph Matzl, "AKW-Löschsystem entspricht Standards nicht: "Feuer am Dach" in der Atomruine Mochovce", *Kronen Zeitung*, 18 June 2021 (in German), see https://www.krone.at/2440644, accessed 5 July 2021.

construction.[1595] Another raid was undertaken one year later, in March 2020, when the national criminal agency entered the Mochovce site looking into a discrepancy between the "composition, manufacturing process or origin" of certain components at the reactors and their documentation, relating to one pipe subcontractor. However, the press reported concerns the investigation could spread to other suppliers, further delaying startup.[1596]

In addition to the delays and cost overruns, concerns have been raised about the state of the power market, with prices currently at very low levels with €20–25/MWh (US$21–27/MWh) and electricity demand following the sluggish economy and the short- and medium-term impact of COVID-19 pandemic.

Slovenia



Slovenia jointly owns the Krsko nuclear power plant with Croatia—a 696-MW Westinghouse PWR. In 2020, it provided a stable 6 TWh or 38 percent of Slovenia's electricity, a nuclear share well below the maximum of 42.4 percent in 2005. The reactor is built in an earthquake zone and on 29 December 2020 it was shut down temporarily following a 6.3 magnitude event close to the town of Petrinja in the Zagreb region, around 30 km from the plant.[1597] In March 2021, the Austrian Environmental Group Global 2000 released a report which highlighted the seismic vulnerability of the site and called for not only further technical review, but new geological investigations.[1598]

The reactor was started in 1981 with an initial operational life of 40 years. In July 2015, an Inter-State Commission agreed to extend the plant's operational lifetime to 60 years, so that it would continue until 2043, as well as to construct a dry storage facility for the spent fuel. In May 2016, a spokeswoman for the operator NEK (Nuklearna Elektrarna Krško) said: "The lifespan of Krsko has been extended providing that the plant passes a security check every 10 years with the next checks due in 2023 and 2033."[1599] In 2018, the operator announced around €50 million (US$57 million) worth of investment being planned for 2019, mostly for completing safety upgrades (partially implementing findings of EU post-Fukushima stress tests) and replacing obsolete equipment. The first outage for that was undertaken in October 2019, followed by a second one in April 2021, which lasted one month. On 25 March 2021, the Austrian National Council voted unanimously on a resolution instructing the country's Environment Minister to work towards the avoidance of the lifetime extension of Krško.

1595 - *TASR*, "NAKA na letisku zadržala exšéfa Slovenských elektrární. Preverujú podozrenia týkajúce sa Mochoviec", *FinWeb*, 15 April 2019 (in Slovak), see https://finweb.hnonline.sk/ekonomika/1924600-naka-na-letisku-zadrzala-exsefa-slovenskych-elektrarni-preveruju-podozrenia-tykajuce-sa-mochoviec, accessed 10 April 2021.

1596 - Phil Chaffee, "Slovakia: Police Raid Mochovce New Build", *NIW*, 6 March 2020.

1597 - *NEI*, "Krsko nuclear plant restarts after earthquake triggers shutdown", 4 January 2021, see https://www.neimagazine.com/news/newskrsko-nuclear-plant-restarts-after-earthquake-triggers-shutdown-8435716/, accessed 10 April 2021.

1598 - Oda Becker and Patricia Lorenz, "Nothing learned from Fukushima: Atomic stress tests in the Slovenian Krško nuclear power plant still not implemented", Global 2000, March 2021, see https://www.global2000.at/sites/global/files/2021-AtomStresstest.pdf, accessed 5 July 2021.

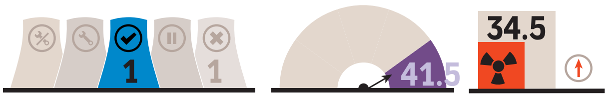
1599 - *NEI*, "Life extension for Slovenia's Krslo NPP", 6 May 2016, see http://www.neimagazine.com/news/newslife-extension-for-slovenias-krslo-npp-4885976/, accessed 10 April 2021.

As part of the co-ownership, Croatia is partly responsible for waste management and its preferred location for storage of the material produced by the Krško plant is proving controversial with its neighbors as it is only one km from its border with Bosnia and Herzegovina whose Foreign Minister, in April 2020, characterized the proposal as unacceptable.[1600]

In January 2010, an application was made by the nuclear operator to the Ministry of Economy to build an additional unit, but no advancement of the project has been reported ever since.

FORMER SOVIET UNION

Armenia



Armenia has one remaining reactor at the Metsamor nuclear power plant, situated within 30 kilometers of the capital Yerevan. The Armenian-2 called reactor provided 2.6 TWh or 34.5 percent of the country's electricity in 2020, up from the previous year by 6.7 percentage points but down from a maximum nuclear share of 45 percent in 2009.

The reactor started generating electricity in January 1980 and is a first-generation, Soviet-designed reactor, a VVER-440 v270. In December 1988, Armenia suffered a major earthquake that led to the rapid closure of its two reactors in March 1989. During the early 1990s and following the collapse of the former Soviet Union, a territorial dispute between Armenia and Azerbaijan resulted in an energy blockade that led to significant power shortages which led to the Government's decision in 1993 to re-open Unit 2 at Metsamor. Since 2003, the Metsamor plant is operated by InterRAO, a subsidiary of Russian Rosatom, as a part of an arrangement to repay debts to Rosatom's TVEL fuel supplier.

In October 2012, the Armenia Government announced that it planned to operate Metsamor until 2026. The lifetime extension was made possible by a Russian loan of US$270 million and a US$30 million grant. In 2011, the Armenian Nuclear Regulatory Authority had granted the reactor an extension of its operating license until 2021, subject to annual safety demonstrations starting 2016.[1601]

In June 2016, the European Nuclear Safety Regulators Group (ENSREG) issued the "EU Peer Review Report of the Armenian Stress Tests"[1602] confirming numerous safety-related problems. In September 2017, the European Commission published its proposed partnership agreement with Armenia, which included recommendations for co-operation on "the closure and safe decommissioning of Metsamor nuclear power plant and the early adoption of a road

1600 - Igor Todorović, "BiH warns Croatia against storing nuclear waste from Krško at border", *Balkan Green Energy News*, 3 April 2020, see https://balkangreenenergynews.com/bih-warns-croatia-against-storing-nuclear-waste-from-krsko-at-border/, accessed 10 April 2021.

1601 - *NEI*, "Armenian NPP to close for refurb", 21 March 2019, see https://www.neimagazine.com/news/newsarmenian-npp-to-close-for-refurb-7054023/, accessed 10 April 2021.

1602 - ENSREG, "EU Peer Review Report of the Armenia Stress Tests", June 2016, see http://www.ensreg.eu/document/armenia-stress-tests-peer-review-20-24-june-2016, accessed 10 April 2021.

map or action plan to that effect."[1603] Opposition parties in Turkey called on their Government in December 2019 through a parliamentary resolution to take steps to resolve the risks posed by Metsamor. In March 2019, Armenian Prime Minister Nikol Pashinyan stated that there were no plans to close Metsamor and that "we will extend the lifecycle of the nuclear power station as long as possible, although it is clear that it cannot work forever."[1604]

In February 2020, Government officials said that they were considering, as part of the country's 2040 energy strategy, further extending the life of the reactor along with measures to increase its output by 12-15 percent.[1605] This was confirmed in January 2021, when the cabinet approved the 2040 energy strategy, which notes that the current US$330-million-investment program, designed to extend the operating life of Unit 2, will be completed by 2023. A consequence of the program is the closure of the unit for at least 140 days in 2021. The energy strategy also says that, if the safe operation is confirmed, the government will operate the facility at least until 2036, which is expected to require additional investments of US$150 million.[1606] The plan also includes proposals for the construction of an additional reactor.[1607]

For years, Armenia has been negotiating with Russia for the construction of a new 1000 MW unit and signed an intergovernmental agreement to that effect in August 2010. Since then, little progress has been made, and there is no clear choice on future technologies, with some proposing the development of Small Modular Reactors (SMRs).[1608]

In March 2020, the European Commission published a Communication proposing a new "Eastern Partnership Policy Beyond 2020", which included recommendations on energy policy and nuclear power. The proposal notes that diversification of fuel supply is necessary, notably via renewable energy sources. Furthermore, it acknowledges that countries may choose nuclear power but that "the EU's forerunner role in binding nuclear legislation will be the basis of further bilateral exchanges. We will continue to organize nuclear stress test peer reviews and follow-up activities".[1609]

The power plant remains a source of continual tension with neighboring Azerbaijan and in July 2020 a senior Azerbaijani official threatened a missile strike against Metsamor during renewed fighting on the Armenia-Azerbaijan border. Furthermore, Galib Israfilov, Azerbaijan ambassador to the IAEA, sent a letter to the Director General in which he said the "continued

1603 - European Commission, "Annex to the Joint Proposal for a Council Decision on the conclusion, on behalf of the European Union, of the Comprehensive and Enhanced Partnership Agreement between the European Union and the European Atomic Energy Community and their Member States, of the one part and the Republic of Armenia, of the other part.", 25 September 2017, see https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A52017JC0037, accessed 10 April 2021.

1604 - *NEI*, "Armenian NPP to close for refurb", 21 March 2019, see https://www.neimagazine.com/news/newsarmenian-npp-to-close-for-refurb-7054023/, accessed 10 April 2021.

1605 - *NEI*, "Armenia considers further life extension for Metsamor -", 2 March 2020, see https://www.neimagazine.com/news/newsarmenia-considers-further-life-extension-for-metsamor-7802500, accessed 10 April 2021.

1606 - *NEI*, "Armenia to extend nuclear plant service beyond 2026", 18 January 2021, see https://www.neimagazine.com/news/newsarmenia-to-extend-nuclear-plant-service-beyond-2026-8457690/, accessed 10 April 2021.

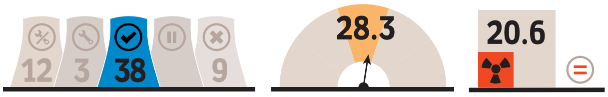
1607 - Phil Chaffee, "Interview: Azerbaijan Eager for Mechanism to Address Metsamor Concerns", *NIW*, 7 August 2020.

1608 - *Arka News Agency*, "Minister: Armenia not to give up the idea of building new nuclear power plant", 20 October 2017, see http://arka.am/en/news/technology/minister_armenia_not_to_give_up_the_idea_of_building_new_nuclear_power_plant/, accessed 10 April 2021.

1609 - European Commission and High Representative of the Union for Foreign Affairs and Security Policy, "Eastern Partnership policy beyond 2020 — Reinforcing Resilience - an Eastern Partnership that delivers for all", 18 March 2020, see https://eeas.europa.eu/sites/eeas/files/1_en_act_part1_v6.pdf.

operations of Metsamor NPP would be a high risk for the entire region due to potential earthquakes in the immediate area.”[1610]

Russia



In 2020, nuclear energy contributed 20.6 percent to the country’s electricity mix with another record production of 202 TWh of electricity as new reactors have come online in 2019–2020.

2020 saw one new reactor, Leningrad 2-2, connected to the grid in October with the start of commercial operation in March 2021, and the closure of Unit 2 at the original Leningrad station, a 925 MW Chernobyl-type RBMK in November.[1611] Consequently, as of mid-2021, 38 reactors are operating in the Russian Federation and nine are permanently closed.

Two large reactors remain under construction at Kursk II, which is a particularly important project, as they would be the first of the latest Russian design, the VVER-TOI (VVER-V-510). These are 1200 MW, Generation III+ design, and destined for export. At construction start of Unit 1, completion was scheduled for late 2023, and in April 2020, the first deputy director for construction claimed that the project was on schedule.[1612]

In June 2020, Rosenergoatom announced that preparation work would begin for the construction of four new reactors, Units 3 and 4 at Leningrad II, as well as two reactors at Smolensk.[1613]

In June 2021, Rosatom announced that it has started construction of an innovative fast reactor that will use liquid lead as a coolant and uranium-plutonium nitride for fuel. The objective for the BREST-OD-300 reactor is for it to operate by 2026 and it is said to cost 100 billion rubles (US$1.4 billion).[1614]

Construction started at Baltic-1, a 1109 MW VVER-491 reactor project, in February 2012. However, construction was suspended in June 2013 for a variety of reasons, including recognition of the limited market for electricity. Accordingly, WNISR has removed it from the project construction listing. Despite no indication that construction has ever restarted, the project remains “under construction” in IAEA-PRIS statistics.

In August 2016, a Government decree called for the construction of an additional 11 reactors by 2030, including two new Fast Breeder Reactors (FBRs), a VVER-600 at Kola, and seven new VVER–TOI units at Kola, Smolensk, Nizhny Novgorod, Kostrom and Tatar.[1615]

1610 - Phil Chaffee, “Interview: Azerbaijan Eager for Mechanism to Address Metsamor Concerns”, *NIW*, 2020, op. cit.

1611 - *NEI*, “Leningrad-II-2 begins commercial operation”, 23 March 2021, see https://www.neimagazine.com/news/newsleningrad-ii-2-begins-commercial-operation-8618701/, accessed 10 April 2021.

1612 - *NEI*, “Russia’s Kursk II on schedule”, 14 April 2020, see https://www.neimagazine.com/news/newsrussias-kursk-ii-on-schedule-7872033/, accessed 10 April 2021.

1613 - *WNN*, “Russia begins preparatory work for four new reactors”, 26 June 2020, see https://www.world-nuclear-news.org/Articles/Russia-begins-preparatory-work-for-four-new-reacto, accessed 10 April 2021.

1614 - *NIW*, “Construction Starts on Lead-Cooled Fast Reactor”, 11 June 2021.

1615 - *WNN*, “Russia to build 11 new nuclear reactors by 2030”, 10 August 2016, see https://www.world-nuclear-news.org/NP-Russia-to-build-11-new-nuclear-reactors-by-2030-10081602.html#:~:text=A%20Russian%20government%20decree%20published,sodium%2Dcooled%20fast%20neutron%20reactors, accessed 10 April 2021.

In early 2017, the CEO of Rosatom said that the Government would end state support for the construction of new nuclear units in 2020, and therefore any new reactors would have to be financed primarily via commercial nuclear energy projects on the international market. Even before this date, the budget for construction of new reactors was expected to be a modest US$250–280 million in the period 2018–2020,[1616] which may explain the lack of new construction in Russia beyond Kursk II.

In March 2021, in its strategic review Rosatom said that by 2045 nuclear should provide 25 percent of the country's electricity. This will, according to Rosatom CEO Alexei Likhachev, require the commissioning of 24 blocks, including at new sites and in new regions.[1617] According to the WNA's nuclear profile for Russia, as of May 2021, the Government estimated that 15 units will be completed in or by 2030, including the two reactors under construction (Kursk 2-1 and 2-2).[1618] Their list then includes two more reactors at Leningrad and two reactors at Smolensk (2-1 and 2-2). However, it was reported that Rosatom received a budget of only 880 billion rubles (US$11 billion) and not the requested 1.16 trillion rubles (US$15.6 billion) for construction through to 2035. In the summer of 2020, Rosatom announced that it would build four new reactors (two VVER-1200 and two VVER-TOIs) to replace the aging RBMKs.[1619] Commissioning of the fast reactor at Beloyarsk was delayed until 2036, from 2027. Therefore, with actual construction ongoing on only two units, it is extremely unlikely that any of these reactors will be operational by the start of the next decade. There are also plans to expand the construction of floating nuclear plants and to increase their output, although no specific timetables have been published.

Russia has closed nine power generating reactors: Obninsk-1, Beloyarsk-1 and -2, Bilibino-1, Leningrad-1 and -2 and Novovoronezh 1–3. The average age of the Russian reactor fleet is now 28.3 years, with close to two thirds being 31 years or more, of which 11 operated for 41 years or more. (see Figure 74). Therefore, a key issue for the industry is how to manage its aging units.

There are six classes of reactors in operation: the RBMK (a graphite-moderated reactor of the Chernobyl type), the VVER-440, the VVER-1000, the VVER-1200, the KLT-40 and FBRs. Designed for an operational lifetime of 30 years both the RBMKs and VVER-440 designs have been granted 15-year lifetime extensions to enable them to operate for 45 years. There are plans to extend the operating life in some cases to 60 years[1620], while the VVER-1000s are expected to work for up to 50 years. Consequently, the closure of Leningrad-1 and -2 is potentially a significant event, as, after 45 years of operation, it would indicate that 60-year operational lifetime is beyond the RMBK potential.

1616 - *NIW*, "Briefs – Russia", 22 September 2017.

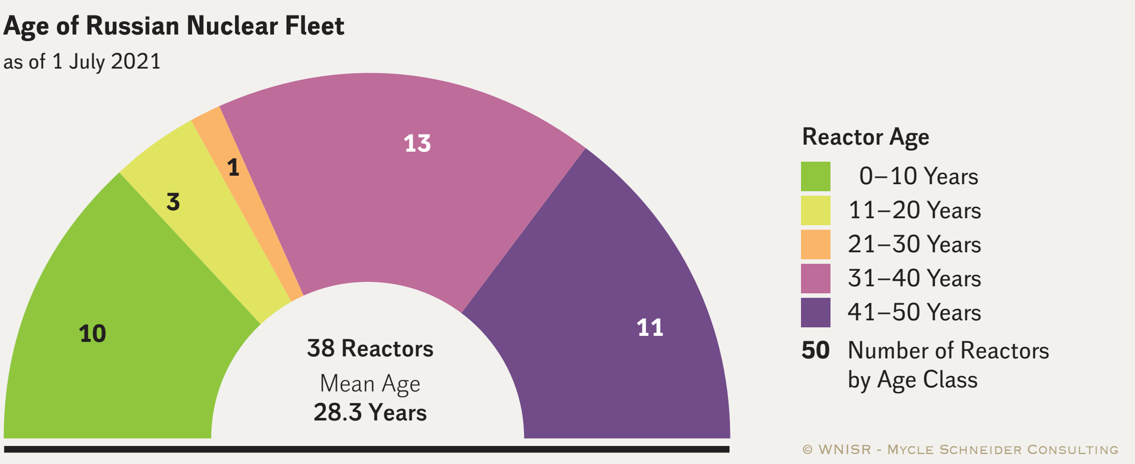
1617 - *NEI*, "Rosatom's development plans", 11 March 2021, see https://www.neimagazine.com/news/newsrosatoms-development-plans-8592063/, accessed 10 April 2021.

1618 - WNA, "Nuclear Power in Russia", World Nuclear Association, July 2019, see https://www.world-nuclear.org/information-library/country-profiles/countries-o-s/russia-nuclear-power.aspx, accessed 30 July 2019.

1619 - Gary Peach, "Rosatom Orders Four Reactors To Replace Aging RBMKs", *NIW*, 17 July 2020.

1620 - *NEI*, "Russia permanently closes Novovoronezh 3", 4 January 2017, see http://www.neimagazine.com/news/newsrussia-permanently-closes-novovoronezh-3-5709099/, accessed 10 April 2021.

Figure 74 · Age Distribution of the Russian Nuclear Fleet



Sources: WNISR, with IAEA-PRIS, 2021

The country also has two Fast Breeder Reactors (FBRs) in operation at Beloyarsk. The older and smaller of the two reactors is a 600 MW unit, which started in 1980 with an expected operational lifetime of 30 years. This was extended for the second time in April 2020 for a further five years to enable the unit to operate until 2025,[1621] but plans are being developed to enable the unit to operate for 60 years. The BN-800 is in the course of converting from high enriched uranium (HEU) to mixed oxide plutonium-uranium (MOX) fuel that should be completed by 2022.[1622] The new VVER-1200 reactors in Novovorenezh II and Leningrad II have a design lifetime of 60 years, with plans to extend this to 80. The floating KLT-40 reactors on the Akademik Lomonosov are designed for three or four 12-year operational cycles.

Russia is an aggressive exporter of nuclear power, with, according to Rosatom, 35 separate projects in various stages of advancement including: Bangladesh (two reactors at Rooppur); Belarus (two at Ostrovets); China (two at Tianwan and two in the Liaoning province); Egypt (four at El Dabaa); Finland (one at Hanhikivi); Hungary (two at Paks); India (four at Kudankulam); and Turkey (four at Akkuyu).[1623] Alexey Likhachev, head of Rosatom, expects that by 2030 up to 70 percent of their revenue will come from outside the country. Likhachev claims that the current order book is worth US$190 billion, of which US$133 billion for projects this decade and US$90 billion on projects already underway.[1624] However, WNISR considers of these only nine reactors as recently connected to the grid or under construction: two each in Bangladesh, Belarus and India and three in Turkey, plus Bushehr-2 in Iran—this does not include previously exported reactors, such as those to China (Tianwan-1–4) of those in Central and Eastern Europe.

1621 - *NIW*, "Briefs—Russia", 3 April 2020.

1622 - IPFM, "BN-800 reactor to fully transition to MOX fuel in 2022", 9 June 2020, see http://fissilematerials.org/blog/2020/06/bn-800_reactor_to_fully_t.html, accessed 22 May 2021.

1623 - Rosatom, "Projects", Undated, see https://rosatom.ru/en/investors/projects/, accessed 10 April 2021.

1624 - *Reuters*, "Russia's nuclear company Rosatom on a drive to sell nuclear technology overseas", as published in *The Moscow Times*, 24 May 2020, see https://www.themoscowtimes.com/2019/06/24/russias-rosatom-sees-foreign-revenues-new-products-fuelling-rapid-growth-a66135, accessed 10 April 2021.

The relative success of Russia's export drive in a niche market of state-funded projects is not primarily the technology but the access to cheap financing that accompanies the deals.

Ukraine

Ukraine has 15 operating reactors, two of the VVER-440 design and the rest VVER-1000s. They provided 72 TWh or 51 percent of power generation in the country in 2020, a drop from the previous year with 78 TWh or 54 percent.

Twelve out of Ukraine's 15 reactors were connected to the grid in the 1980s and had an original design lifetime of 30 years. Ukraine has carried out a safety upgrade program for all of its reactors at an estimated cost of €1.45 billion (US$1.62 billion) in total, of which the European Bank for Reconstruction and Development (EBRD) and EURATOM contributed €600 million (US$670 million) between them. The disbursement of the loan has been gradual, and the third tranche was only made available in 2020.

The nuclear operator has proposed to extend lifetimes of some of the reactors for another 20 years. The proposal was accepted and now constitutes a core element of the nuclear strategy approved by the Government. The country has four closed reactors, all at the Chernobyl nuclear power plant. Three nuclear reactors (two VVER-440s and one VVER-1000) at Rovno (also spelled Rivne) have been granted a lifetime extension of 20 years,[1625] three units at South Ukraine for ten years, and four units at Zaporozhye for ten years.[1626, 1627]

Two reactors, Khmelnitsky-3 and -4, are officially under construction, but WNISR removed them from the construction list as no active work has been reported in many years. Building work started in 1986 and 1987 but stopped in 1990. In September 2015, the Ukrainian Parliament voted to cancel the project.[1628] In January 2017, the Russian Government confirmed that the 2011-agreement on the completion of the units had been canceled.[1629] However the Ukrainian Government appears determined to finish them and in September 2020 a Presidential decree instructed the Cabinet to submit a bill on the location, design and construction of the two units, with some suggestions that the total cost of completing Khmelnitsky-3 and -4 in current prices is estimated at UAH 76.8 billion (US$2.8 billion).[1630] It was then reported in August 2020 that nuclear utility Energoatom resumed work on the construction of Khmelnitsky-3 and -4

1625 - *NEI*, "Life extension for Ukraine's Rovno 3", 23 July 2018, see https://www.neimagazine.com/news/newslife-extension-for-ukraines-rovno-3-6258731/, accessed 10 April 2021.

1626 - *NEI*, "Life extension for Ukraine's Zaporozhye 4", 16 October 2018, see https://www.neimagazine.com/news/newslife-extension-for-ukraines-zaporozhye-4-6803714/, accessed 10 April 2021.

1627 - *NEI*, "Energoatom marks life extension of Ukraine's Zaporozhye 5 -", 1 February 2021, see https://www.neimagazine.com/news/newsenergoatom-marks-life-extension-of-ukraines-zaporozhye-5-8484622/, accessed 10 April 2021.

1628 - Ed Adamczyk, "Ukraine scraps nuclear reactor deal with Russia", *UPI*, 16 September 2015, see https://www.upi.com/Top_News/World-News/2015/09/16/Ukraine-scraps-nuclear-reactor-deal-with-Russia/9811442413199/, accessed 10 April 2020.

1629 - *NEI*, "Russia ends Khmelnitsky construction agreement with Ukraine", 13 January 2017, see http://www.neimagazine.com/news/newsrussia-ends-khmelnitsky-construction-agreement-with-ukraine-5718894/, accessed 10 April 2021.

1630 - *NEI*, "Working group reports on situation at Ukraine's Khmelnitsky nuclear plant", 6 October 2020, see https://www.neimagazine.com/news/newsworking-group-reports-on-situation-at-ukraines-khmelnitsky-nuclear-plant-8166180/, accessed 10 April 2021.

and promised to approve a plan for completing the units for operation in 2026.[1631] In July 2021, Energoatom's acting President set a target of completing all pre-construction activities by 1 October 2021, adding that "Once the Law on KhNPP units 3 and 4 construction is adopted, everything will move very quickly".[1632]

In August 2017, the Government adopted an energy strategy which aims to maintain the current level of nuclear in the power mix of about 50 percent up to 2035, while at the same time to halve the level of energy intensity in the economy and increase the contribution of renewables to electricity to 25 percent (excluding hydro with 13 percent).[1633] The Government is also considering the future use of SMRs, with Holtec International, Ukraine's Energoatom and the country's State Scientific and Technology Centre (SSTC) entering a formal partnership to advance the U.S. company's SMR-160 for deployment.[1634] The SMR-160 remains under development and no country in the world has licensed the design yet. In March 2020, Energy Minister Oleksiy Orzhel, who was formerly head of the Energy Sector Better Regulation Office and head of the Ukrainian Association of Renewable Energy, was fired. It has been suggested that the dismissal was due to the Minister's apparent favor of renewable energy and his disdain for coal and nuclear power.[1635]

Proposals are now being developed to introduce a direct power line from Khmelnitsky-2 to the European market. The Ukraine-EU Energy Bridge project, with an estimated cost of €243 million (US$290 million), is to be carried out in the form of a public-private partnership between the Ukrainian state and an investor consortium consisting of Westinghouse Electric Sweden, Luxembourg-based Polish Polenergia International, and UK-based EDF Trading.[1636] Ukraine is already exporting electricity to Hungary, Romania and Slovakia through the Burshtyn 'energy island' and to Poland and Moldova, while also importing electricity from Russia and Belarus. The Khmelnitsky project foresees electricity export in two ways: via the 750 kV transmission line to Rzeszów in Poland and the line to the Albertirsa substation in Hungary. Upgrading work on these lines would enable the addition of 1000 MWe of nuclear power to the existing export potential of Burshtyn Energy Island.[1637] It is now two years since the appointment of the consortium to take forward the project, but little progress has been made despite ongoing support from the Government.

1631 - *NEI*, "Ukraine's president orders draft bill on development of nuclear energy", 24 September 2020, see https://www.neimagazine.com/news/newsukraines-president-orders-draft-bill-on-development-of-nuclear-energy-8148257/, accessed 10 April 2021.

1632 - Energoatom, "Energoatom intensifies works on Khmelnytskyi NPP unit 3 completion", 23 July 2021, see http://www.energoatom.com.ua/en/press_center-19/company-20/p/energoatom_intensifies_works_on_khmelnytskyi_npp_unit_3_completion-47716, accessed 24 July 2021.

1633 - *NEI*, "Ukraine reveals new energy strategy", 28 August 2017, see http://www.neimagazine.com/news/newsukraine-reveals-new-energy-strategy-5910630/, accessed 10 April 2021.

1634 - *WNN*, "Consortium established for SMR-160 deployment in Ukraine", 12 June 2019, see https://world-nuclear-news.org/Articles/Consortium-established-for-SMR-160-deployment-in-U#:~:text=Holtec%20International%2C%20Ukraine's%20Energoatom%20and,reactor%20for%20deployment%20in%20Ukraine, accessed 10 April 2021.

1635 - Gary Peach, "Ukraine: Is Nuclear at a Crossroads?", *NIW*, 27 March 2020.

1636 - Ukraine Energy, "Winner of 'Ukraine-EU Energy Bridge' project is determined", 15 August 2019, see https://ua-energy.org/en/posts/15-08-2019-2370f1a2-3ba4-439b-b2d0-b8b382d349ab, accessed 10 April 2021.

1637 - *WNN*, "Energoatom awaits approval for energy bridge tender", 18 April 2018, see http://www.world-nuclear-news.org/NP-Energoatom-awaits-approval-for-energy-bridge-tender-18041801.html, accessed 10 April 2021.

The Ministry of Energy is also considering other means to consume the excess electricity in the country including cryptocurrency mining and the creation of data centers near nuclear power plants, with a pilot project connected to the Zaporozhye nuclear power plant.[1638]

1638 - *Interfax Ukraine*, "Cryptomining is modern tool to remove surplus of electricity – Energy ministry", 7 May 2020, see https://en.interfax.com.ua/news/economic/660620.html, accessed 10 April 2021.

ANNEX 2 – STATUS OF JAPANESE NUCLEAR FLEET

Table 22 – Status of Japanese Nuclear Reactor Fleet (as of 1 July 2021)

Operator	Reactor	MW	Startup Year	Age Years	Shutdown		NRA Compliance[b]		Status
					Date[a] dd/mm/yy	Duration	Application dd/mm/yy	Approval dd/mm/yy	
CHUBU	Hamaoka-3 (BWR)	1 056	1987	34.4	29/11/10	10.6	16/06/15		LTO
	Hamaoka-4 (BWR)	1 092	1993	28.4	13/05/11	10.1	14/02/14[c]		LTO
	Hamaoka-5 (BWR)	1 325	2004	17.2	14/05/11	10.1			LTO
CHUGOKU	Shimane-2 (BWR)	789	1988	33.0	27/01/12	9.4	25/12/13		LTO
HEPCO	Tomari-1 (PWR)	550	1988	32.6	22/04/11	10.2	08/07/13		LTO
	Tomari-2 (PWR)	550	1990	30.8	26/08/11	9.8	08/07/13		LTO
	Tomari-3 (PWR)	866	2009	11.6	05/05/12	9.2	08/07/13		LTO
HOKURIKU	Shika-1 (BWR)	505	1993	28.5	01/03/11	10.3			LTO
	Shika-2 (BWR)	1 108	2005	16.0	11/03/11	10.3	12/08/14		LTO
JAPCO	Tokai-2 (BWR)	1 060	1978	43.3	11/03/11	10.3	20/05/14	Second Stage: 18/10/18[d]	LTO
	Tsuruga-2 (PWR)	1 108	1986	34.0	07/05/11	10.2	05/11/15		LTO
KEPCO	Mihama-3 (PWR)	780	1976	45.4	14/05/11	(10.1)	17/03/15	27/02/2020[e]	Restarted 29/06/2021
	Ohi-3 (PWR)	1 127	1991	30.1	02/09/13	(4.5)	08/07/13	01/09/17	Restarted 16/03/18
	Ohi-4 (PWR)	1 127	1992	29.0	15/09/13	(4.6)	08/07/13	01/09/17	Restarted 11/05/18
	Takahama-1 (PWR)	780	1974	47.3	10/01/11	10.5	17/03/15	Second Stage: 10/06/16[f]	LTO
	Takahama-2 (PWR)	780	1975	46.4	25/11/11	9.6	17/03/15	Second Stage: 10/06/16[f]	LTO
	Takahama-3 (PWR)	830	1984	37.1	20/02/12	(3.9)	08/07/13	09/10/15	Restarted 9/06/17[g]
	Takahama-4 (PWR)	830	1984	36.7	21/07/11	(5.8)	08/07/13	09/10/15	Restarted 22/05/17
KYUSHU	Genkai-3 (PWR)	1 127	1993	28.0	11/12/10	(7.3)	12/07/13	14/09/17	Restarted 23/03/18
	Genkai-4 (PWR)	1 127	1996	24.6	25/12/11	(6.5)	12/07/13	14/09/17	Restarted 20/06/18
	Sendai-1 (PWR)	846	1983	37.8	10/05/11	(4.3)	08/07/13	27/05/15	Restarted[h] 14/08/15
	Sendai-2 (PWR)	846	1985	36.2	01/09/11	(4.1)	08/07/13	27/05/15	Restarted[h] 15/10/15
SHIKOKU	Ikaka-3 (PWR)	846	1994	27.3	29/04/11	(5.3)	08/07/13	19/04/16	Restarted 15/08/16 LTO since December 2019[i]
TEPCO	Kashiwazaki Kariwa-1 (BWR)	1 067	1985	36.4	06/08/11	9.9			LTO
	Kashiwazaki Kariwa-2 (BWR)	1 067	1990	31.4	05/07/07	14			LTO
	Kashiwazaki Kariwa-3 (BWR)	1 067	1992	28.6	16/07/07	14			LTO
	Kashiwazaki Kariwa-4 (BWR)	1 067	1993	27.5	16/07/07	14			LTO
	Kashiwazaki Kariwa-5 (BWR)	1 067	1989	31.8	25/01/12	9.4			LTO
	Kashiwazaki Kariwa-6 (BWR)	1 315	1996	25.4	26/03/12	9.3	27/09/13[j]	First Stage: 27/12/17	LTO
	Kashiwazaki Kariwa-7 (BWR)	1 315	1996	24.5	23/08/11	9.9	27/09/13	First Stage: 27/12/17	LTO

Operator	Reactor	MW	Startup Year	Age Years	Shutdown		NRA Compliance[b]		Status
					Date[a] dd/mm/yy	Duration	Application dd/mm/yy	Approval dd/mm/yy	
TOHOKU	Higashi Dori-1 (BWR)	1 067	2005	15.8	06/02/11	10.4	10/06/14		LTO
	Onagawa-2 (BWR)	796	1994	26.5	06/11/10	10.7	27/12/13	First Stage: 26/02/20[k]	LTO
	Onagawa-3 (BWR)	796	2001	20.1	11/03/11	10.3			LTO
Total: 33 Reactors / 31.7 GWe									

Sources: JAIF, NRA, compiled by WNISR, 2021

Notes

BWR = Boiling Water Reactor; **PWR** = Pressurized Water Reactor; **LTO** = Long-Term Outage.

(a) – The shutdown dates are from JAIF, "Current Status of Nuclear Power Plants in Japan", Japan Atomic Industrial Forum, as of 6 June 2019, see https://www.jaif.or.jp/cms_admin/wp-content/uploads/2019/06/jp-npps-operation190606_en.pdf, accessed 7 July 2019.

(b) – Unless otherwise indicated the application and approval dates are from NRA, "Current circumstances regarding examinations for NPP adherence to new regulations", Nuclear Regulatory Authority, 15 May 2019; and NRA, "原子力発電所の新規制基準適合性審査の状況" ["Regarding the progress status of the new regulatory standard compliance examination, (Power reactor relation)"], 1 July 2020 (in Japanese), see https://www.nsr.go.jp/data/000257174.pdf, accessed 28 July 2020, and NRA, "Status of Application for Review of Commercial Power Reactor", in "Annual Report FY 2019", March 2021, see https://www.nsr.go.jp/data/000347153.pdf, accessed 11 June 2021.

(c) – Application withdrawn and resubmitted on 26 January 2015.

(d) – Nuclear Regulatory Authority's (NRA) Approval for Basic Design (Step 2). In November 2018, NRA also approved lifetime extension to 60 years; see JAIF, "NRA Allows Tokai-2 to Be Operated for Sixty Years, a First for a BWR", 16 November 2018, see https://www.jaif.or.jp/en/nra-allows-tokai-2-to-be-operated-for-sixty-years-a-first-for-a-bwr/, accessed 28 April 2019.

(e) – 2020 date from NRA, "Status of Application for Review of Commercial Power Reactor" in "Annual Report FY 2019", March 2021, see https://www.nsr.go.jp/data/000347153.pdf. Application for extension of operating period was approved by NRA on 16 November 2016. However, the Mihama-3 reactor will be shut down on 23 October 2021, due to failing the deadline of installation of specialized safety facilities. JAIF, "Current Status of Nuclear Power Plants in Japan", 10 August 2021, see https://www.jaif.or.jp/cms_admin/wp-content/uploads/2021/08/jp-npps-operation20210810_en.pdf, accessed 13 August 2021.

(f) – For both Takahama-1 and -2, the first two steps of the conformity review were achieved on 10 June 2016. The NRA also granted KEPCO approval of extension of operation for 20 years on 20 June 2016. For details, see NRA, "The NRA approved the extension of operation period of Takahama Power Station Units 1 and 2", 21 June 2016, see http://www.nsr.go.jp/data/000154256.pdf, accessed 14 July 2017.

(g) – Takahama-3 had operated briefly between 29 January and 10 March 2016, before it was shut down by court order. The "Shutdown Duration" is calculated until the first restart.

(h) – Kyushu Electric Power Company was required to finish installing counter-terrorism facilities at the Sendai-1 and -2 reactors by 17 March and 21 May 2020, respectively, but missed the deadline. As a result, Sendai-1 has been shut down since 16 March 2020 was restarted in November 2020. While Sendai-2 was shut down on 20 May 2020 after only operating for four months following its maintenance and inspection outage completed in January. It was restarted in December 2020. See *Reuters*, "TABLE-Japan nuclear reactor operations: Kyushu Electric restarts Sendai No. 2 reactor", 13 January 2021.

(i) – In December 2019, Ikata-3 was shut down for maintenance and refueling (with restart of operation expected on 27 April 2020). On 17 January 2020, the Hiroshima High Court ruled in favor of a lawsuit brought by local residents within a 50-kilometer radius of the Ikata plant, the effect of which was to extend the outage of the Ikata-3 reactor, see *Asahi Shimbun*, "Residents win appeal to halt Ikata reactor over safety fears", 17 January 2020, see http://www.asahi.com/ajw/articles/AJ202001170057.html, accessed 15 May 2020. On 18 March 2021 the Hiroshima High Court overturned on appeal its earlier 2020 ruling, opening the way for restart following completion of periodic inspections. As of 1 July 2021, it is expected to restart in October 2021, hence meeting the LTO criteria.

(j) – On 16 June 2017, TEPCO re-filed its application with the Nuclear Regulatory Authority (NRA) to confirm compliance with safety requirements for Kashiwazaki Kariwa-6 and -7. The NRA had requested resubmission in February 2017.

(k) – JAIF, "NRA Approves Changes to Reactor Installation for Onagawa-2 under New Regulatory Standards", 27 February 2020, see https://www.jaif.or.jp/en/nra-approves-changes-to-reactor-installation-for-onagawa-2-under-new-regulatory-standards/, accessed 20 May 2020.

ANNEX 3 - STATUS OF NUCLEAR POWER IN THE WORLD

Table 23 – Status of Nuclear Power in the World (as of 1 July 2021)

Country	Nuclear Fleet					Power	Energy
	Operating		LTO	Mean Age(a)	Under Construction	Share of Electricity(b)	Share of Commercial Primary Energy(c)
	Units	Capacity (MW)	Units	Years	Units		
Argentina	3	1 641		30.8	1	7.5% (+)	3% (=)
Armenia	1	415		41.5		34.5% (+)	
Bangladesh	-	-		-	2		
Belarus	1	1 110		0.7	1	1%	
Belgium	7	5 942		41.3		39.1% (-)	13.9% (=)
Brazil	2	1 884		30.1		2.1% (=)	1.1% (=)
Bulgaria	2	2 006		31.8		40.8% (+)	19.8% (2019)
Canada	19	13 624		38		14.6% (=)	6.4 (=)
China	52	49 589		8.5	18	4.9% (=)	2.2% (=)
Czech Republic	6	3 934		30		37.3% (+)	17.4% (+)
Finland	4	2 794		42.3	1	33.9.% (=)	19.1% (=)
France	56	61 370		36.1	1	67.1% (-)	36.1% (=)
Germany	6	8 113		34.5		11.3% (-)	4.7% (=)
Hungary	4	1 902		36.0		48% (-)	14.7% (=)
India	21	6 590	1	23.2/22.5	7	3.3% (=)	1.2% (=)
Iran	1	915		9.8	1	1.7% (=)	0.5% (=)
Japan	9	8 640	24	30.4/33.9	1	5.1% (-)	2.2% (=)
Mexico	2	1 552		29.4		4.9% (=)	1.6% (=)
Netherlands	1	482		48,0		3.2% (=)	1.1% (=)
Pakistan	6	2 332		15	1	7.1% (=)	2.4% (=)
Romania	2	1 300		19.5		19.9% (+)	7.7% (=)
Russia	38	28 597		28.3	3	20.6% (=)	6.8% (=)
Slovakia	4	1 837		29.3	2	53.1% (=)	21% (2019)
Slovenia	1	688		39.7		37.8% (=)	18.5% (2019)
South Africa	2	1 860		36.6		5.9% (=)	2.8% (=)
South Korea	23	22 199	1	22/21.9	4	29.6% (+)	12.1% (+)
Spain	7	7 121		36.4		22.2% (=)	10.4% (+)
Sweden	6	6 859		39		29.8% (-)	21.3% (-)
Switzerland	4	2 960		45.3		35.1% (-)	18.9% (=)
Taiwan	3	2 859		37.4		12.7% (=)	5.8% (=)
Turkey	-	-		-	3		
UAE	1	1 345		0.9	3	1.1%	
UK	13	7 883		37.4	2	14.5% (-)	6.5% (=)
Ukraine	15	13 107		32.4		51.2% (-)	20.4% (-)
USA	93	95 523		40.6	2	19.7% (=)	8.4% (=)
EU27	**106**	**104 348**		**35.9**	**4**	**24.8% (-)(c)**	**11% (=)**
World	**415**	**368 923**	**26**	**30.9**	**53**	**10.1% (=)(c)**	**4.3% (=)**

Sources: WNISR with IAEA-PRIS, BP, 2021

(a) – Including reactors in LTO/Excluding reactors in LTO (when different).

(b) – From IAEA-PRIS, "Nuclear Share of Electricity Generation in 2020", as of 3 August 2021, except France and Switzerland (National sources).

(c) – From BP, "Statistical Review of World Energy", 2021.

ANNEX 4 – NUCLEAR REACTORS IN THE WORLD "UNDER CONSTRUCTION"

Table 24 – Nuclear Reactors in the World "Under Construction" (as of 1 July 2021)

Country	Units	Capacity MW net	Model	Construction Start (dd/mm/yyyy)	Expected Grid Connection	Delayed
ARGENTINA	**1**	**25**				
Carem25		25	CAREM (PWR)	08/02/2014	2024[1]	yes
BANGLADESH	**2**	**2 160**				
Rooppur-1		1 080	VVER-1200	30/11/2017	2023[2] (commercial operation)	
Rooppur-2		1 080	VVER-1200	14/07/2018	2024[3] (commercial operation)	
BELARUS	**1**	**1 109**				
Belarusian-2		1 109	VVER V-491	03/06/2014	2022[4]	yes
CHINA	**18**	**17 062**				
Changjiang-3		1 000	HPR-1000[5]	31/03/2021	2026[6]	
Fangchenggang-3		1 000	HPR-1000	24/12/2015	2021[7]	
Fangchenggang-4		1 000	HPR-1000	23/12/2016	2022[8]	
Fuqing-6		1 000	HPR-1000	22/12/2015	2021[9]	yes
Hongyanhe-6		1 000	ACPR-1000+	24/07/2015	2022[10]	yes
Sanaocun-1		1 117	HPR-1000	31/12/2020	2026[11]	
Shidao Bay 1-1[12]		100	HTR-PM	01/12/2012	2021[13]	yes
Shidao Bay 1-2		100	HTR-PM	01/12/2012	2021[14]	yes
Shidao-Bay 2-1[15]		1 400	CAP1400	04/2019[16]	2024[17]	
Shidao-Bay 2-2		1 400	CAP1400	11/2019[18]	2024[19]	
Taipingling-1		1 116	HPR-1000	26/12/2019[20]	2025[21] (grid connection)	
Taipingling-2		1 116	HPR-1000	15/10/2020	2026[22] (grid connection)	
Tianwan-7		1 100	VVER V-491	19/05/2021	2026[23]	
Xiapu-1		600	CFR-600	29/12/2017	2023[24]	
Xiapu-2		600	CFR-600	29/12/2020[25]	2026[26]	
Xudabao-3		1 100	VVER V-491	19/05/2021	2027[27]	
Zhangzhou-1		1 000	HPR-1000	16/10/2019[28]	2024[29] (grid connection)	
Zhangzhou-2		1 000	HPR-1000	04/09/2020[30]	2025[31]	
FINLAND	**1**	**1 600**				
Olkiluoto-3		1 600	EPR	12/08/2005	2/2022[32]	yes
FRANCE	**1**	**1 600**				
Flamanville-3		1 600	EPR	03/12/2007	2023[33]	yes

Country	Units	Capacity MW net	Model	Construction Start (dd/mm/yyyy)	Expected Grid Connection	Delayed
INDIA	**7**	**5 194**				
Kakrapar-4		630	PHWR-700	22/11/2010	February 2022[34] (commissioning)	yes
Kudankulam-3		917	VVER V-412	29/06/2017	2024[35]	yes
Kudankulam-4		917	VVER V-412	23/10/2017	2025[36]	yes
Kudankulam-5		1 000	VVER V-412	29/06/2021[37]	2026/2027[38]	
PFBR		470	FBR	23/10/2004	10/2022[39]	yes
Rajasthan-7		630	PHWR	18/07/2011	02/2022[40] (expected completion)	yes
Rajasthan-8		630	PHWR	30/09/2011	03/2023[41] (commercial operation)	yes
IRAN	**1**	**1 196**				
Bushehr-2		1 196	VVER V-446	02/1976[42]	2024	yes
JAPAN	**1**	**1 325**				
Shimane-3		1 325	ABWR	12/10/2007	2025?[43]	yes
Pakistan	**1**	**1 014**				
Kanupp-3		1 014	HPR-1000	31/05/2016	2022[44] (expected operation)	
RUSSIA	**3**	**2 650**				
BREST-OD-300		300	FBR	08/06/2021[45]	2026	
Kursk 2-1		1 115	VVER V-510	29/04/2018	042022[46]	
Kursk 2-2		1 115	VVER V-510	15/04/2019	2023[47]	
SLOVAKIA	**2**	**880**				
Mochovce-3		440	VVER V-213	01/01/1985	2021[48]	yes
Mochovce-4		440	VVER V-213	01/01/1985	2023[49]	yes
SOUTH KOREA	**4**	**5 360**				
Shin-Hanul-1		1 340	APR-1400	10/07/2012	3/2022[50] (commercial operation)	yes
Shin-Hanul-2		1 340	APR-1400	19/06/2013	3/2023[51] (commercial operation)	yes
Shin-Kori-5		1 340	APR-1400	03/04/2017	2024[52]	yes
Shin-Kori-6		1 340	APR-1400	20/09/2018	2025[53]	yes
TURKEY	**3**	**3 342**				
Akkuyu-1		1 114	VVER V-509	03/04/2018	2024[54]	yes
Akkuyu-2		1 114	VVER V-509	08/4/2020	2025[55]	
Akkuyu-3		1 114	VVER V-509	10/03/2021	2026[56]	
UAE	**3**	**4 035**				
Barakah-2		1 345	APR-1400	30/05/2013	2021[57]	yes
Barakah-3		1 345	APR-1400	24/09/2014	2022[58]	yes
Barakah-4		1 345	APR-1400	30/07/2015	2023[59]	yes

Country	Units	Capacity MW net	Model	Construction Start (dd/mm/yyyy)	Expected Grid Connection	Delayed
UK	**2**	**3 260**				
Hinkley Point C-1	1	1 630	EPR-1750	11/12/2018[60]	2026[61]	yes
Hinkley Point C-2	1	1 630	EPR-1750	12/12/2019[62]	2027[63]	yes
USA	**2**	**2 234**				
Vogtle-3		1 117	AP-1000	12/03/2013	2022[64]	yes
Vogtle-4		1 117	AP-1000	19/11/2013	2023[65]	yes
World	**53**	**54 047**		**1976–2021**	**2021–2027**	**31**

Sources: Various, compiled by WNISR, 2021

1 - Further delayed. In 2019, CAREM was rescheduled to begin operating in late 2021 or 2022. The construction, suspended in 2019 “due to breaches by contractor companies”, was expected to restart in May 2020, with no indication about the impact this would have on project’s timeline. See *NEI*, “Work resumes on nuclear projects in Argentina”, 23 April 2020, see https://www.neimagazine.com/news/newswork-resumes-on-nuclear-projects-in-argentina-7887154, accessed 30 July 2020.

In July 2021 CNA announced that NA-SA had been contracted to complete the reactor, and that “this new contract establishes a duration of 36 months to complete the reactor building”. CNEA, “CNEA y la empresa NA-SA firman un contrato para completar la construcción del CAREM”, Press Release, 5 July 2021 (in Spanish), see https://www.argentina.gob.ar/noticias/cnea-y-la-empresa-na-sa-firman-un-contrato-para-completar-la-construccion-del-carem, accessed 8 July 2021.

2 - Rosatom, “First concrete poured at the constructed Rooppur NPP site (Bangladesh)”, Press Release, 30 November 2017, see http://www.rusatom-overseas.com/media/news/first-concrete-poured-at-the-site-constructed-npp-rooppur-bangladesh.html/, accessed 17 August 2020.

3 - Rosatom, “Main construction of the 2nd Unit of Rooppur NPP begins with the ‘First Concrete’ ceremony”, Press Release, 14 July 2018, see http://rosatom.ru/en/press-centre/news/main-construction-of-the-2nd-unit-of-rooppur-npp-begins-with-the-first-concrete-ceremony/, accessed 15 July 2018.

4 - Further delayed. In early 2020, startup of Belarusian-2 was officially delayed to 2021. BelTA, “Second reactor of Belarusian nuclear power plant getting flushed, cleansed”, 17 June 2020, see https://atom.belta.by/en/belaes_en/view/second-reactor-of-belarusian-nuclear-power-plant-getting-flushed-cleansed-10678/, accessed 16 July 2020. As of July 2021, fuel loading and criticality are expected in autumn 2021, and commercial operation in 2022. *Platts Nuclear News Flashes*, “Belarus Ostravets-2 nuclear plant first criticality expected in autumn: minister”, 21 May 2021.

5 - The HPR-1000 also goes by the name Hualong One.

6 - Construction period is expected to be 60 months. *NEI*, “First concrete poured for China’s Changjiang 3”, 1 April 2021, see https://www.neimagazine.com/news/newsfirst-concrete-poured-for-chinas-changjiang-3-8644649, accessed 2 April 2021.

7 - No information concerning expected startup date in CGN’s announcement of construction start. CGN’s Annual Reports for 2016 to 2020 refer to 2022 as “Expected Date of Commencement of Operation” for Fangchenggang-3 and -4. Sources in China suggested that because the two units are the first HPR-1000 to be constructed, grid connection appears impossible before 2020–21 for Unit 3 and 2021–22 for Unit 4, although CGN has pledged to do its utmost to connect its first domestic Generation III reactor to the grid in 2021, at the earliest in November 2021. WNISR2019 advanced the date for the first reactor from 2022 to 2021.

8 - CGN, “Annual Report 2020”, 2021, see http://en.cgnp.com.cn/encgnp/c100882/2021-04/08/c95f2296e95a4aab8a1d7b749996bb43/files/72fd1f144fa44cefba5496fb45eaaab6.pdf, accessed 1 June 2021.

9 - Delayed. The completion date announced at construction start was 2020. See *WNN*, “First concrete for sixth Fuqing unit”, 22 December 2015, see http://www.world-nuclear-news.org/NN-First-concrete-for-sixth-Fuqing-unit-2212154.html, accessed 26 June 2016. Grid connection is expected in 2021. CNNC, “First Hualong One begins commercial operation”, 2 February 2021, see https://en.cnnc.com.cn/2021-02/02/c_586987.htm, accessed 30 June 2021.

10 - Delayed. In January 2020, CGN announced that operation of Hongyanhe-6 was delayed to 2022, a delay of six months. CGN Power, “Inside Information - Operation Briefings for the Fourth Quarter of 2019”, 6 January 2020, see http://en.cgnp.com.cn/encgnp/c20191226/202001/917f4904f06d4826be1ae98e96780703/files/0627a0191ddb4a07bcfe0b4764a196e4.pdf, accessed 12 January 2020. See also CGN, “Annual Report 2020”, 2021.

11 - CGN, “Annual Report 2020”, 2021.

12 - IAEA-PRIS reports the twin High Temperature Reactors (HTR-PM) being under construction at the Shidao Bay site plant as consisting of one 200-MW unit. Accordingly, in previous WNISR editions, Shidao Bay-1 has been accounted for as one unit. However, it turns out that Shidao Bay-1 (also called Shidaowan-1) consists of two 100-MW reactors, and consequently, as of WNISR2020, they are considered separately, i.o.w. as two units under construction (Shidao Bay 1-1 and 1-2). See CNEA, “Key components of second HTR-PM reactor connected”, n.d., see http://en.china-nea.cn/site/content/176.html, accessed 10 May 2020.

13 - Repeatedly delayed. Grid connection is now expected in 2021, see Fu Li, “Chinese HTR Program”, presented at the IFNEC SMR Webinar Series, 23 June 2020, see https://www.ifnec.org/ifnec/upload/docs/application/pdf/2020-06/slides_deck_-_webinar_4.pdf, accessed 5 July 2020. The first fuel was shipped to the site in January 2021, but as of 1 July 2021, no information on fuel loading has been published. See CNNC, "World's first HTGR nuclear fuel elements shipped", 12 January 2021, see http://en.cnnc.com.cn/2021-01/12/c_581651.htm, accessed 14 January 2021.

14 - Twin reactor. See previous note.

15 - Provisional names for the two CAP1400 at Rongcheng/Shidaowan. Construction of those reactors was introduced in WNISR stats in 2020 following *NIW* articles (in particular 10 July 2019) and confirmation from sources in China. In July 2019, NIW classified them as "under construction" on the basis of the NNSA map as of June 2019. See *NIW*, "Why the Secrecy Over Reactor Construction Start?", 12 July 2019.

16 - According to sources in China, first basemat concrete for the first CAP1400 reactor was poured on 8 April 2019. See also C.F. Yu, "CGN's Taipingling Project Moves Ahead", *NIW*, 20 December 2019. See previous note.

17 - No official startup dates at this point. According to sources in China, the expected construction duration of CAP1400 from Zheng Mingguang is about 56 months. WNISR2021 uses 2024 as expected grid connection.

18 - According to sources in China, first basemat concrete for the second CAP1400 reactor was poured in November 2019. See previous notes.

19 - No official startup dates at this point. WNISR2021 uses 2024 for grid connection date. See previous notes.

20 - CGN, "Annual Report 2019", CGN Power, April 2020, see http://en.cgnp.com.cn/encgnp/c100882/202004/f3c20533b65c4cf3a41583190c02057c/files/a5bc0c2ac79c425398a2296b2b054005.pdf, accessed 2 April 2020.

21 - CGN, "Annual Report 2020", 2021.

22 - CGN, "Annual Report 2020", 2021. (Changed from 2025 in WNISR2020).

23 - According to sources in China, the contract between China and Russia stipulated a construction duration of 65 months. Rosatom stated about the Tianwan-7 and -8 project "the units are scheduled to be commissioned in 2026-2027". See Rosatom, "Start of new unit construction at China's Tianwan and Xudapu nuclear power plants", Press Release, 19 May 2021, see https://rosatom.ru/en/press-centre/news/start-of-new-unit-construction-at-china-s-tianwan-and-xudapu-nuclear-power-plants/, accessed 14 June 2021.

24 - *WNN*, "China begins building pilot fast reactor", 29 December 2017, see http://www.world-nuclear-news.org/NN-China-begins-building-pilot-fast-reactor-2912174.html, accessed 30 December 2017.

25 - Not listed in IAEA-PRIS. *NEI*, "China begins construction of second CFR-600 fast reactor", 4 January 2021, see https://www.neimagazine.com/news/newschina-begins-construction-of-second-cfr-600-fast-reactor-8435608, accessed 5 January 2021.

26 - No official information about construction start/expected grid connection. WNISR2021 uses 2026.

27 - No official startup date at this point. According to sources in China, the expected construction duration of VVER-1200/V491 is 69 months. Rosatom stated about the Xudabao Project, "the units are expected to be commissioned in 2026-2027".

See Rosatom, "Start of new unit construction at China's Tianwan and Xudapu nuclear power plants", 19 May 2021, see https://rosatom.ru/en/press-centre/news/start-of-new-unit-construction-at-china-s-tianwan-and-xudapu-nuclear-power-plants/, accessed 14 June 2021.

28 - CNNC, "CNNC's Zhangzhou nuclear plant goes into construction", 23 December 2019, see https://en.cnnc.com.cn/2019-12/23/c_435889.htm, accessed 17 January 2020.

29 - No official startup date. Construction duration of Hualong One design given as 60 months.

30 - *WNN*, "Zhangzhou unit 2 construction starts", 4 September 2020, see https://www.world-nuclear-news.org/Articles/Construction-starts-of-second-Zhangzhou-unit, accessed 4 September 2020.

31 - No official startup date. Construction duration of Hualong One design given as 60 months.

32 - Further delayed. Grid connection is expected in February 2022, a further delay of about nine months compared to WNISR2020. See TVO, "The regular electricity production of OL3 EPR will be postponed due to extension of turbine overhaul", 20 August 2021, see https://www.tvo.fi/en/index/news/pressreleasesstockexchangereleases/2021/theregularelectricityproductionofol3eprwillbepostponedduetoextensionofturbineoverhaul.html, accessed 29 August 2021. As of 1 July 2021, hot functional test was ongoing. TVO, "Olkiluoto 3 prepares for first criticality", 30 June 2021, see https://www.tvo.fi/en/index/news/pressreleasesstockexchangereleases/2021/olkiluoto3preparesforfirstcriticality.html, accessed 1 July 2021.

33 - Probably further delayed. Delayed many times from its original planned startup date of 2012. Latest provisional dates are fuel loading by the end of 2022 and grid connection in 2023. However, there are many uncertainties and EDF warned that "The risk relating to the schedule and completion cost is therefore very high and the project could face other potentially significant additional costs and delays in the event of new contingencies…"; see EDF, "Universal Registration Document 2020—Annual Financial Report", filed 15 March 2021, see https://www.edf.fr/en/the-edf-group/dedicated-sections/investors-shareholders/reference-documents, accessed 26 July 2021.

34 - Further delayed (five months since WNISR2021). MoSPI, "Project Implementation Status Report of Central Sector Projects Costing Rs. 150 crore & above (January-March, 2021)", Ministry of Statistics and Programme Implementation, 2021, see http://www.cspm.gov.in/english/qr/QPSIR4thQTR2020-21.pdf, accessed 30 June 2021.

35 - Delayed. Although NPCIL, still uses 2023 for Kudankulam-3 & -4 as expected date of commercial operation, NIW reports that "Units 3 and 4 … will now be completed in September 2024 and March 2025, respectively, according to a government document." Rakesh Sharma, "Kudankulam-5 Construction Start Marks New Milestone", *NIW*, 2 July 2021.

36 - Delayed. See previous note.

37 - Rosatom, "ROSATOM begins construction of Kudankulam NPP Unit 5 in India", 29 June 2021, see https://rosatom.ru/en/press-centre/news/rosatom-begins-construction-of-kudankulam-npp-unit-5-in-india-/, accessed 30 June 2021.

38 - The expected construction duration of Kudankulam-5 is 66 months., Lok Sabha, "Unstarred Question No.2756: Kudankulam Nuclear Power Plant", Department of Atomic Energy, Answered by Jitendra Singh, Minister of State for Personnel, Public Grievances & Pensions and Prime Minister's Office, Government of India, 10 March 2021.

39 - Repeatedly delayed. Operation is now expected in October 2022, a delay of one year compared to WNISR2020. Lok Sabha, "Unstarred Question No. 330: Construction of PFBR", Department of Atomic Energy, Answered by Jitendra Singh, Minister of State for Personnel, Public Grievances, Pensions and Prime Minister's Office, Government of India, 3 February 2021, see https://dae.gov.in/writereaddata/lsusq%20330.pdf.

40 - Delayed. As of March 2020, anticipated date for commissioning was March 2022, a year and a half delay compared to WNISR2019. Rajya Sabha, "Unstarred Question No. 1602: Commissioning of heavy water reactor at Kakrapar Nuclear Plant", Department of Atomic Energy, Answered by Jitendra Singh, Minister of State for Personnel Public Grievances & Pensions and Prime Minister's Office, Government of India, 5 March 2020. No detail in 2021 in MoSPI, "Project Implementation Status Report of Central Sector Projects Costing Rs. 150 crore & above (January-March, 2021)", 2021, op. cit.

41 - Repeatedly delayed. No indications of changes since WNISR2020. MoSPI, "Project Implementation Status Report of Central Sector Projects Costing Rs. 150 crore & above (January-March, 2021)", 2021, op. cit.

42 - Original construction of Bushehr-2 had started in February 1976, and the reactor remained listed as under construction in PRIS-IAEA, "Nuclear Power Reactors in the World", until the 1994 edition. See WNISR, "Iran: Construction Restart of Busheer-2", 14 November 2019, see https://www.worldnuclearreport.org/Iran-Construction-Restart-of-Busheer-2.html.

43 - Construction status unclear. 2025 based on WNISR estimates.

44 - Reportedly delayed to first quarter 2022, see *The News*, "PM Imran Khan inaugurates 1,100 MW Chinese-built nuclear power plant", 21 May 2021, see https://www.thenews.com.pk/latest/837916-pm-imran-khan-inaugurates-1100-mw-chinese-built-nuclear-power-plant, accessed 22 July 2021, from planned startup in 2021, see "PNRA Annual Report 2018", 2019 and "PNRA Annual Report 2019", 2020.

45 - Rosatom, "ROSATOM starts construction of unique power unit with BREST-OD-300 fast neutron reactor", 8 June 2021, see https://www.rosatom.ru/en/press-centre/news/rosatom-starts-construction-of-unique-power-unit-with-brest-od-300-fast-neutron-reactor/, accessed 5 July 2021.

46 - WNA, "Nuclear Power in Russia", Updated May 2021, see https://www.world-nuclear.org/information-library/country-profiles/countries-o-s/russia-nuclear-power.aspx, accessed 30 July 2021.

47 - Ibidem.

48 - Further delayed. Fuel loading and startup expected in 2021. Slovenské elektrárne, "Slovenské elektrárne approaches the commissioning of Mochovce 3", 13 May 2021, see https://www.seas.sk/article/slovenske-elektrarne-approaches-the-commissioning-of-mochovce-3/441, accessed 30 June 2021.

49 - Further delayed. Fuel loading of Mochovce-3 is expected in 2023.

50 - Further delayed since WNISR2020. As of July 2021, Commercial operation is expected in March 2022 (almost 1.5 year delay compared to WNISR2020), with fuel loading taking place in July 2021. KEPCO, "Acquisition of Operating License for Shin-Hanul Unit 1 and First Fuel Loading", 16 July 2021, see https://www.kepco-enc.com/eng/selectBbsNttView.do?key=1621&bbsNo=342&nttNo=37370&searchCtgry=&searchCnd=all&searchKrwd=&pageIndex=1&integrDeptCode=, accessed 27 July 2021.

51 - Further delayed since WNISR2020. As of June 2021, Commercial operation is expected in March 2023 (over 1.5 year delay compared to WNISR2020). KHNP, "Nuclear Power Construction—Shin-Hanul #1,2", Various Dates, see https://cms.khnp.co.kr/eng/content/547/main.do?mnCd=EN03020303, last accessed 30 June 2021.

52 - Delayed. Construction officially started in April 2017, suspended in July to resume October of the same year. Commercial operation at construction start was October 2021, it is now expected in March 2023, almost 1.5 year of delay. KHNP, "Nuclear Power Construction – Shin-Kori #5,6", Various Dates, see http://cms.khnp.co.kr/eng/content/548/main.do?mnCd=EN03020304, last accessed 30 June 2021. However, in March 2021, KHNP applied for an extension of the construction license, with a completion schedule for Shin Kori-5 now extended one additional year until 31 March 2024, and for Shin Kori-6, nine months later to 31 March 2025.

53 - Delayed. KHNP, "Nuclear Power Construction—Shin-Kori #5,6", Various dates, see http://cms.khnp.co.kr/eng/content/548/main.do?mnCd=EN03020304, last accessed 30 June 2021. See previous note.

54 - Delayed. In March 2019, the project management announced that it had finished the concreting of the basemat for the nuclear island and that it was now expected that Akkuyu-1 would be physically completed in 2023, with generation coming at a later date. Phil Chaffee, "New Build, Revised 2023 Milestone for Akkuyu", *NIW*, 29 March 2019.

55 - Official startup date is often quoted as 2024, but WNISR2021 uses a 5-year construction period. *Daily Sabah*, "Construction starts on 2nd unit of Turkey's 1st nuclear power plant Akkuyu", 28 June 2020, see https://www.dailysabah.com/business/energy/construction-starts-on-2nd-unit-of-turkeys-1st-nuclear-power-plant-akkuyu, accessed 28 June 2020.

56 - The Akkuyu reactors are officially to be completed one per year starting in 2023. See *WNN*, "Akkuyu construction to be completed by 2026, says project CEO", 10 February 2021, see https://www.world-nuclear-news.org/Articles/Akkuyu-fully-operational-by-2026,-says-project?feed=feed, accessed 10 April 2021. However, WNISR2021 keeps a 5-year construction time, and a one-per-year startup frequency, beginning with Akkuyu-1 in 2024.

57 - Delayed. Fuel loading was completed at the end of March 2021, and startup is expected later in 2021. See ENEC, "Unit 1 of Barakah Plant Started Commercial Operations", 6 April 2021, see https://www.enec.gov.ae/news/latest-news/unit-1-of-barakah-plant-started-commercial-operations/, accessed 30 June 2021. Connected to the grid on 14 September 2021.

58 - Delayed. WNISR2021 keeps 2022, a three-year delay compared to original schedule.

59 - Delayed. WNISR2021 keeps 2023, a three-year delay compared to original schedule.

60 - See WNISR, "The Oddly Discreet Construction Start of Hinkley Point C", 29 December 2018, see https://www.worldnuclearreport.org/The-Oddly-Discreet-Construction-Start-of-Hinkley-Point-C.html, accessed 24 August 2019.

61 - First delay acknowledged. EDF, "Hinkley Point C project update", Press Release, 27 January 2021, see https://www.edf.fr/en/the-edf-group/dedicated-sections/journalists/all-press-releases/hinkley-point-c-project-update-1, accessed 27 January 2021.

62 - See WNISR, "Strangely Belated Announcement of Hinkley Point C-2 Construction Start", 18 March 2020, see https://www.worldnuclearreport.org/Strangely-Belated-Announcement-of-Hinkley-Point-C-2-Construction-Start.html.

63 - No official startup date announced at construction start. Although there is no official confirmation of delay at this point, EDF acknowledged the delay for HPC-1, and stated "the risk of COD [Commercial Operation Date] delay of Units 1 and 2 is maintained at respectively 15 and 9 months" and "the level of probability remains high" for the realization of this risk. WNISR2021 thus considers both units as delayed.

64 - Further delayed. "The company currently projects a Unit 3 in-service date in the second quarter of 2022 and a Unit 4 in-service date in the first quarter of 2023". Georgia Power, "Georgia Power announces revised schedule, cost forecast for Vogtle units 3 & 4", 29 July 2021, see https://www.georgiapower.com/company/news-center/2021-articles/cost-forecast-for-vogtle.html, accessed 30 July 2021.

65 - Further delayed. See Previous note.

ANNEX 5 – ABBREVIATIONS

ELECTRICAL AND OTHER UNITS

KW	kilowatt (unit of installed electric power capacity)
kWh	kilowatt hour (unit of electricity production or consumption)
MW	megawatt (10^6 watts)
MWe	megawatt electric (as distinguished from megawatt thermal, MWt)
GW	gigawatt (10^9 watts)
GWe	gigawatt electric
TWh	terawatt hour (10^{12} watt-hours)
Bq	Becquerel
mSv	millisievert
mSv/h	millisievert per hour
Sv	Sievert
Sv/h	Sievert per hour

ABWR	Advanced Boiling Water Reactor
AEA	Atomic Energy Act (U.S.)
AECL	Atomic Energy of Canada Limited
AEOI	Atomic Energy Organization of Iran
AHWR	Advanced Heavy Water Reactor
ALPS	Advanced Liquid Processing Systems
APR	Advanced Pressurized Water Reactor (Reactor Type)
ASLB	Atomic Safety Licensing Board (U.S. Nuclear Regulatory Commission)
ASN	*Autorité de Sûreté Nucléaire* – Nuclear Safety Authority (France)
BAI	Board of Audit and Inspection (South Korea)
BNEF	Bloomberg New Energy Finance
BOO	Build-Own-Operate
BWR	Boiling Water Reactor (Reactor design)
CANDU	CANadian Deuterium Uranium (Reactor design, Canada)
CAREM	Central Argentina de Elementos Modulares – Small Modular PWR Design (under construction in/by Argentina)
CEA	*Commissariat à l'énergie atomique et aux énergies alternatives* – The French Alternative Energies and Atomic Energy Commission or Central Electricity Authority (India)
CEFR	China Experimental Fast Reactor
CEZ	Chernobyl Exclusion Zone
ČEZ	*České Energetické Závody* – State-owned Energy Utility (Czech Republic)
CfD	Contract for Difference
CGN	China General Nuclear Power Corporation
CLP	Containment Liner Plates
CNEA	*Comisión Nacional de Energía Atómica* – National Atomic Energy Commission (Argentina) or China Nuclear Energy Association
CNIC	Citizens' Nuclear Information Center (Japan)

CNNC	China National Nuclear Corporation
CNSC	Canadian Nuclear Safety Commission
DOE	Department of Energy (South Africa or U.S.)
EDF	*Électricité de France* – Power Utility (France)
EIA	Environmental Impact Assessment or Energy Information Administration, also referred to as U.S.EIA (U.S.)
ENEC	Emirates Nuclear Energy Corporation
ENEL	*Ente Nazionale per l'Energia Elettrica* – National Electric Power Corporation (Italy)
ENSREG	European Nuclear Safety Regulators Group
EPR	European Pressurized Water Reactor
FA	Fiche d'Anomalie — Anomaly Report (EDF Categories)
FBI	Federal Bureau of Investigation (U.S.)
FERC	Federal Energy Regulatory Commission
FL&P	Florida Light and Power (U.S. Utility)
FL3	Flamanville-3 (French Reactor)
FNC	*Fiche de Non-Conformité* – Non-Conformance Report (EDF Categories)
FOAK	First-Of-A-Kind
GCR	Gas-Cooled Reactor (Reactor Type) or *Global Construction Review* (Publication)
GE	General Electric (Company, U.S.)
HDR	Heißdampfreaktor – Superheated steam reactor
HFT	Hot Functional Test
HTGR	High Temperature Gas Cooled Reactor
HTR	High Temperature (Gas Cooled) Reactor
HTR-PM	High-Temperature gas-cooled Reactor Pebble-bed Module (Demonstration plant, China)
HWBLWR	Heavy-Water Moderated Boiling Light-Water Cooled Reactor
IAEA	International Atomic Energy Agency
IEA	International Energy Agency
IESO	Independent Electricity System Operator (Canada)
IPCC	Intergovernmental Panel on Climate Change
IRENA	International Renewable Energy Agency
IRP	Integrated Resource Plan
ITDB	Incident and Trafficking Database (UNECE, United Nations)
JAEC	Japan Atomic Energy Commission or Jordan Atomic Energy Commission
JAPC	Japan Atomic Power Company
JCER	Japan Center for Economic Research
JPDR	Japan Power Demonstration Reactor
KA-CARE	King Abdullah City for Atomic and Renewable Energy (Saudi Arabia)
KEPCO	Kansai Electric Power Company (Japan) or Korea Electric Power Corporation (South Korea)
KHNP	Korea Hydro & Nuclear Power (South Korea)
KNPP	Kudankulam Nuclear Power Project (India)
KPMG	Klynveld, Peat, Marwick & Goerdeler (Company)
LCOE	Levelized Cost of Energy

LDP	Liberal Democratic Party (Japan)
LTE	Long-Term Enclosure
LTO	Long-Term Outage
LWGR	Light-Water Gas-cooled Reactors (Reactor type)
MAFF	Ministry of Agriculture, Forestry and Fisheries (Japan)
MEMR	Ministry of Energy and Mineral Resources (Jordan)
METI	Ministry of Economy, Trade and Industry (Japan)
MHLW	Ministry of Health, Labor and Welfare (Japan)
MoU	Memorandum of Understanding
MOX	Mixed Oxide Fuel
NDA	Nuclear Decommissioning Authority (U.K.)
NDC	Nationally Determined Contributions
NEA	Nuclear Energy Agency (of the OEDC) or National Energy Administration (China)
NEI	Nuclear Energy Institute (U.S.) or *Nuclear Engineering International* (Publication)
NEPA	National Environmental Policy Act (U.S.)
NISA	Nuclear and Industrial Safety Agency (Japan)
NIW	Nuclear Intelligence Weekly (Publication)
NOAK	Nth-Of-A-Kind
NPCIL	Nuclear Power Corporation of India Limited
NPP	Nuclear Power Plant
NPPA	Nuclear Power Plants Authority (Egypt)
NPS	Nuclear Power Station or National Policy Statement (U.K.)
NRA	Nuclear Regulation Authority (Japan)
NRC	U.S. Nuclear Regulatory Commission
NSC	New Safe Confinement (Chernobyl, Ukraine) *or* Nuclear Safety Commission (Japan, now NRA)
NSSC	Nuclear Safety and Security Commission (South Korea)
NTI	Nuclear Threat Initiative
NW	*Nucleonics Week* (Publication)
OECD	Organisation for Economic Co-operation and Development
OL3	Olkiluoto-3 (Reactor, Finland)
ONR	Office for Nuclear Regulation (UK)
OPG	Ontario Power Generation (Canada)
PAEC	Pakistan Atomic Energy Commission
PBO	Parent Body Organization
PFBR	Prototype Fast Breeder Reactor (Reactor, India)
PGE	*Polska Grupa Energetyczna* — State-owned Public Power Company (Poland)
PHWR	Pressurized Heavy Water Reactor (Reactor type)
PLEX	Plant Life Extension
PPA	Power Purchase Agreement
PRIS	Power Reactor Information System (of the IAEA)
PV	Photovoltaic

PWR	Pressurized Water Reactor (Reactor type)
R&D	Research and Development
RAB	Regular Asset Base
REMIT	Regulation on wholesale Energy Market Integrity and Transparency (EU)
RPV	Reactor Pressure Vessel
RTE	*Réseau de Transport d'Électricité* — Transmission System Operator (France)
RVI	Reactor Vessel Internals
RWE	*Rheinisch-Westfälisches Elektrizitätswerk* — Rhine-Westphalia Power Utility (Germany)
SAUEZM	State Agency of Ukraine on Exclusion Zone Management
SCG&E	South Caroline Electric & Gas (Company, U.S.)
SCHEER	EU-Commission's Scientific Committee on Health, Environmental and Emerging Risks
SE	*Slovenské Elektrárne* — Slovak Power Utility
SGHWR	Steam Generating Heavy Water Reactor (Reactor Design, U.K.)
SMART	System-integrated Modular Advanced Reactor (SMR Design, South Korea)
SMR	Small Modular Reactor
Sogin	*Società Gestione Impianti Nucleari SpA* – State-owned Decommissioning Company (Italy)
SSM	*Strålsäkerhetsmyndigheten* – Radiation Safety Authority (Sweden)
START	National Consortium for the Study of Terrorism and Responses to Terrorism
STUK	*Säteilyturvakeskus* – Radiation and Nuclear Safety Authority (Finland)
SÚJB	*Státní úřad pro jadernou bezpečnost* – State Office for Nuclear Safety (Czech Republic)
TEPCO	Tokyo Electric Power Company (Japan)
TMI	Three Mile Island Nuclear Power Plant (U.S.)
TVEL	Nuclear fuel cycle Company (Russia)
TVO	*Teollisuuden Voima Oyj* – Nuclear Power Company (Finland)
UAE	United Arab Emirates
UAMPS	Utah Associated Municipal Power Systems (U.S.)
ÚJD	*Úrad jadrového dozoru Slovenskej republiky* – Nuclear Regulatory Authority (Slovakia)
UNFCCC	United Nations Framework Convention on Climate Change
UNSCEAR	United Nations Scientific Committee on the Effects of Atomic Radiation
VAT	Value Added Tax
VVER	*Vodo-Vodianoï Energuetitcheski Reaktor* – Russian Pressurized Water Reactor Designs
WANO	Word Association of Nuclear Operators
WNA	World Nuclear Association
WNN	*World Nuclear News* (Publication)

ANNEX 6 – ABOUT THE AUTHORS

Mycle Schneider is an independent international analyst on energy and nuclear policy based in Paris. He is the Coordinator and Publisher of the World Nuclear Industry Status Report (WNISR). He is a founding board member of the International Energy Advisory Council (IEAC) and served as the Coordinator of the Seoul International Energy Advisory Council (SIEAC). He is a member of the International Panel on Fissile Materials (IPFM), based at Princeton University, the International Nuclear Security Forum (INSF), both in the U.S, and the International Nuclear Risk Assessment Group (INRAG), Austria. He provided information and consulting services, amongst others, to the Austrian Ministry for Climate Action, Environment, Energy, the Belgian Energy Minister, the French and German Environment Ministries, the U.S. Agency for International Development, the International Atomic Energy Agency (IAEA), the European Commission, and the French Institute for Radiation Protection and Nuclear Safety (IRSN). Schneider has given evidence and held briefings at national Parliaments in 15 countries and at the European Parliament. He has given lectures at over 20 universities and engineering schools around the globe. In 1997, along with Japan's Jinzaburo Takagi, he received the Right Livelihood Award, also known as the "Alternative Nobel Prize".

Antony Froggatt joined Chatham House in 2007 where he is Senior Research Fellow and Deputy-Director of the Environment and Society Programme. He studied energy and environmental policy at the University of Westminster and the Science Policy Research Unit at Sussex University and is currently an Associate Member of the Energy Policy Group at Exeter University. For over 20 years he has been involved in the publication of the World Nuclear Industry Status Report (WNISR). At Chatham House, he specializes on global electricity policy and the public understanding of climate change. He has worked as an independent consultant for two decades with environmental groups, academics and public bodies in Europe and Asia as well as a freelance journalist. His most recent research project is understanding the energy and climate policy implications of Brexit.

Julie Hazemann, based in Paris, France, is the Director of EnerWebWatch, an international documentation monitoring service, specializing in energy and climate issues, launched in 2004. As an information engineer and researcher, she has maintained, since 1992, a world nuclear reactor database and undertakes data-modelling and data-visualization work for the World Nuclear Industry Status Report (WNISR). Active in information and documentation project-management, she has a strong tropism for information structuration, dataviz and development of electronic information products. She also undertakes specialized translation and research activities for specific projects. She is a member of négaWatt (France) and develops EnerWebWatch in the framework of the Coopaname Coop.

Ali Ahmad is a Research Fellow at Harvard Kennedy School's Project on Managing the Atom (MTA) and International Security Program (ISP). His research interests include energy security and resilience and the political economy of nuclear energy in newcomer markets, with focus on the Middle East. Prior to joining MTA, Ali served as Director of the Energy Policy and Security Program at the American University of Beirut. From 2013 to 2016, Ali was a postdoctoral fellow at Princeton University's Program on Science and Global Security where he worked on informing nuclear diplomacy with Iran. Outside academia, Ali is a senior consultant at the World Bank advising the Energy and Extractive Industries Global Practice. Ali holds a first degree in Physics from the Lebanese University and a PhD in Engineering from Cambridge University.

Mariana Budjeryn is a Research Associate with the Project on Managing the Atom (MTA) at Harvard Kennedy School's Belfer Center for Science and International Affairs. Formerly, she held appointments as a Stanton Nuclear Security Fellow at MTA, a fellow at Harvard Davis Center for Russian and Eurasian Studies, and as a visiting professor at Tufts University and Peace Research Institute Frankfurt. Mariana Budjeryn's research focuses on the international non-proliferation regime, arms control, and post-Soviet nuclear history. Her analytical contributions appeared in *The Nonproliferation Review*, *Harvard International Review*, *World Affairs Journal*, *Arms Control Today*, *The Washington Post*, *Bulletin of the Atomic Scientists*, *War on the Rocks*, and in the publications of the Woodrow Wilson International Center for Scholars where she is a Global Fellow. Mariana Budjeryn's book "Inheriting the Bomb: Soviet Collapse and Nuclear Disarmament of Ukraine" is forthcoming in 2022 with *Johns Hopkins University Press*. She holds a PhD in Political Science, an MA in International Relations from Central European University (formerly) in Budapest, Hungary, and a BA in Political Science from the Kyiv-Mohyla Academy in Ukraine.

Yuichi Kaido, since his registration as a lawyer in 1981, has been involved in numerous lawsuits related to nuclear power, including the Monju lawsuit, the Rokkasho nuclear fuel cycle lawsuit, and the Hamaoka nuclear power plant lawsuit. As Secretary-General of the Japan Federation of Bar Associations (April 2010–May 2012), he was involved in the legal response to the earthquake disaster and the nuclear power plant accident. As co-chair of the National Liaison Group of Lawyers for a Nuclear Power Free Japan, he has been involved in a number of lawsuits to hold TEPCO executives and others criminally and civilly responsible for the aftermath of the March 11 disaster and to halt operation of nuclear power plants. Publications include "Nuclear Power Plant Litigation", (*Iwanami Shinsho*, 2011); "Independent Judiciary Confronts Nuclear Power Plant Litigation: Reevaluation of the Supreme Court Judgment on Ikata Nuclear Power Plant", (*Hanrei Jihou*, No. 2354, 11 February 2008); "Safety Required of Nuclear Power Plants in the Disaster Archipelago: The Role of the Constitution in Denuclearization Litigation", (*Constitutional Law Review*, No. 6, May 2020, *Shinzansha Publishing Co*).

Naoto Kan is a Japanese politician and former Prime Minister of Japan (2010–2011). Since 2017, he serves his 12th term as elected Member of the House of Representatives of the National Diet of Japan and is Chief Executive Advisor to the Constitutional Democratic Party of Japan (CDPJ). He was first elected in 1980 and remained in office until 1996, when he became Minister of Health and Welfare (1996). Prior to becoming Prime Minister in 2010, he held various Government positions within the Yukio Hatoyama Cabinet, including Minister of State for National Policy (2009), Minister of State for Science and Technology Policy (2009), Deputy Minister of Finance and Minister of State for Economic and Fiscal Policy (2010). Within the Democratic Party of Japan (DPJ), he served as President (1998–1999; 2002–2004 and 2010–2011), Vice-President (2006), and Secretary-General (2000–2002). Naoto Kan graduated from the Faculty of Applied Physics of the Tokyo Institute of Technology in 1970 and received his Patent Attorney license in 1971.

Tadahiro Katsuta holds a PhD in plasma physics from Hiroshima University (1997). He is currently a Professor at Meiji University, Tokyo, Japan. During 2014–2015 he was a Visiting Fellow in the Program on Science and Global Security (PSGS) at Princeton University, U.S. He is researching Japan's spent fuel management issues. He is also studying the Fukushima Daiichi nuclear power plant accident and following the new regulation standards with a focus on technical and political aspects. He has been appointed by Japan's Nuclear Regulation Authority (NRA) as a member of the study teams on the New Regulatory Requirements for Commercial Nuclear Power Reactors, for Nuclear Fuel Facilities, Research Reactors, and for Nuclear Waste Storage/Disposal Facilities. During 2008–2009, he conducted research on multilateral nuclear fuel cycle systems as a Visiting Fellow at PSGS. During 2006–2008, he carried out research at the University of Tokyo on separated plutonium issues linked to the Rokkasho reprocessing plant. During 1999–2005, he worked as a researcher at the Citizens' Nuclear Information Center (CNIC) in Tokyo.

Thibault Laconde is the Founding Chair of Callendar, a company focused on physical climate risks assessment, its customers include large infrastructure operators and developers in France and beyond. He previously worked for the French Ministry of Defense as well as for various humanitarian and development organizations. He is also active in the vulgarization of climate risks, in particular with Énergie & Développement, an award-winning blog, and teaching on climate transition issues at French Engineering School CentraleSupelec (2016–2019). Thibault Laconde holds an engineering degree from Supelec and a Master of Administration from Paris-1 Panthéon-Sorbonne.

Mathilde Le Moal currently works as a research associate for RealistRevolt. She holds a BA in Politics and International Relations from the University of York and a MSc in "Global Crime, Justice and Security", a multi-disciplinary course combining insights from criminology, law and international politics, which she attended at the University of Edinburgh. Specifically, her research interests include nuclear deterrence, disarmament/non-proliferation as well as nuclear trafficking and nuclear terrorism.

Hisako Sakiyama is the Chair of the Board of Directors of the 3/11 Fund for Children with Thyroid Cancer, which was established in 2016 to provide various forms of support, including financial, for children diagnosed with thyroid cancer following the Fukushima Nuclear Power Plant Disaster. Hisako Sakiyama has also acted as expert witness in a number of lawsuits following the Fukushima disaster. She is a member of the Takagi School, founded by the late Jinzaburo Takagi in 1999 to train citizen scientists. She served as a member of the National Diet of Japan Fukushima Nuclear Accident Independent Investigation Commission. She received her M.D. and Ph.D. from Chiba University School of Medicine and was a research associate in the department of biochemistry at the Massachusetts Institute of Technology (MIT) (1968–1972). She was a senior researcher at the National Institute of Radiological Sciences (NIRS), working on cancer cell biology (1975–2000).

Tatsujiro Suzuki is a Vice Director, Professor of Research Center for Nuclear Weapons Abolition at Nagasaki University (RECNA), Japan. Before joining RECNA, he was a Vice Chairman of Japan Atomic Energy Commission (JAEC) of the Cabinet Office from January 2010 to March 2014. Until then, he was an Associate Vice President of the Central Research Institute of Electric Power Industry (CRIEPI) in Japan (1996–2009) and Visiting Professor at the Graduate School of Public Policy, University of Tokyo (2005–2009), an Associate Director of MIT's International Program on Enhanced Nuclear Power Safety from 1988–1993 and a Research Associate at MIT's Center for International Studies (1993–1995). He is a member of the Advisory Board of Parliament's Special Committee on Nuclear Energy since June 2017. He is also a Council Member of Pugwash Conferences on Science and World Affairs (2007–2009 and from 2014~), Co-Chair of the International Panel on Fissile Materials (IPFM) and a Board member of Asia Pacific Leadership Network for Nuclear Non-Proliferation and Disarmament (APLN). Dr. Suzuki has a PhD in nuclear engineering from Tokyo University (1988).

M.V. Ramana is the Simons Chair in Disarmament, Global and Human Security and Director of the Liu Institute for Global Issues at the School of Public Policy and Global Affairs, University of British Columbia, Vancouver, Canada. During 2020–2021, he was a Scholar at the Peter Wall Institute for Advanced Studies. He received his Ph.D. in theoretical physics from Boston University. Ramana is the author of "The Power of Promise: Examining Nuclear Energy in India" (*Penguin Books*, 2012) and co-editor of "Prisoners of the Nuclear Dream" (*Orient Longman*, 2003). He is a member of the International Panel on Fissile Materials (IPFM), the International Nuclear Risk Assessment Group (INRAG) and the Canadian Pugwash Group. He is the recipient of a Guggenheim Fellowship and a Leo Szilard Award from the American Physical Society.

Ben Wealer is a Research Associate at the Workgroup Infrastructure Policy (WIP) at Berlin University of Technology (TU Berlin), and guest researcher at DIW Berlin (German Institute for Economic Research). He holds a PhD in economics and an MSc in Industrial Engineering from TU Berlin. His field of research is the political economy of nuclear power with a focus on decommissioning, radioactive waste management, and the economics of nuclear power plant newbuild. He is a founding member of a research project on nuclear energy in Germany, Europe, and beyond run jointly by TU Berlin and DIW Berlin, and he is a co-author of the first German independent decommissioning monitoring survey.

Agnès Stienne is an artist, cartographer, and independent graphic designer. She has contributed for over a decade to the French journal *Le Monde Diplomatique*, and the Visioncarto.net website dedicated to cartographical experimentation. She has created numerous "narrative cartographics" to illustrate a wide range of complex subjects and issues. The results of her research are featured on Visioncarto.net, as "geo-poetic" briefs, in which she uses aquarelle-paint to translate her findings into maps and data-visualizations. In 2021, she published "Inside the nebula of the Bill & Melinda Gates Foundation", a series of visualizations of the Foundation's 2017 funding and donations. For several years, she has been leading a research project focusing on agricultural practices, "land grabbing" and other fundamental agricultural and food related issues. Among her latest works set in continuity with her pieces on the "Geography of the oil palm", she created a series of paintings based on satellite images from Google Earth, which were exhibited along with her works "Geopoetics of Fields" ("Géopoétique des champs") in Le Mans (France) in October 2020 and February 2021.

Friedhelm Meinaß, born in 1948, is a visual artist and painter based in the Frankfurt area, Germany. His characteristic pieces including his cover art for Nina Hagen, are on display in the German History Museum in Berlin, and his work is internationally acclaimed. Amongst others, Meinaß has cooperated with Leonard Bernstein, The Byrds, Johnny Cash, Vladimir Horowitz and Billy Joel. He is collaborating with the Designer Constantin E. Breuer, who congenially implements his ideas. Meinaß held a professorship at the University of Design in Darmstadt in the early 1970s.