Global Launch Event

The World Nuclear Industry Status Report 2021
(WNISR2021)
www.WorldNuclearReport.org

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28 September 2021
The World Nuclear Industry
Status Report 2021

A Mycle Schneider Consulting Project
Paris, September 2021

The World Nuclear Industry
Status Report 2021

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Former Prime Minister of Japan | Member of the House of Representatives, Japan

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Mycle Schneider works as independent international consultant on energy and nuclear policy. He is the initiator, coordinator and publisher of the World Nuclear Industry Status Reports. He is a Founding Board Member and the Spokesperson for the International Energy Advisory Council (IEAC). He is a Founding Member of the International Nuclear Risk Assessment Group (INRAG) and a member of the International Nuclear Security Forum (INSF), based at the Stimson Center, USA. He is a member of the International Panel on Fissile Materials (IPFM), based at Princeton University, USA.

Between 2004 and 2009, he has been in charge of the Environment and Energy Strategies Lecture of the International Master of Science for Project Management for Environmental and Energy Engineering at the Ecole des Mines in Nantes, France.

From 2000 to 2010, he was an occasional advisor to the German Environment Ministry. 1998–2003, he was an advisor to the French Environment Minister’s Office and to the Belgian Minister for Energy and Sustainable Development. Mycle Schneider has given evidence or held briefings at national Parliaments in 16 countries and at the European Parliament. He has advised Members of the European Parliament from four different groups over the past 30+ years. He has given lectures or had teaching appointments at over 20 universities and engineering schools in 10 countries.
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”

Sources: WNISR, with BP, IAEA-PRIS, 2021
Nuclear Production in 2019-2020 and Historic Maximum in TWh and % of Electricity Production

Sources: WNISR, with IAEA-PRIS, RTE and SFOE, 2021
GLOBAL OVERVIEW – ROLE OF NUCLEAR POWER

Nuclear Electricity Production 1985–2020 in the World...
in TWh (net) and Share in Electricity Generation (gross)

...and in China and the Rest of the World
in TWh (net)

2020
For the first time since 2012, world nuclear production decreased, by around 3.9%.

Sources: WNISR, with BP, IAEA-PRIS, 2021
Nuclear Electricity Production 1985–2020 in the World...
in TWh (net) and Share in Electricity Generation (gross)

...and in China and the Rest of the World
in TWh (net)

2020
For the first time since 2012, world nuclear production decreased, by around 3.9%.
Outside of China, it dropped by 5.1% to the lowest level since 1995.

Sources: WNISR, with BP, IAEA-PRIS, 2021
Reactor Startups and Closures in the World

in Units, from 1954 to 1 July 2021

Sources: WNISR, with IAEA-PRIS, 2021
Reactor Startups and Closures in the World

in Units, from 1954 to 1 July 2021

Reactor Startups
- China
- Rest of the World

Reactor Closures
- All Countries (No Chinese in Total)

Sources: WNISR, with IAEA-PRIS, 2021
GLOBAL OVERVIEW – STARTUPS AND CLOSURES WORLD OUTSIDE CHINA

2001–2020

World
- 95 Startups,
- 98 Closures

China
- 47 Startups
- No Closure

World Outside China
- 48 Startups,
- 98 Closures

Net Balance –50

Sources: WNISR, with IAEA-PRIS, 2021
Nuclear Reactors and Net Operating Capacity in the World
in Units and GWe, from 1954 to 1 July 2021

Sources: WNISR, with IAEA-PRIS, 2021
Reactors Under Construction in the World

in Units, from 1951 to 1 July 2021

Construction Status
as of 1 July 2021

- Construction Later Abandoned or Suspended
- Construction Completed or Underway
- Construction Starts

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Sources: WNISR, with IAEA-PRIS, 2021
## Nuclear Reactors “Under Construction” (as of 1 July 2021)

<table>
<thead>
<tr>
<th>Country</th>
<th>Units</th>
<th>Capacity (MW net)</th>
<th>Construction Start</th>
<th>Grid Connection</th>
<th>Units Behind Schedule</th>
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<td><strong>1976 - 2021</strong></td>
<td><strong>2021 - 2027</strong></td>
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Sources: WNISR, with IAEA-PRIS, 2021
Average Annual Durations from Construction Start to Grid Connection
by Grid Connection Date, from 1954 to 1 July 2021

Duration in Years

Number of Reactors
1  5  10  20  30

Sources: WNISR, with IAEA-PRIS, 2021
### Construction Times of 63 Units Started-up 2011–2020

<table>
<thead>
<tr>
<th>Country</th>
<th>Units</th>
<th>Construction Time (in Years)</th>
<th>Mean Time</th>
<th>Minimum</th>
<th>Maximum</th>
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<td>Russia</td>
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<td>World</td>
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<td></td>
<td>9.9</td>
<td>4.1</td>
<td>42.8</td>
</tr>
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Duration from Construction Start to Grid Connection 2010–2019

Sources: WNISR, with IAEA-PRIS, 2021
Construction Starts of Nuclear Reactors in the World
in Units, from 1951 to 1 July 2021

Construction Status
as of 1 July 2021
- Construction Abandoned or Suspended
- Construction Completed
- Under Construction...

Sources: WNISR, with IAEA-PRIS, 2021

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Construction Starts of Nuclear Reactors in the World

in Units, from 1951 to 1 July 2021

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Sources: WNISR, with IAEA-PRIS, 2021

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GENERAL OVERVIEW — AGE EVOLUTION OF TOP 5 REACTOR FLEETS

Evolution of Mean Age of Top 5 Reactor Fleets in the World

in Years, as of year-end 1954–2020

Mean Age
in Years,
as of 31 December 2020

- USA 40.2
- France 35.6
- World 30.7
- Russia 27.8
- South Korea 21.4
- China 8.3

Sources: WNISR, with IAEA-PRIS, 2021

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Timelines of 23 U.S. Reactors Subject to Early-Retirement 2009–2025
as of 1 July 2021

Closed Units
Crystal River-3*
San Onofre-2
San Onofre-3
Kewaunee
Vermont Yankee
Fort Calhoun-1
Oyster Creek
Pilgrim-1
Three Mile Island-1
Indian Point-2
Duane Arnold-1
Indian Point-3

Units Scheduled for Closure
Palisades
Diablo Canyon-1
Diablo Canyon-2
Early Closure Without New Subsidies**
Byron-1
Byron-2
Dresden-2
Dresden-3
Reversed Early Closure
Davis Besse-1
Perry-1***
Beaver Valley-1
Beaver Valley-2

Sources: Various, compiled by WNISR, 2021

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Nuclear Electricity Production in France 1990–2020

in TWh and Share in Electricity Generation (net)

Sources: RTE, 2000–2021
Unavailability of French Nuclear Reactors in 2020

Cumulated Duration of Unavailability at Zero Power (in Days)

Average full outage time by reactor: 115.5 days

2020

Unavailability at zero power affecting the French nuclear fleet reached a total of 6,475 reactor-days, an average of 115.5 days per reactor.

All of the 56 reactors were affected, with cumulated outages between 3.5 days and the full year.

Sources: RTE and EDF, 2021
Tatsujiro Suzuki is a Vice Director, Professor at the Research Center for Nuclear Weapons Abolition at Nagasaki University (RECNA), Japan. Before joining RECNA, he was a Vice Chairman of the 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 in Japan (1996-2009), 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 (1993-95). 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 (2007-09 and from 2014~). Dr. Suzuki has a PhD in nuclear engineering from Tokyo University (1988).
Unit 1

Spent fuel pool

Unit 2

Unit 3

Removed fuel assemblies 566/566
(Completed 2021/2/28)

Unit 4

Removed fuel assemblies 1535/1535
(Completed 2014/12/22)

• For about 73% of the 1.1 million m³ of contaminated water, the concentration of up to 62 radionuclides other than tritium exceeds regulatory standards and must be re-purified.
• The re-treated water must be diluted by a factor of 100 to meet the regulatory standard for tritium.
• The process will take at least three decades.

• **35,500 Evacuees** (as of April 2021): The government intends to continue lifting 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**: Only 127 out of 54,412 samples (0.23%) taken (11 months of FY2020) were found contaminated beyond the legal limits. Food import restrictions remain in 14 countries.

• **Decontamination**: As of April 2021, around 76 percent of the total amount of 14 million m³ of contaminated soil had been shipped. The soil is to be processed through various stages of volume reduction before being retransported to a final repository.
• **Thyroid Radiation Dosimetry and Potassium Iodine**
  
  – 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: 380,000 children eligible for examination.**
  
  – 260 malignant or suspected malignant cases, 218 were diagnosed as cancer, as of July 2021 – several dozen times higher than usual.

• **Causal Relationship Between Thyroid Dose and Cancer Incidence**
  
  – Exposure doses were calculated on the bases of aircraft external radiation measurements in the evacuation zone and three regions outside. As a result, the causal relationship between radiation and cancer incorrectly seems to disappear.
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 (A) 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 (B).

Sources: Fund for Children with Thyroid Cancer, FHMSOC, 2021
• Other Cancer Cases and Other Disaster Related Deaths
  – Mortality rates decreased and morbidity have remained flat in nine other prefectures.
  – Incidence rates in Fukushima have increased since 2012.
  – Deaths from heart attack increased by 10-20% in Fukushima in 2011 for ages 40-69 and 70+.
  – The number of officially recognized “disaster related deaths” following evacuation in three prefectures reached 3,717 by late 2020.

• Health Issues of Nuclear Power Plant Workers
  – Maximum documented dose was 679 mSv, 174 workers (0.7%) are documented to have been exposed to more than 100 mSv. Average dose was 12.4 mSv.
  – Reliability of these values is highly questionable as the doses were then only measured in groups due to the lack of individual dosimeters.
  – No health study on workers has been published.
• **Government.** Cost Estimates rose from US$74.3 billion in 2012 to US$223.1 billion in 2021.
  
  – Decommissioning increased by a factor of five to US$75 billion and compensation by 26 percent to US$74 billion.
  
  – Decontamination, not factored into the first estimate, represents US$52.5 billion and a new position for “others” comes in with US$21.6 billion.

• **JCER (Japan Center for Economic Research).** Cost Estimates range from US$322 billion to US$758 billion depending on the scenario:
  
  – Decontamination estimated at US$186 billion and compensation at 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 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.
• **Government Responsibility: Divided outcome, all cases appealed**
  – Sendai High-Court decision (Sept. 2020) and the Tokyo High-Court decision (Feb. 2021) acknowledged government responsibility.
  – A separate Tokyo High-Court decision (Feb. 2021) rejected the responsibility of the state.

• **TEPCO Cases**
  – Criminal Case: Tokyo District Court acquitted three TEPCO executives from criminal responsibility (Sep. 2019).
  – Civil Liability Case: Underway.

• **Lawsuits Against Reactor Operation and Restarts**
  – April 2015: Hiroshima High Court, provisional injunction against Ikata-3.
  – March 2021: Mito District Court, injunction against Tokai Daini, because of missing credible evacuation plan.
Mariana Budjeryn is a Research Associate with the Project on Managing the Atom (MTA) at the Harvard Kennedy School’s Belfer Center. 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’s research focuses on the international non-proliferation regime, arms control, and post-Soviet nuclear history. Mariana’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.
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 will be 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.
Small Modular Reactors (SMRs) – Public Attention

• Lots of media coverage
• Some public funding
• Favourable regulation

Example Canada

• 2018: Federal funding for SMR roadmap
• 2020: Federal government released action plan
• October 2020: CAD20 million (US$16 million) in federal funding to Terrestrial Energy
• March 2021: CAD50 million (US$40 million) in federal funding to Moltex
• October 2020: Ontario Power Generation announced agreements with GE Hitachi, Terrestrial Energy and X-energy
• **Argentina**
  Carem-25 construction start 2014; November 2020 report: “physical completion of Carem 25 is at 70%”; No completion date.

• **China**
  HTR-PM construction start 2012; projected to generate electricity in 2017; recently became critical (four years late).

• **Russia**
  KLT-40S construction start 2007; projected to start operations in October 2010; commissioned in May 2020; load factors in 2020 just 29 and 16 percent.
SMRs – Reactor Design Delays

India
AHWR 2000 projection: operating by 2011; no current construction plans.

USA
NuScale 2008 projection: electricity generation by 2015-16; current: 2029-30?

Russia
“Federal Program for Advanced Nuclear Technologies” in 2012: 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; BREST construction start in June 2021.
• Loss of economies of scale
  - Nuclear power is already costly

• More spent fuel/proliferation potential
  - Accentuates problems
Ali Ahmad is a Research Fellow studying energy policy at Harvard Kennedy School’s Project on Managing the Atom and International Security Program. 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. Ali holds a first degree in Physics from the Lebanese University and a PhD in Engineering from Cambridge University.
CLIMATE CHANGE IS NUCLEAR POWER’S LATEST CHALLENGE

About two-thirds of extreme weather events were made more likely or more severe by anthropogenic climate change.

The strongest evidence is on the links of climate change to heat extremes, followed by droughts and extreme rain or flooding.

The operations of thermal power plants, including nuclear, are increasingly vulnerable to these extreme weather events driven by climate change.

Sources: Nature, 2018
Climate change can disrupt the operations of nuclear power plants through different pathways:

- **Thermal disruptions** related to the ambient temperature and availability of water.
- **Violent storms** including hurricanes or typhoons, as well as floods, lightning, etc.
- **Indirect disruptions** due to wildfires, jellyfish proliferation, etc.
The increasing emphasis on “energy resilience” demands new types of suitability assessments of national energy plans that consider technology-specific and system-wide vulnerabilities.

Climatic disruptions could be more consequential for nuclear power as they could compound (or be a precursor) of a serious nuclear accident.

In principle, nuclear power can adapt to dealing with climate disruptions. However, major tradeoffs and economic losses will be incurred.
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 Energie & 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.
Weather-related disruptions of nuclear power production in France since 2015:

- **357 outages** identified
- At least a few dozen disruptions a year
- Up to **2,300 reactor-hours** lost in a year
- Up to **6.2 GW** unavailable

Sources: RTE and Callendar, 2021
Climate Related Unavailabilities of French Nuclear Power Plants 2015–2020
Maximum Simultaneous Unavailable Capacity

in GW per Year per Cause

Weather-related disruptions of nuclear power production in France since 2015:

- **357 outages** identified
- At least a few dozen disruptions a year
- Up to **2,300 reactor-hours** lost in a year
- Up to **6.2 GW** unavailable
Climate Related Unavailabilities of French Nuclear Power Plants 2015–2020
in GWh by Most Probable Cause and Month

Sources: REMIT, compiled by Callendar 2021
Climate Related Unavailabilities of French Nuclear Power Plants 2015–2020

in GWh per Year and Site

Sources: REMIT, compiled by Callendar 2021
Mathilde Le Moal currently works as a research associate for RealistRevolt, as a research intern at the French Ministry of Defense and as a volunteer within the CBRN mitigation training department of FSF-IHCE (NGO).

She became passionate about the study of nuclear deterrence, nonproliferation and disarmament during her BA in Politics and International Relations at the University of York. She initially specialized in the study of France’s nuclear weapons policymaking. During her interdisciplinary masters in Global Crime, Justice and Security at the university of Edinburgh, she broadened her scope of inquiry with her research on transnational criminal groups’ involvement in nuclear trafficking.
Why This Chapter? Why Now?

- Recent cases of bribery and fraud in South Carolina, Illinois and Ohio.
- WNISR2020 refers to the term “corrupt” 14 times in connection with corruption cases involving 9 countries on 4 continents.
- Older notorious bribery cases (e.g. Transnuklear affair in Europe in 1980s)
- Other criminal activities: sabotage, nuclear trafficking, organized crime.

➔ What kind of criminal behaviours affect the nuclear industry?
➔ Patterns? e.g. motives behind the crimes? enabling factors?
Typology of Crimes

- **Bribery**
  - ‘business to business’
  - public officials

- **Fraud (counterfeiting and falsification)**
  - grand collusion schemes
  - company-level fraud

- **Sabotage & unauthorized access** to sensitive areas

- **Organized crime**
  - trafficking of nuclear/radiological materials
  - unlicensed workers

*Traditional definition of ‘crime’: conviction or substantial prima facie evidence.*
Scope

● **PART I - Typology of corrupt practices** (bribery and fraud)
  ○ 2010-2020 / Top-8 nuclear power fleets by operating capacity (2020): Canada, China, France, Japan, Russia South Korea, Ukraine, the U.S.
  ○ Crimes tried/having taken place during the investigated period of time.
  ○ Notable degree of severity.

● **PART II - Sabotage and organized crime in Japan, Russia and the U.S.**
  ○ No specific timeframe.
  ○ Insider involvement.
  ○ Nuclear power plants.

*Sources*: academic literature, START Database, NTI, IAEA reports & Factsheets, parliamentary reports, court cases, newspaper articles, documentaries, police reports...
Limitations

● **Scope**
  ○ Analysis focused on a **limited number of countries**.
  ○ **PART II** excludes outsider attacks, nuclear terrorism & cyber threats, cases having taken place in other fuel chain facilities.

● **Access to data**
  ○ Counterfeit or Fraudulent Items (CFIs)
  ○ Nuclear trafficking - **START** and CNS databases publicly available
  ○ Sabotage - the 2014 Doel Nuclear Power Plant incident

● **A systemic issue?**
Antony Froggatt joined Chatham House in 2007 and is Deputy Director and a Senior Research Fellow in the Energy, Environment and Resources Department. He has worked as an independent consultant for 20 years with environmental groups, academics and public bodies in Europe and Asia. His most recent research projects are understanding the energy and climate policy implications of Brexit, climate risk (particularly in China), and on the technological and policy transformation of the energy sector. Since 1992 he has been the co-author of the World Nuclear Industry Status Report, a now annual independent review of the nuclear sector.
Global Investment Decisions in New Renewables and Nuclear Power
in US$ billion, 2004-2020


in TWh (gross)

- Wind
- Solar
- Other Renewables
- Nuclear

Sources: BP Statistical Review, 2021
Selected Historical Mean Costs by Technology

LCOE values in US$/MWh *

- Nuclear: 123 → 163
- Coal: 111 → 112
- Gas - Combined Cycle: 83 → 59
- Wind: 135 → 41
- Solar PV-Crystalline: 359 → 37

* Reflects total decrease in mean LCOE since Lazard’s LCOE VERSION 3.0 in 2009.

Source: Lazard Estimates, 2020
2050 Forecasted Average Cost of Electricity from Nuclear and Renewables

in US$/MWh

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Source: IEA, 2021
Nuclear vs. Non-Hydro Renewable Electricity Production in China 2000–2020

in TWh (gross)

- Wind
- Solar
- Other Non-Hydro Renewables
- Nuclear

Sources: BP Statistical Review, 2021
Electricity Production in the EU27 2011–2020

in TWh/year

Note: Due to rounding, numbers may not add up

Sources: IAEA-PRIS, Agora Energiewende and Ember, 2021
Wind, Solar and Nuclear Capacity and Electricity Production in India 2000–2020

Sources: WNISR with IAEA-PRIS, IRENA, BP Statistical Review, 2021
• In 2020, nuclear power generation plunged by an unprecedented margin except for the aftermath of 3/11 (2011–12), while operational nuclear capacity has reached a new peak in mid-2021. More capacity, less output.

• Non-hydro renewables—mainly wind, solar and biomass—have outperformed nuclear power on a global scale. Hydro alone has been generating more power than nuclear for most of the past three decades.

• For the first time, non-hydro renewables generated more power in the European Union than nuclear, and renewables including hydro generated more power than all fossil fuels combined.

• Net nuclear capacity addition—new startups minus closures—declined to 0.4 GW, compared to >150 GW for renewables alone. Nuclear is irrelevant in today’s electricity capacity newbuild market.

• Small Modular Reactors (SMRs) get a lot of media coverage, some public money, but are so far unavailable commercially and will not be—if ever—for another 10–15 years. Pilot projects in Argentina, China, and Russia have been disappointing.

• The situation at Fukushima, onsite/offsite, remains unstable. Effects on health and well-being are significant. Cost estimates have risen, currently range from US$223.1 billion (Gov.) to US$322–758 billion (independent). Japanese courts have acquitted Government/TEPCO officials over disaster responsibility but ruled against reactor operation in some cases.

• Nuclear power demonstrated a high sensibility to the COVID-19 pandemic. A first analysis shows that it has a low resilience against the most common climate change effects. Nuclear’s resilience will likely further decline.

• There is a real question about the exposure of the nuclear power sector to criminal activities including bribery and corruption, counterfeiting and other falsification schemes, as well as infiltration by organized crime.
Expected vs. Real Duration from Construction Start to Grid Connection for Startups 2018–2020

in Years

Belarus
Belarusian-1 5

China
Fuying-5 4.5
Haiyang-1 4.8
Haiyang-2 4.8
Sanmen-1 4.5
Sanmen-2 4.7
Taishan-1 4.1
Taishan-2 4.3
Tianwan-4 4.6
Tianwan-5 5.1
Yangjiang-5 4.1
Yangjiang-6 4.7

South Korea
Shin-Kori-4 5

Russia
Akademik Lomonosov-1 3.7
Akademik Lomonosov-2 3.7
Leningrad 2-1 5
Leningrad 2-2 5
Novovoronezh 2-2 5
Rostov-4 6

UAE
Barakah-1 5

Sources: WNISR, with IAEA-PRI, 2021

© WNISR - Mycle Schneider Consulting
Expected vs. Real Duration from Construction Start to Grid Connection for Startups 2018–2020
in Years

<table>
<thead>
<tr>
<th>Country</th>
<th>Project</th>
<th>Expected Construction Time</th>
<th>Construction Suspension</th>
<th>Delay</th>
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<tbody>
<tr>
<td>Belarus</td>
<td>Belarusian-1</td>
<td>5</td>
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<tr>
<td>China</td>
<td>Fuyong-5</td>
<td>4.5</td>
<td>5.6</td>
<td>8.9</td>
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<tr>
<td></td>
<td>Haiyang-1</td>
<td>4.8</td>
<td>8.3</td>
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<tr>
<td></td>
<td>Haiyang-2</td>
<td>4.8</td>
<td>8.7</td>
<td></td>
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<tr>
<td></td>
<td>Sanmen-1</td>
<td>4.5</td>
<td>8.7</td>
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<tr>
<td></td>
<td>Sanmen-2</td>
<td>4.7</td>
<td>9.2</td>
<td></td>
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<tr>
<td></td>
<td>Taishan-1</td>
<td>4.1</td>
<td>8.7</td>
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<td></td>
<td>Taishan-2</td>
<td>4.5</td>
<td>5.1</td>
<td>9.6</td>
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<tr>
<td></td>
<td>Tianwan-4</td>
<td>4.6</td>
<td>5.5</td>
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<td></td>
<td>Tianwan-5</td>
<td>4.1</td>
<td>4.7</td>
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<td>South Korea</td>
<td>Shin-Kori-4</td>
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<td>Russia</td>
<td>Akademik Lomonosov-1</td>
<td>3.7</td>
<td>12.7</td>
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<tr>
<td></td>
<td>Akademik Lomonosov-2</td>
<td>3.7</td>
<td>12.7</td>
<td></td>
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<tr>
<td></td>
<td>Leningrad 2-1</td>
<td>5</td>
<td>9.4</td>
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<td></td>
<td>Leningrad 2-2</td>
<td>5</td>
<td>10.5</td>
<td></td>
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<td>Novovoronezh 2-2</td>
<td>5</td>
<td>9.8</td>
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<td></td>
<td>Rostov-4</td>
<td>6</td>
<td>35.1</td>
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<td>UAE</td>
<td>Barakah-1</td>
<td>5</td>
<td>8.1</td>
<td></td>
</tr>
</tbody>
</table>

Sources: WNISR, with IAEA-PRIS, 2021
Abandoned Reactor Constructions from 1970 to 1 July 2021
in Units by Cancellation Year and Country

- Brazil - 1
- Cuba - 2
- USA - 42
- Austria - 1
- Bulgaria - 2
- Czech Rep. - 2
- Germany - 6
- Italy - 3
- Lithuania - 1
- Poland - 2
- Romania - 3
- Russia - 12
- Spain - 4
- Sweden - 1
- Ukraine - 6
- Japan - 1
- N. Korea - 1
- Philippines - 1
- Taiwan - 2

Sources: WNISR, with IAEA-PRIS, 2021
Age of World Nuclear Fleet
as of 1 July 2021

415 Reactors
Mean Age 30.9 Years

Reactor Age
- 0–10 Years
- 11–20 Years
- 21–30 Years
- 31–40 Years
- 41–50 Years
- 51 Years and Over

50 Number of Reactors by Age Class

Sources: WNISR, with IAEA-PRIS, 2021
Age of Closed Nuclear Reactors in the World
as of 1 July 2021

196 Reactors
Mean Age
27.1 Years

Reactor Age
- 0–10 Years
- 11–20 Years
- 21–30 Years
- 31–40 Years
- 41–50 Years

50 Number of Reactors by Age Class

Sources: WNISR, with IAEA-PRIS, 2021
**Projection 2021–2050 of Nuclear Reactors/Capacity in the World**

*General assumption of 40-year mean lifetime*

Operating and Under Construction as of 1 July 2021, in GWe and Units

---

Sources: Various, compiled by WNISR, 2021
PROJECTIONS – THE 40-Year Lifetime Projection

Projection 2020–2050 of Nuclear Reactors/Capacity in the World

General assumption of 40-year mean lifetime + Authorized Lifetime Extensions
Operating and Under Construction as of 1 July 2020, in GWe and Units

Capacity in GWe

Yearly Balance

Reactor Startup

Reactor Closures

Capacity Added

Capacity Closed

Number of Reactors

Sources: Various, compiled by WNISR, 2021
World Nuclear Reactor Fleet
in Units, from July 2021 to 2050

Composition of World Fleet
- LTO
- Lifetime > 40 Years
- Lifetime ≤ 40 Years

Sources: Various, compiled by WNISR, 2021
Age of Chinese Nuclear Fleet
as of 1 July 2021

Reactor Age
- 0–10 Years
- 11–20 Years
- 21–30 Years

52 Reactors
Mean Age
8.5 Years

Number of Reactors by Age Class
- 40 Reactors (0–10 Years)
- 9 Reactors (11–20 Years)
- 3 Reactors (21–30 Years)

Sources: WNISR, with IAEA-PRIS, 2021
Evolution of Nuclear Reactors' Average Closure Age 1963 – 1 July 2021

by Closure Year

Number of Reactors

1 2 5 12 25

Age in Years

Average Closure Age 2016–2020: 42.6 years

Sources: WNISR, with IAEA-PRIS, 2021
FRANCE FOCUS – EVOLUTION OF NUCLEAR FLEET

Nuclear Reactors and Net Operating Capacity in France
in Units and GWe, 1959–2020

- Reactors in Operation
- Reactors in LTO
- Operating Capacity

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Sources: WNISR, with IAEA-PRIS, 2021
French Reactor Startups and Closures 1959–2020

in Units

Startups

Operating
- PWR

Closed
- PWR
- GCR
- HWGCR
- FBR

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Sources: WNISR, with IAEA-PRIS, 2021
**Monthly Nuclear Production in France**
in TWh, 2012–mid-2021

Sources: RTE, 2021
Unavailability of French Nuclear Reactors in 2020
Reactors Offline the Same Day (Zero Output)
in Units and Capacity

2020
On 335 days—92% of the year—10 reactors or more did not provide any power at least part of the day, of which 169 days—46% of the year—20 or more reactors.
The maximum number of reactors offline simultaneously was 30 (33 GW) and the minimum 6 (6.7 GW).
Twenty reactors or more were off-line simultaneously during the equivalent of 158.5 days (43% of the year).

Sources: compiled by WNISR, with RTE Data, 2020–2021
Age of French Nuclear Fleet
as of 1 July 2021

Reactor Age
- 21–30 Years
- 31–40 Years
- 41–50 Years

50 Number of Reactors by Age Class

Sources: WNISR with IAEA-PRIS, 2021
French Public Opinion Survey on Energy Sources

What is your opinion about each of the following energy sources?

- Solar: 91.2%
- Wind: 81.6%
- Hydro: 78.4%
- Biomass: 68.4%
- Gas: 43.1%
- Nuclear: 34.3%
- Oil: 25.6%

Ranking of Energies According to Positive Opinion in %

Sources: IRSN, 2021
Rise and Fall of the Japanese Nuclear Program - 1963 to July 2021
Fleet (in GW) and Electricity Generation (in TWh)

Sources: WNISR with IAEA-PRIS, 2021
Status of Reactors Officially Operational in Japan vs. WNISR Assessment
in Units, as of year end 2005–2020 and mid-2021

1 July 2021
Officially Operating
33 Reactors

WNISR Status
9 Operating:
Sendai-1 & -2,
Takahama-3 & -4, Ohi-3 & -4,
Genkai-3 & -4, Mihama-3.
24 in LTO of which
Kashiwazaki-Kariwa 2–4
since 2007.

YEAR: Officially closed
(YEAR): last production year,
WNISR Closure

Status

- Operating
- Long Term Outage
  of which since
  2007 Earth Quake
- WNISR Closed

* To be decommissioned, but not officially closed yet

Sources: Various, compiled by WNISR
Age of Japan Nuclear Fleet
as of 1 July 2021

- 33 Reactors
- 9 Operating
- 24 in LTO
- Mean Age: 30.4 Years

Reactor Age
- 11–20 Years
- 21–30 Years
- 31–40 Years
- 41–50 Years

50 Number of Reactors
by Age Class

Sources: WNISR with IAEA-PRIS, 2021
## Expected Closure Dates of U.K. Nuclear Reactor Fleet – As of 1 July 2021

<table>
<thead>
<tr>
<th>Reactor</th>
<th>Type/Model</th>
<th>Net Capacity (MW)</th>
<th>Grid Connection</th>
<th>Age</th>
<th>Expected Closure</th>
<th>Status / Comment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dungeness B-1</td>
<td>AGR</td>
<td>545</td>
<td>03/04/1983</td>
<td>38.2</td>
<td></td>
<td>Closed. Last power generation on 28 September 2018</td>
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<tr>
<td>Dungeness B-2</td>
<td>AGR</td>
<td>545</td>
<td>29/12/1985</td>
<td>35.4</td>
<td></td>
<td>Closed. Last power generation on 27 August 2018</td>
</tr>
<tr>
<td>Hartlepool A-1</td>
<td>AGR</td>
<td>590</td>
<td>01/08/1983</td>
<td>37.8</td>
<td></td>
<td>March 2024</td>
</tr>
<tr>
<td>Hartlepool A-2</td>
<td>AGR</td>
<td>595</td>
<td>31/10/1984</td>
<td>36.6</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Heysham A-1</td>
<td>AGR</td>
<td>485</td>
<td>09/07/1983</td>
<td>37.9</td>
<td></td>
<td>2024</td>
</tr>
<tr>
<td>Heysham A-2</td>
<td>AGR</td>
<td>575</td>
<td>11/10/1984</td>
<td>36.6</td>
<td></td>
<td>2024</td>
</tr>
<tr>
<td>Heysham B-1</td>
<td>AGR</td>
<td>620</td>
<td>12/07/1988</td>
<td>32.9</td>
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<td>2030</td>
</tr>
<tr>
<td>Heysham B-2</td>
<td>AGR</td>
<td>620</td>
<td>11/11/1988</td>
<td>32.6</td>
<td></td>
<td>2030</td>
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<tr>
<td>Hinkley Point B-1</td>
<td>AGR</td>
<td>485</td>
<td>30/10/1976</td>
<td>44.6</td>
<td></td>
<td>July 2022</td>
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<tr>
<td>Hinkley Point B-2</td>
<td>AGR</td>
<td>480</td>
<td>05/02/1976</td>
<td>45.3</td>
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<td>January 2022</td>
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<tr>
<td>Hunterston B-1</td>
<td>AGR</td>
<td>490</td>
<td>06/02/1976</td>
<td>45.3</td>
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<tr>
<td>Hunterston B-2</td>
<td>AGR</td>
<td>495</td>
<td>31/03/1977</td>
<td>44.2</td>
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<tr>
<td>Sizewell-B</td>
<td>PWR</td>
<td>1,198</td>
<td>14/02/1995</td>
<td>26.3</td>
<td></td>
<td>2035</td>
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<tr>
<td>Torness-1</td>
<td>AGR</td>
<td>595</td>
<td>25/05/1988</td>
<td>33</td>
<td></td>
<td>2030</td>
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<td>Torness-2</td>
<td>AGR</td>
<td>605</td>
<td>03/02/1989</td>
<td>32.3</td>
<td></td>
<td>2030</td>
</tr>
</tbody>
</table>

Sources: EDF Energy, 2021
Age of UK Nuclear Fleet
as of 1 July 2021

Reactor Age
- 21–30 Years
- 31–40 Years
- 41–50 Years

50 Number of Reactors by Age Class

13 Reactors
Mean Age
37.4 Years

Sources: WNISR with IAEA-PRIS, 2021
The Age of U.S. Nuclear Fleet as of 1 July 2021 is shown in the diagram. There are 93 reactors with a mean age of 40.7 years.

Reactor Age:
- 0–10 Years: 1 reactor (1.1%)
- 11–20 Years: 4 reactors (4.3%)
- 21–30 Years: 21 reactors (22.6%)
- 31–40 Years: 41 reactors (43.8%)
- 41–50 Years: 10 reactors (10.8%)
- 51 Years and Over: 3 reactors (3.2%)

Sources: WNISR with IAEA-PRIS, 2021
Evolution of Nuclear Reactors' Average Closure Age in the U.S. 1963 – 1 July 2021

by Closure Year

2016–2020
6 Reactors Closed
Average Closure Age: 46.2 Years

Age in Years

Sources: WNISR with IAEA-PRIS, 2021
## Thyroid Cancers Identified in the Fukushima Prefectural Health Management Survey

<table>
<thead>
<tr>
<th></th>
<th></th>
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<tr>
<td></td>
<td></td>
<td>116</td>
<td>71</td>
<td>31</td>
<td>33</td>
<td>9</td>
<td>260</td>
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<tr>
<td>Male / Female</td>
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<td>39 / 77</td>
<td>32 / 39</td>
<td>13 / 18</td>
<td>14 / 19</td>
<td>2 / 7</td>
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<tr>
<td>Age as of 3/11 (Average Age)</td>
<td></td>
<td>6–18 (14.9±2.6)</td>
<td>5–18 (12.6±3.2)</td>
<td>5–16 (9.6±2.9)</td>
<td>0–12 (7.9±2.9)</td>
<td>6–18 (17.1±0.7)</td>
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<td>Confirmed</td>
<td></td>
<td>102</td>
<td>55</td>
<td>29</td>
<td>27</td>
<td>6</td>
<td>219</td>
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<tr>
<td>Histologic Type</td>
<td></td>
<td>PTC: 100 Poorly differentiated TC: 1</td>
<td>PTC: 54 Other type of TC: 1</td>
<td>PTC: 29</td>
<td>PTC: 27</td>
<td>PTC: 5 FTC: 1</td>
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<td></td>
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<td>Benign nodule: 1</td>
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<tr>
<td>Participants</td>
<td></td>
<td>300,472 (81.7%)</td>
<td>270,540 (71.0%)</td>
<td>217,921 (64.7%)</td>
<td>183,298 (62.3%)</td>
<td>7,621 (8.7%)</td>
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</tr>
<tr>
<td>(Participation rate)</td>
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<td></td>
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</tr>
</tbody>
</table>

Sources: FHMSOC, July 2021
Fukushima Disaster Induced Costs
in US$ billion

Sources: METI, 2016; METI, 2021; JCER, 2019
Review of Manufacturing Records Relating to Components Manufactured at Creusot Forge
as of January 2019

As of January 2019, EDF had submitted summary reports to the ASN relating to 1,580 components installed in the 58 then operating reactors. They comprised a total of 879 Non-Conformance Reports (FNC) and 2,982 Anomaly Reports (FA), or an average of 2.44 irregularities per component (up to 4.47/component on average in one reactor). Those irregularities affect the entire fleet with 66.6 per reactor on average (from 27 to 122 per reactor).

Number of Reports per Reactor
- Anomaly Report (FA)
- Non-Conformance Report (FNC)
- Average Number of Irregularities (FA+FNC) per Component

Sources: EDF, "Dossiers de fabrication", 2019
### Overview of Reactor Decommissioning Worldwide (as of July 2021)

<table>
<thead>
<tr>
<th>Country</th>
<th>Closed Reactors</th>
<th>Warm-up</th>
<th>Hot-zone</th>
<th>Ease-off</th>
<th>LTE</th>
<th>Completed</th>
<th>Share of Completed</th>
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<tbody>
<tr>
<td>USA</td>
<td>40</td>
<td>9</td>
<td>0</td>
<td>4</td>
<td>13</td>
<td>14</td>
<td>35%</td>
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<td>UK</td>
<td>32</td>
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<td>0</td>
<td>32</td>
<td>0</td>
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<td>0%</td>
</tr>
<tr>
<td>Germany</td>
<td>30</td>
<td>8</td>
<td>8</td>
<td>1</td>
<td>5</td>
<td>1</td>
<td>17%</td>
</tr>
<tr>
<td>Japan</td>
<td>27</td>
<td>26</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>4%</td>
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<td>France</td>
<td>14</td>
<td>4</td>
<td>2</td>
<td>8</td>
<td>0</td>
<td>0</td>
<td>0%</td>
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<td>Russia</td>
<td>9</td>
<td>0</td>
<td>0</td>
<td>9</td>
<td>0</td>
<td>0</td>
<td>0%</td>
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<td>7</td>
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<td>4</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0%</td>
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<td>Canada</td>
<td>6</td>
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<td>0</td>
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<td>0%</td>
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<td>Bulgaria</td>
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<td>0</td>
<td>0</td>
<td>0</td>
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<td>0%</td>
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<tr>
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</tr>
<tr>
<td>Netherlands</td>
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</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>196</strong></td>
<td><strong>72</strong></td>
<td><strong>15</strong></td>
<td><strong>14</strong></td>
<td><strong>74</strong></td>
<td><strong>20</strong></td>
<td><strong>10%</strong></td>
</tr>
</tbody>
</table>

Sources: Various, compiled by WNISR, 2021
Overview of Completed Reactor Decommissioning Projects, 1954–2020

in the U.S., Germany and Japan, as of 1 July 2021

**United States**
- Shippingport
- Yankee NPS
- Elk River
- Pathfinder
- Saxton
- CVTR
- Big Rock Point
- Lacrosse
- Haddam Neck
- Fort St. Vrain
- Maine Yankee
- Rancho Seco-1
- Trojan
- Shoreham

**Germany**
- VAK Kahl
- Gundremmingen-A (KRB A)
- HDR Grosswalzheim
- Niederaichbach (KKN)
- Wuegassen (KWW)

**Japan**
- JPDR

Sources: Various, compiled by WNISR, 2021
Progress and Status of Reactor Decommissioning in Selected Countries
in Units, June 2018 – June 2021

Sources: Various, compiled by WNISR, 2021
Regional Breakdown of Nuclear and Renewable Energy Investment Decisions
in US$ Billion, 2011–2020

Sources: BNEF/UNEP, REN21 and WNISR Original Analysis, 2021
Wind, Solar and Nuclear Developments: Installed Capacity and Electricity Production in the World

Capacity Added Since 2000
in GWe

Annual Production Compared to 1997
in net added TWh

Sources: WNISR with IAEA-PRIS, IRENA, BP Statistical Review, 2021
Wind, Solar and Nuclear Capacity and Electricity Production in the World

Installed Capacity in GWe

Wind
Solar
Nuclear
Nuclear (excl. LTO)

Annual Production in TWh/year

Nuclear
Wind
Solar

Sources: WNISR with IAEA-PRIS, IRENA, BP Statistical Review, 2021
Power Generation in the World Annual Production Compared to 2010
in added TWh (gross) by Source

- Non-Hydro Renewables
- Gas
- Hydro
- Coal
- Nuclear
- Oil

Sources: BP Statistical Review, 2021
Wind, Solar and Nuclear Capacity and Electricity Production in China 2000–2020

Sources: WNISR with IAEA-PRIS, IRENA, BP Statistical Review, 2021
Wind, Solar and Nuclear Developments: Installed Capacity and Electricity Production in the EU27

Capacity Added Since 2000
in GWe net

Annual Production Compared to 1997
in net added TWh

Sources: WNISR with IAEA-PRIS, IRENA, BP Statistical Review, 2021
Wind, Solar and Nuclear Capacity and Electricity Production in the EU27

Installed Capacity in GWe

Annual Production in TWh/year

Sources: WNISR with IAEA-PRIS, IRENA, BP Statistical Review, 2021
Wind, Solar and Nuclear Capacity and Production in the U.S. 2000–2020

Installed Capacity in GW

Wind
Nuclear
Solar

Annual Production in TWh/year

Wind
Nuclear
Solar

Sources: WNISR with IAEA-PRIS, IRENA, BP Statistical Review, 2021
Climate Related Unavailabilities of French Nuclear Power Plants 2015–2020
in GWh by Most Probable Cause and Year

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Climate Related Unavailabilities of French Nuclear Power Plants 2015–2020
in GWh per Most Probable Cause and Site

© WNISR - MYCLE SCHNEIDER CONSULTING

REMIT, compiled by Callendarr 2021
Climate Related Unavailabilities of French Nuclear Power Plants 2015–2020
Maximum Simultaneous Unavailable Capacity
in GW per Year per Cause

Sources: RTE and Callendar, 2021
Reactor Startups and Closures in the EU27

in Units, from 1959 to 1 July 2021

Sources: WNISR with IAEA-PRIS, 2021
Nuclear Reactors and Net Operating Capacity in the EU 27
in Units and GWe, from 1959 to 1 July 2021

1989
Maximum Number
of Reactors: 136

2002
Maximum Operating
Capacity: 124.5 GWe

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Sources: WNISR with IAEA-PRIS, 2021
Age of Nuclear Fleet in the EU27
as of 1 July 2021

106 Reactors
Mean Age
35.9 Years

77

11

3

15

Reactor Age
11–20 Years
21–30 Years
31–40 Years
41–50 Years

50 Number of Reactors by Age Class

Sources: WNISR with IAEA-PRIS, 2021
Age of Western European Nuclear Fleet
as of 1 July 2021

104 Reactors
Mean Age
37.4 Years

74
8
21
1

Reactor Age
- 21–30 Years
- 31–40 Years
- 41–50 Years
- 51 Years and Over

50 Number of Reactors by Age Class

Sources: WNISR with IAEA-PRIS, 2021
Main Evolution of the German Power System Between 2010 and 2020 in TWh

- Fossil Fuel Reduction: -130 TWh
  - Fossil fuel and nuclear generation reductions...
- Nuclear Reduction: -76 TWh
- Net Export Increase: 5 TWh
- Consumption Decrease: -67 TWh
- Renewables Increase: 146 TWh

... are covered by consumption decrease and renewable production increase.

Sources: AG EnergieBilanz, 2021
Age of Swiss Nuclear Fleet
as of 1 July 2021

Reactor Age
- 31–40 Years
- 41–50 Years
- 51 Years and Over

50 Number of Reactors by Age Class

Sources: WNISR with IAEA-PRIS, 2021
Age of Russian Nuclear Fleet

as of 1 July 2021

38 Reactors
Mean Age
28.3 Years

Reactor Age

0–10 Years
11–20 Years
21–30 Years
31–40 Years
41–50 Years

50 Number of Reactors
by Age Class

Sources: WNISR with IAEA-PRIS, 2021