

Nuclear power

Nuclear power is the use of nuclear reactions that release nuclear energy^[5] to generate heat, which most frequently is then used in steam turbines to produce electricity in a nuclear power plant. The term includes nuclear fission, nuclear decay and nuclear fusion. Presently, the nuclear fission of elements in the actinide series of the periodic table produce the vast majority of nuclear energy in the direct service of humankind, with nuclear decay processes, primarily in the form of geothermal energy, and radioisotope thermoelectric generators in niche uses making up the rest.

Owing, fundamentally, to the control on the power or heat increase, that is inherent to the slow delayed critical fission process,^[6] Fission-electric power stations and engines have and continue to be built, as an alternative to the dominant fossil-fuel power systems of the world. Fission-electricity is one of the leading low carbon power generation methods of producing electricity, and in terms of total life-cycle greenhouse gas emissions per unit of energy generated, has emission values lower than renewable energy when the latter is taken as a single energy source.^{[7][8]} A 2014 analysis of the carbon footprint literature by the Intergovernmental Panel on Climate Change (IPCC) reported that the embodied total life-cycle emission intensity of fission electricity has a median value of 12 g CO₂eq/kWh which is the lowest out of all commercial baseload energy sources.^{[9][10]} This is contrasted with coal and fossil gas at 820 and 490 g CO₂ eq/kWh.^{[9][10]} From the beginning of fission-electric power station commercialization in the 1970s, nuclear power prevented the emission of about 64 billion tonnes of carbon dioxide equivalent that would have otherwise resulted from the burning of fossil fuels in thermal power stations.^[11]

There is a social debate about nuclear power.^{[12][13][14]} Proponents, such as the World Nuclear Association and Environmentalists for Nuclear Energy, contend that nuclear power is a safe, sustainable energy source that reduces carbon emissions.^[15] Opponents, such as Greenpeace International and NIRS, contend that nuclear power poses many threats to people and the environment.^{[16][17][18]} Far-reaching fission power reactor accidents, or accidents that resulted in medium to long-lived fission product contamination of inhabited areas, have occurred in Generation I and II reactor designs. These include the Chernobyl disaster in 1986, the Fukushima Daiichi nuclear disaster in 2011, and the more contained Three Mile Island accident in 1979.^[19] There have also been some nuclear submarine accidents.^{[19][20][21]} In terms of lives lost per unit of energy generated, analysis has determined that fission-electric reactors have caused fewer fatalities per unit of energy generated than the other major sources of energy generation. Energy production from coal, petroleum, natural gas and hydroelectricity has caused a greater number of fatalities per unit of energy generated due to air pollution and energy accident effects.^{[22][23][24][25][26][27]}

As of 2017, the International Atomic Energy Agency states that 60 reactors, mostly of Generation III reactor design, are under construction around the world, with the majority in Asia.^[28] Collaboration on research & developments towards greater passive nuclear safety, efficiency and recycling of spent fuel in future Generation IV reactors presently includes Euratom and the co-operation of more than 10 permanent countries globally.^[29]



The 1200 MWe, Leibstadt fission-electric power station in Switzerland. The boiling water reactor (BWR), located inside the dome capped cylindrical structure, is dwarfed in size by its cooling tower. The station produces a yearly average of 25 million kilowatt-hours per day, sufficient to power a city the size of Boston.^[1]



The Palo Verde Nuclear Generating Station, the largest in the US with 3 pressurized water reactors (PWRs), is situated in the Arizona desert. It uses sewage from cities as its cooling water in 9 squat mechanical draft cooling towers.^{[2][3]} Its total spent fuel/"waste" inventory produced since 1986, is contained in dry cask storage cylinders located between the artificial body of water and the electrical switchyard.

Contents

History

- Origins
 - First nuclear reactor
- Early years
- Development
- Three Mile Island and Chernobyl
- Nuclear renaissance
- Fukushima Daiichi Nuclear Disaster
- Post-Fukushima
- Future of the industry

Industry

- Companies
- Capacity and production
- Economics

Nuclear power plants

Life cycle of nuclear fuel

- Conventional fuel resources
 - Breeding
- Solid waste
 - High-level radioactive waste
 - Low-level radioactive waste
 - Waste relative to other types
 - Waste disposal
- Reprocessing
 - Depleted uranium

Accidents, attacks and safety

- Accidents
- Attacks and sabotage

Nuclear proliferation

Environmental issues

- Climate change

Comparison with renewable energy

Nuclear decommissioning

Debate on nuclear power

Use in space

Research

- Advanced concepts
- Hybrid nuclear fusion-fission
- Nuclear fusion

See also

References

Further reading

External links

- Introduction



U.S. nuclear powered ships,(top to bottom) cruisersUSS *Bainbridge*, USS *Long Beach* and USS *Enterprise*, the first nuclear-powered aircraft carrier. Picture taken in 1964 during a record setting voyage of 26,540 nmi (49,152 km) around the world in 65 days without refueling. Crew members are spelling out Einstein's mass-energy equivalence formula $E = mc^2$ on the flight deck.



The Russian nuclear-powered icebreaker NS *Yamal* on a joint scientific expedition with theNSF in 1994.

History

Origins

In 1932 physicist Ernest Rutherford discovered that when lithium atoms were "split" by protons from a proton accelerator, immense amounts of energy were released in accordance with the principle of mass–energy equivalence. However, he and other nuclear physics pioneers Niels Bohr and Albert Einstein believed harnessing the power of the atom for practical purposes anytime in the near future was unlikely, with Rutherford labeling such expectations "moonshine."^[30]

The same year, his doctoral student James Chadwick discovered the neutron,^[31] which was immediately recognized as a potential tool for nuclear experimentation because of its lack of an electric charge. Experimentation with bombardment of materials with neutrons led Frédéric and Irène Joliot-Curie to discover induced radioactivity in 1934, which allowed the creation of radium-like elements at much less the price of natural radium.^[32] Further work by Enrico Fermi in the 1930s focused on using slow neutrons to increase the effectiveness of induced radioactivity. Experiments bombarding uranium with neutrons led Fermi to believe he had created a new, transuranic element, which was dubbed hesperium.^[33]

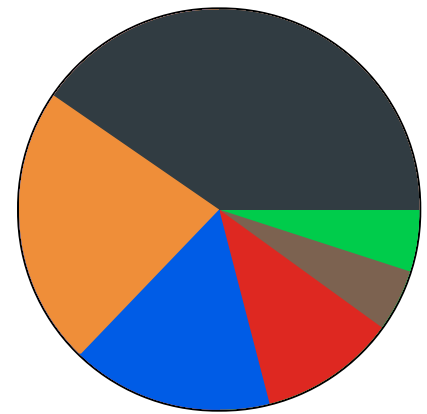
But in 1938, German chemists Otto Hahn^[34] and Fritz Strassmann, along with Austrian physicist Lise Meitner^[35] and Meitner's nephew, Otto Robert Frisch,^[36] conducted experiments with the products of neutron-bombarded uranium, as a means of further investigating Fermi's claims. They determined that the relatively tiny neutron split the nucleus of the massive uranium atoms into two roughly equal pieces, contradicting Fermi.^[33] This was an extremely surprising result: all other forms of nuclear decay involved only small changes to the mass of the nucleus, whereas this process—dubbed "fission" as a reference to biology—involved a complete rupture of the nucleus. Numerous scientists, including Leó Szilárd, who was one of the first, recognized that if fission reactions released additional neutrons, a self-sustaining nuclear chain reaction could result. Once this was experimentally confirmed and announced by Frédéric Joliot-Curie in 1939, scientists in many countries (including the United States, the United Kingdom, France, Germany, and the Soviet Union) petitioned their governments for support of nuclear fission research, just on the cusp of World War II, for the development of a nuclear weapon.^[37]

First nuclear reactor

In the United States, where Fermi and Szilárd had both emigrated, this led to the creation of the first man-made reactor, known as Chicago Pile-1, which achieved criticality on December 2, 1942. This work became part of the Manhattan Project, a massive secret US government military project to make enriched uranium by building large reactors to breed plutonium for use in the first nuclear weapons. The US tested atom bombs and eventually these weapons were used to attack the cities of Hiroshima and Nagasaki.

In 1945, the first widely distributed account of nuclear energy, in the form of the pocketbook *The Atomic Age*, discussed the peaceful future uses of nuclear energy and depicted a future where fossil fuels would go unused. Nobel laureate Glenn Seaborg, who later chaired the Atomic Energy Commission, is quoted as saying "there will be nuclear powered earth-to-moon shuttles, nuclear powered artificial hearts, plutonium heated swimming pools for SCUBA divers and much more".^{[38][39]}

The United Kingdom, Canada,^[40] and the USSR proceeded to research and develop nuclear industries over the course of the late 1940s and early 1950s. Electricity was generated for the first time by a nuclear reactor on December 20, 1951, at the EBR-I experimental station near Arco, Idaho, which initially produced about 100 kW.^{[41][42]} Work was also strongly researched in the US on nuclear marine propulsion, with a test reactor being developed by 1953 (eventually, the USS Nautilus, the first nuclear-powered submarine, would launch in 1955).^[43] In 1953, US President Dwight Eisenhower gave his "Atoms for Peace" speech at the United Nations, emphasizing the need to develop "peaceful" uses of nuclear power quickly. This was followed by the 1954 Amendments to the Atomic Energy Act which allowed rapid declassification of US reactor technology and encouraged development by the private sector.



2012 World [civil] electricity generation by fuels (IEA, 2014)^[4]

Coal/Peat (40.4%)
Natural Gas (22.5%)
Hydro (16.2%)
Nuclear fission (10.9%)
Oil (5.0%)
Others (Renew.) (5.0%)

Early years

On June 27, 1954, the USSR's Obninsk Nuclear Power Plant became the world's first nuclear power plant to generate electricity for a power grid, and produced around 5 megawatts of electric power.^{[44][45]}

Later in 1954, Lewis Strauss, then chairman of the United States Atomic Energy Commission (U.S. AEC, forerunner of the U.S. Nuclear Regulatory Commission and the United States Department of Energy) spoke of electricity in the future being "too cheap to meter".^[46] Strauss was very likely referring to hydrogen fusion^[47] — which was secretly being developed as part of Project Sherwood at the time—but Strauss's statement was interpreted as a promise of very cheap energy from nuclear fission. The U.S. AEC itself had issued far more realistic testimony regarding nuclear fission to the U.S. Congress only months before, projecting that "costs can be brought down... [to]... about the same as the cost of electricity from conventional sources..."^[48]

In 1955 the United Nations' "First Geneva Conference", then the world's largest gathering of scientists and engineers, met to explore the technology. In 1957 EURATOM was launched alongside the European Economic Community (the latter is now the European Union). The same year also saw the launch of the International Atomic Energy Agency (IAEA).

The world's first commercial nuclear power station, Calder Hall at Windscale, England, was opened in 1956 with an initial capacity of 50 MW (later 200 MW).^{[49][50]} The first commercial nuclear generator to become operational in the United States was the Shippingport Reactor (Pennsylvania, December 1957).

One of the first organizations to develop nuclear power was the U.S. Navy, for the purpose of propelling submarines and aircraft carriers. The first nuclear-powered submarine, USS Nautilus, was put to sea in December 1954.^[51] As of 2016, the U.S. Navy submarine fleet is made up entirely of nuclear-powered vessels, with 75 submarines in service. Two U.S. nuclear submarines, USS Scorpion and USS Thresher, have been lost at sea. The Russian Navy is currently (2016) estimated to have 61 nuclear submarines in service; eight Soviet and Russian nuclear submarines have been lost at sea. This includes the Soviet submarine K-19 reactor accident in 1961 which resulted in 8 deaths and more than 30 other people were over-exposed to radiation.^[20] The Soviet submarine K-27 reactor accident in 1968 resulted in 9 fatalities and 83 other injuries.^[21] Moreover, Soviet submarine K-429 sank twice, but was raised after each incident. Several serious nuclear and radiation accidents have involved nuclear submarine mishaps.^{[19][21]}

The U.S. Army also had a nuclear power program, beginning in 1954. The SM-1 Nuclear Power Plant, at Fort Belvoir, Virginia, was the first power reactor in the U.S. to supply electrical energy to a commercial grid (VEPCO), in April 1957, before Shippingport. The SL-1 was a U.S. Army experimental nuclear power reactor at the National Reactor Testing Station in eastern Idaho. It underwent a steam explosion and meltdown in January 1961, which killed its three operators.^[52] In the Soviet Union at The Mayak Production Association facility there were a number of accidents, including an explosion, that released 50–100 tonnes of high-level radioactive waste, contaminating a huge territory in the eastern Urals and causing numerous deaths and injuries. The Soviet regime kept this accident secret for about 30 years. The event was eventually rated at 6 on the seven-level INES scale (third in severity only to the disasters at Chernobyl and Fukushima).



The first light bulbs ever lit by electricity generated by nuclear power at EBR-1 at Argonne National Laboratory-West, December 20, 1951.



Calder Hall, United Kingdom – The world's first commercial nuclear power station. First connected to the national power grid on 27 August 1956 and officially opened by Queen Elizabeth II on 17 October 1956



The Shippingport Atomic Power Station in Shippingport, Pennsylvania was the first commercial reactor in the United States and was opened in 1957.

Development

Installed nuclear capacity initially rose relatively quickly, rising from less than 1 gigawatt (GW) in 1960 to 100 GW in the late 1970s, and 300 GW in the late 1980s. Since the late 1980s worldwide capacity has risen much more slowly, reaching 366 GW in 2005. Between around 1970 and 1990, more than 50 GW of capacity was under construction (peaking at over 150 GW in the late 1970s and early 1980s) — in 2005, around 25 GW of new capacity was planned. More than two-thirds of all nuclear plants ordered after January 1970 were eventually cancelled.^[51] A total of 63 nuclear units were canceled in the USA between 1975 and 1980.^[53]

During the 1970s and 1980s rising economic costs (related to extended construction times largely due to regulatory changes and pressure-group litigation)^[54] and falling fossil fuel prices made nuclear power plants then under construction less attractive. In the 1980s (U.S.) and 1990s (Europe), flat load growth and electricity liberalization also made the addition of large new baseload capacity unattractive.

The 1973 oil crisis had a significant effect on countries, such as France and Japan, which had relied more heavily on oil for electric generation (39%^[55] and 73% respectively) to invest in nuclear power^[56]

Some local opposition to nuclear power emerged in the early 1960s,^[57] and in the late 1960s some members of the scientific community began to express their concerns.^[58] These concerns related to nuclear accidents, nuclear proliferation, high cost of nuclear power plants, nuclear terrorism and radioactive waste disposal.^[59] In the early 1970s, there were large protests about a proposed nuclear power plant in Wyhl, Germany. The project was cancelled in 1975 and anti-nuclear success at Wyhl inspired opposition to nuclear power in other parts of Europe and North America.^{[60][61]} By the mid-1970s anti-nuclear activism had moved beyond local protests and politics to gain a wider appeal and influence, and nuclear power became an issue of major public protest.^[62] Although it lacked a single co-ordinating organization, and did not have uniform goals, the movement's efforts gained a great deal of attention.^[63] In some countries, the nuclear power conflict "reached an intensity unprecedented in the history of technology controversies"^[64]

In France, between 1975 and 1977, some 175,000 people protested against nuclear power in ten demonstrations.^[65] In West Germany, between February 1975 and April 1979, some 280,000 people were involved in seven demonstrations at nuclear sites. Several site occupations were also attempted. In the aftermath of the Three Mile Island accident in 1979, some 120,000 people attended a demonstration against nuclear power in Bonn.^[65] In May 1979, an estimated 70,000 people, including then governor of California Jerry Brown, attended a march and rally against nuclear power in Washington, D.C.^[66] Anti-nuclear power groups emerged in every country that has had a nuclear power programme.

Three Mile Island and Chernobyl

Health and safety concerns, the 1979 accident at Three Mile Island, and the 1986 Chernobyl disaster played a part in stopping new plant construction in many countries,^[58] although the public policy organization, the Brookings Institution states that new nuclear units, at the time of publishing in 2006, had not been built in the U.S. because of soft demand for electricity, and cost overruns on nuclear plants due to regulatory issues and construction delays.^[67] By the end of the 1970s it became clear that nuclear power would not grow nearly as dramatically as once believed. Eventually, more than 120 reactor orders in the U.S. were ultimately cancelled^[68] and the construction of new reactors ground to a halt. A cover story in the February 11, 1985, issue of Forbes magazine commented on the overall failure of the U.S. nuclear power program, saying it "ranks as the largest managerial disaster in business history"^[69]



Washington Public Power Supply System Nuclear Power Plants 3 and 5 were never completed.



120,000 people attended an anti-nuclear protest in Bonn, Germany on October 14, 1979, following the Three Mile Island accident^[65]

Unlike the Three Mile Island accident, the much more serious Chernobyl accident did not increase regulations affecting Western reactors since the Chernobyl reactors were of the problematic RBMK design only used in the Soviet Union, for example lacking "robust" containment buildings.^[70] Many of these RBMK reactors are still in use today. However, changes were made in both the reactors themselves (use of a safer enrichment of uranium) and in the control system (prevention of disabling safety systems), amongst other things, to reduce the possibility of a duplicate accident.^[71]

An international organization to promote safety awareness and professional development on operators in nuclear facilities was created: WANO; World Association of Nuclear Operators.

Opposition in Ireland and Poland prevented nuclear programs there, while Austria (1978), Sweden (1980) and Italy (1987) (influenced by Chernobyl) voted in referendums to oppose or phase out nuclear power. In July 2009, the Italian Parliament passed a law that cancelled the results of an earlier referendum and allowed the immediate start of the Italian nuclear program.^[72] After the Fukushima Daiichi nuclear disaster a one-year moratorium was placed on nuclear power development,^[73] followed by a referendum in which over 94% of voters (turnout 57%) rejected plans for new nuclear power.^[74]

Nuclear renaissance

Since about 2001 the term *nuclear renaissance* has been used to refer to a possible nuclear power industry revival, driven by rising fossil fuel prices and new concerns about meeting greenhouse gas emission limits.^[80] Since commercial nuclear energy began in the mid-1950s, 2008 was the first year that no new nuclear power plant was connected to the grid, although two were connected in 2009.^{[81][82]}

Fukushima Daiichi Nuclear Disaster

Japan's 2011 Fukushima Daiichi nuclear accident prompted a re-examination of nuclear safety and nuclear energy policy in many countries.^[83] and raised questions among some commentators over the future of the renaissance.^{[84][85][86][87][88]} Germany plans to close all its reactors by 2022, and Italy has re-affirmed its ban on electric utilities generating, but not importing, fission derived electricity.^[83] China, Switzerland, Israel, Malaysia, Thailand, United Kingdom, and the Philippines have also reviewed their nuclear power programs, while Indonesia and Vietnam still plan to build nuclear power plants.^{[89][90][91][92]}

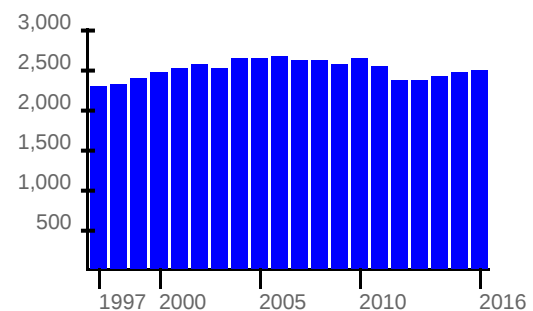
In 2011 the International Energy Agency halved its prior estimate of new generating capacity to be built by 2035.^{[93][94]} In 2013 Japan signed a deal worth \$22 billion, in which Mitsubishi Heavy Industries would build four modern Atmea reactors for Turkey.^[95] In August 2015, following 4 years of near zero fission-electricity generation, Japan began restarting its fission fleet, after safety upgrades were completed, beginning with Sendai fission-electric station.^[96]



The abandoned city of Prip'yat with Chernobyl plant in the distance.

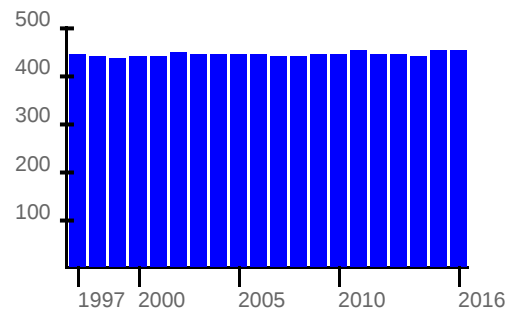


Olkiluoto 3 under construction in 2009. It is the first EPR design, but problems with workmanship and supervision have created costly delays which led to an inquiry by the Finnish nuclear regulator STUK.^[75] In December 2012, Areva estimated that the full cost of building the reactor will be about €8.5 billion, or almost three times the original delivery price of €3 billion.^{[76][77][78]}



Nuclear power generation (TWh)^[79]

The World Nuclear Association has said that "nuclear power generation suffered its biggest ever one-year fall through 2012 as the bulk of the Japanese fleet remained offline for a full calendar year". Data from the International Atomic Energy Agency showed that nuclear power plants globally produced 2346 TWh of electricity in 2012 – seven per cent less than in 2011. The figures illustrate the effects of a full year of 48 Japanese power reactors producing no power during the year. The permanent closure of eight reactor units in Germany was also a factor. Problems at Crystal River, Fort Calhoun and the two San Onofre units in the USA meant they produced no power for the full year, while in Belgium Doel 3 and Tihange 2 were out of action for six months. Compared to 2010, the nuclear industry produced 1% less electricity in 2012.^[97]



Operational nuclear reactors^[79]

Post-Fukushima

The Fukushima Daiichi nuclear accident sparked controversy about the importance of the accident and its effect on nuclear's future. IAEA Director General Yukiya Amano said the Japanese nuclear accident "caused deep public anxiety throughout the world and damaged confidence in nuclear power",^[98] and the International Energy Agency halved its estimate of additional nuclear generating capacity to be built by 2035.^{[93][94]}

Though Platts reported in 2011 that "the crisis at Japan's Fukushima nuclear plants has prompted leading energy-consuming countries to review the safety of their existing reactors and cast doubt on the speed and scale of planned expansions around the world",^[99] Progress Energy Chairman/CEO Bill Johnson made the observation that "Today there's an even more compelling case that greater use of nuclear power is a vital part of a balanced energy strategy".^[100] In 2011, *The Economist* opined that nuclear power "looks dangerous, unpopular, expensive and risky", and that "it is replaceable with relative ease and could be forgone with no huge structural shifts in the way the world works".^[101] Earth Institute Director Jeffrey Sachs disagreed, claiming combating climate change would require an expansion of nuclear power. "We won't meet the carbon targets if nuclear is taken off the table," he said. "We need to understand the scale of the challenge."^[102]



Eight of the seventeen operating reactors in Germany were permanently shut down as part of Germany's *Energiewende*.

Investment banks were critical of nuclear soon after the accident.^[103] Deutsche Bank advised that "the global impact of the Fukushima accident is a fundamental shift in public perception with regard to how a nation prioritizes and values its populations health, safety, security, and natural environment when determining its current and future energy pathways...renewable energy will be a clear long-term winner in most energy systems, a conclusion supported by many voter surveys conducted over the past few weeks."^[104]

In September 2011, German engineering giant Siemens announced it will withdraw entirely from the nuclear industry, as a response to the Fukushima nuclear accident in Japan, and said that it would no longer build nuclear power plants anywhere in the world. The company's chairman, Peter Löscher, said that "Siemens was ending plans to cooperate with Rosatom, the Russian state-controlled nuclear power company in the construction of dozens of nuclear plants throughout Russia over the coming two decades".^{[105][106]}

In February 2012, the United States Nuclear Regulatory Commission approved the construction of two additional reactors at the Vogtle Electric Generating Plant, the first reactors to be approved in over 30 years since the Three Mile Island accident,^[107] but NRC Chairman Gregory Jaczko cast a dissenting vote citing safety concerns stemming from Japan's 2011 Fukushima nuclear disaster, and saying "I cannot support issuing this license as if Fukushima never happened".^[108] Jaczko resigned in April 2012. One week after

Southern received the license to begin major construction on the two new reactors, a dozen environmental and anti-nuclear groups sued to stop the Plant Vogtle expansion project, saying "public safety and environmental problems since Japan's Fukushima Daiichi nuclear reactor accident have not been taken into account".^[109] In July 2012, the suit was rejected by the Washington, D.C. Circuit Court of Appeals.^[110] In 2013, four aging uncompetitive reactors in the United States were closed.^{[111][112]} In the United States, four new Generation III reactors were under construction at Vogtle and Summer station, while a fifth was nearing completion at Watts Bar station, all five were expected to become operational before 2020.^[108]

In 2012, the World Nuclear Association reported that nuclear electricity generation was at its lowest level since 1999.^[97] According to the World Nuclear Association, the global trend is for new nuclear power stations coming online to be balanced by the number of old plants being retired.^[113]

Countries such as Australia, Austria, Denmark, Greece, Ireland, Italy, Latvia, Liechtenstein, Luxembourg, Malta, Portugal, Israel, Malaysia, New Zealand, and Norway have no nuclear power reactors and remain opposed to nuclear power.^{[101][114]}

By 2015, the IAEA's outlook for nuclear energy had become more promising. "Nuclear power is a critical element in limiting greenhouse gas emissions," the agency noted, and "the prospects for nuclear energy remain positive in the medium to long term despite a negative impact in some countries in the aftermath of the [Fukushima-Daiichi] accident...it is still the second-largest source worldwide of low-carbon electricity. And the 72 reactors under construction at the start of last year were the most in 25 years."^[115]

As of 2015, 441 reactors had a worldwide net electric capacity of 382.9 GW, with 67 new nuclear reactors under construction.^[116] Over half of the 67 total being built were in Asia, with 28 in China, where there is an urgent need to control pollution from coal plants.^[117] Eight new grid connections were completed by China in 2015^{[118][119]} and the most recently completed reactor to be connected to the electrical grid, as of January 2016, was at the Kori Nuclear Power Plant in the Republic of Korea.^{[120][121]} In October 2016, Watts Bar 2 became the first new United States reactor to enter commercial operation since 1996.^[122]

Future of the industry

As of January 2016, there are over 150 nuclear reactors planned, equivalent to nearly half of capacity at that time!^[124]

The future of nuclear power varies greatly between countries, depending on government policies. Some countries, many of them in Europe, such as Germany, Belgium, and Lithuania, have adopted policies of nuclear power phase-out. At the same time, some Asian countries, such as China^[125] and India,^[126] have committed to rapid expansion of nuclear power. Many other countries, such as the United Kingdom^[127] and the United States, have policies in between. Japan was a major generator of nuclear power before the Fukushima accident, but as of August 2016, Japan has restarted only three of its nuclear plants, and the extent to which it will resume its nuclear program is uncertain.^[128] While South Korea has a large nuclear power industry, in 2017 responding to widespread public concerns after the Fukushima Daiichi nuclear disaster, the high earthquake risk in South Korea, and a 2013 nuclear scandal involving the use of counterfeit parts, the new government decided to gradually phase out nuclear power as reactors that are now operating or under construction close after 40 years of operations.^{[129][130]}

In 2015, the International Energy Agency reported that the Fukushima accident had a strongly negative effect on nuclear power, yet "the prospects for nuclear energy remain positive in the medium to long term despite a negative impact in some countries in the aftermath of the accident." The IEA noted that at the start of 2014, there were 72 nuclear reactors under construction worldwide, the largest number in 25 years, and that China planned to increase nuclear power capacity from 17 gigawatts (GW) in 2014, to 58 GW in 2020.^[131]



Brunswick Nuclear Plant discharge canal



The Bruce Nuclear Generating Station, the largest nuclear power facility in the world^[123]

In 2016, the US Energy Information Administration projected for its “base case” that world nuclear power generation would increase from 2,344 billion kWh in 2012 to 4,501 billion kWh in 2040. Most of the predicted increase was expected to be in Asia.^[132]

The nuclear power industry in western nations has a history of construction delays, cost overruns, plant cancellations, and nuclear safety issues despite significant government subsidies and support.^{[69][133][134][135]} In December 2013, *Forbes* magazine cited a report which concluded that, in western countries, “reactors are not a viable source of new power”.^[136] Even where they make economic sense, they are not feasible because nuclear’s “enormous costs, political and popular opposition, and regulatory uncertainty”.^[136] This view echoes the statement of former Exelon CEO John Rowe, who said in 2012 that new nuclear plants in the United States “don’t make any sense right now” and won’t be economically viable in the foreseeable future.^[136] John Quiggin, economics professor, also says the main problem with the nuclear option is that it is not economically-viable. Quiggin says that we need more efficient energy use and more renewable energy commercialization.^[137] Former NRC member Peter Bradford and Professor Ian Lowe made similar statements in 2011.^{[138][139]} However, some “nuclear cheerleaders” and lobbyists in the West continue to champion reactors, often with proposed new but largely untested designs, as a source of new power.^{[136][138][140][141][142][143][144]}

Much more new build activity is occurring in developing countries like South Korea, India and China. In March 2016, China had 30 reactors in operation, 24 under construction and plans to build more.^{[145][146][147]} However, according to a government research unit, China must not build “too many nuclear power reactors too quickly”, in order to avoid a shortfall of fuel, equipment and qualified plant workers.^[148]

In the US, licenses of almost half its reactors have been extended to 60 years.^{[149][150]} Two new Generation III reactors are under construction at Vogtle, a dual construction project which marks the end of a 34-year period of stagnation in the US construction of civil nuclear power reactors. The station operator licenses of almost half the present 104 power reactors in the US, as of 2008, have been given extensions to 60 years.^[149] As of 2012, U.S. nuclear industry officials expect five new reactors to enter service by 2020, all at existing plants.^[108] In 2013, four aging, uncompetitive, reactors were permanently closed.^{[111][112]} Relevant state legislatures are trying to close Vermont Yankee and Indian Point Nuclear Power Plant.^[112]

The U.S. NRC and the U.S. Department of Energy have initiated research into Light water reactor sustainability which is hoped will lead to allowing extensions of reactor licenses beyond 60 years, provided that safety can be maintained, as the loss in non-CO₂-emitting generation capacity by retiring reactors “may serve to challenge U.S. energy security, potentially resulting in increased greenhouse gas emissions, and contributing to an imbalance between electric supply and demand.”^[151] Research into nuclear reactors that can last 100 years, known as Centurion Reactors is already being conducted.^[152]

There is a possible impediment to production of nuclear power plants as only a few companies worldwide have the capacity to forge single-piece reactor pressure vessels,^[153] which are necessary in the most common reactor designs. Utilities across the world are submitting orders years in advance of any actual need for these vessels. Other manufacturers are examining various options, including making the component themselves, or finding ways to make a similar item using alternate methods.^[154]

According to the World Nuclear Association, globally during the 1980s one new nuclear reactor started up every 17 days on average, and in the year 2015 it was estimated that this rate could in theory eventually increase to one every 5 days, although no plans exist for that.^[155] As of 2007, Watts Bar 1 in Tennessee, which came on-line on February 7, 1996, was the last U.S. commercial nuclear reactor to go on-line. This is often quoted as evidence of a successful worldwide campaign for nuclear power phase-out.^[156] Electricity shortages, fossil fuel price increases, global warming, and heavy metal emissions from fossil fuel use, new technology such as passively safe plants, and national energy security may renew the demand for nuclear power plants.

Following Westinghouse filing for Chapter 11 bankruptcy protection in March 2017 because of US\$9 billion of losses from nuclear construction projects in the US,^{[157][158]} the future of new nuclear plant construction has largely moved to Asia and the Middle East. China has 21 reactors under construction and 40 planned, Russia has 7 under construction and 25 planned, and South Korea has 3 under construction plus 4 it is building in the United Arab Emirates.^[159]

Industry

Companies

Capacity and production

Nuclear fission power stations, excluding the contribution from naval nuclear fission reactors, provided 11% of the world's electricity in 2012,^[160] somewhat less than that generated by hydro-electric stations at 16%. Since electricity accounts for about 25% of humanity's energy usage with the majority of the rest coming from fossil fuel reliant sectors such as transport, manufacture and home heating, nuclear fission's contribution to the global final energy consumption was about 2.5%.^[161] This is a little more than the combined global electricity production from wind, solar, biomass and geothermal power, which together provided 2% of global final energy consumption in 2014.^[162]

In 2013, the IAEA reported that there were 437 operational civil fission-electric reactors^[163] in 31 countries,^[164] although not every reactor was producing electricity.^[165] In addition, there were approximately 140 naval vessels using nuclear propulsion in operation, powered by about 180 reactors.^{[166][167][168]}

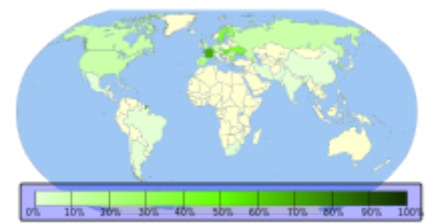
Regional differences in the use of nuclear power are large. The United States produces the most nuclear energy in the world, with nuclear power providing 19%^[169] of the electricity it consumes, while France produces the highest percentage of its electrical energy from nuclear reactors—80% as of 2006.^[170] In the European Union as a whole nuclear power provides 30% of the electricity.^[171] Nuclear power is the single largest low-carbon electricity source in the United States,^[172] and accounts for two-thirds of the European Union's low-carbon electricity.^[173] Nuclear energy policy differs among European Union countries, and some, such as Austria, Estonia, Ireland and Italy, have no active nuclear power stations. In comparison, France has a large number of these plants, with 16 multi-unit stations in current use.

Many military and some civilian (such as some icebreakers) ships use nuclear marine propulsion.^[174] A few space vehicles have been launched using nuclear reactors. 33 reactors belong to the Soviet RORSAT series and one was the American SNAP-10A.

International research is continuing into additional uses of process heat such as hydrogen production (in support of a hydrogen economy), for desalinating sea water, and for use in district heating systems.

Analysis in 2015 by Professor and Chair of Environmental Sustainability Barry W. Brook and his colleagues on the topic of replacing fossil fuels entirely, from the electric grid of the world, has determined that at the historically modest and proven-rate at which nuclear energy was added to and replaced fossil fuels in France and Sweden during each nation's building programs in the 1980s, within 10 years nuclear energy could displace or remove fossil fuels from the electric grid completely, "allow[ing] the world to meet the most stringent greenhouse-gas mitigation targets."^[175] In a similar analysis, Brook had earlier determined that 50% of all global energy, that is not solely electricity, but transportation synfuels etc. could be generated within approximately 30 years, if the global nuclear fission build rate was identical to each of these nation's already proven decadal rates (in units of installed nameplate capacity, GW per year, per unit of global GDP (GW/year/\$)).^[176]

This is in contrast to the conceptual studies for a 100% renewable energy world, which would require an orders of magnitude more costly global investment per year, which has no historical precedent,^{[177][178]} along with far greater land that would need to be devoted to the wind, wave and solar projects, and the inherent assumption that humanity will use less, and not more, energy in the future.^{[176][177][179]} As Brook notes the "principal limitations on nuclear fission are not technical, economic or fuel-related, but are instead linked to complex issues of societal acceptance, fiscal and political inertia, and inadequate critical evaluation of the real-world constraints facing [the other] low-carbon alternatives."^[176]



Share of electricity produced by nuclear power in the world



The status of nuclear power globally (click image for legend)

Economics

Nuclear power plants typically have high capital costs for building the plant, but low fuel costs. Although nuclear power plants can vary their output the electricity is generally less favorably priced when doing so. Nuclear power plants are therefore typically run as much as possible to keep the cost of the generated electrical energy as low as possible, supplying mostly base-load electricity^[181]

Internationally the price of nuclear plants rose 15% annually in 1970–1990.^[182] Yet, nuclear power has total costs in 2012 of about \$96 per megawatt hour (MWh), most of which involves capital construction costs, compared with solar power at \$130 per MWh, and natural gas at the low end at \$64 per MWh.^[183]

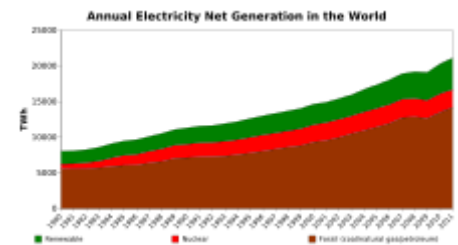
In 2015, the *Bulletin of the Atomic Scientists* unveiled the Nuclear Fuel Cycle Cost Calculator, an online tool that estimates the full cost of electricity produced by three configurations of the nuclear fuel cycle. Two years in the making, this interactive calculator is the first generally accessible model to provide a nuanced look at the economic costs of nuclear power; it lets users test how sensitive the price of electricity is to a full range of components—more than 60 parameters that can be adjusted for the three configurations of the nuclear fuel cycle considered by this tool (once-through, limited-recycle, full-recycle). Users can select the fuel cycle they would like to examine, change cost estimates for each component of that cycle, and even choose uncertainty ranges for the cost of particular components. This approach allows users around the world to compare the cost of different nuclear power approaches in a sophisticated way, while taking account of prices relevant to their own countries or regions.

In recent years there has been a slowdown of electricity demand growth.^[184] In Eastern Europe, a number of long-established projects are struggling to find finance, notably Belene in Bulgaria and the additional reactors at Cernavoda in Romania, and some potential backers have pulled out.^[184] Where the electricity market is competitive, cheap natural gas is available, and its future supply relatively secure, this also poses a major problem for nuclear projects^[184] and existing plants.^[185]

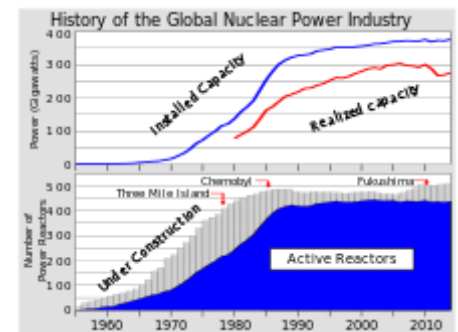
Analysis of the economics of nuclear power must take into account who bears the risks of future uncertainties. To date all operating nuclear power plants were developed by state-owned or regulated utility monopolies^[186] where many of the risks associated with construction costs, operating performance, fuel price, accident liability and other factors were borne by consumers rather than suppliers. In addition, because the potential liability from a nuclear accident is so great, the full cost of liability insurance is generally limited/capped by the government, which the U.S. Nuclear Regulatory Commission concluded constituted a significant subsidy.^[187] Many countries have now liberalized the electricity market where these risks, and the risk of cheaper competitors emerging before capital costs are recovered, are borne by plant suppliers and operators rather than consumers, which leads to a significantly different evaluation of the economics of new nuclear power plants.^[188]

Following the 2011 Fukushima Daiichi nuclear disaster, costs are expected to increase for currently operating and new nuclear power plants, due to increased requirements for on-site spent fuel management and elevated design basis threats.^[189]

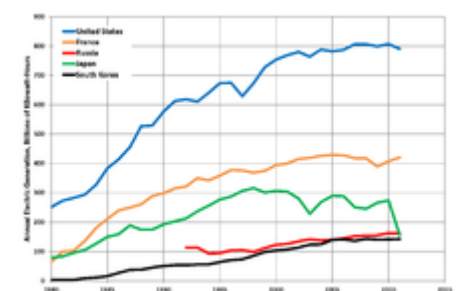
The economics of new nuclear power plants is a controversial subject, since there are diverging views on this topic, and multibillion-dollar investments ride on the choice of an energy source. Comparison with other power generation methods is strongly dependent on assumptions about construction timescales and capital financing for nuclear plants as well as the future costs of fossil fuels and



Net electrical generation by source and growth from 1980 to 2010. (Brown) – fossil fuels. (Red) – Fission. (Green) – "all renewables". In terms of energy generated between 1980 and 2010, the contribution from fission grew the fastest.



The rate of new construction builds for civilian fission-electric reactors essentially halted in the late 1980s, with the effects of accidents having a chilling effect. Increased capacity factor realizations in existing reactors was primarily responsible for the continuing increase in electrical energy produced during this period. The halting of new builds c. 1985, resulted in greater fossil fuel generation, see above graph.



Electricity generation trends in the top five fission-energy producing countries (US EIA data)

renewables as well as for energy storage solutions for intermittent power sources. Cost estimates also need to take into account plant decommissioning and nuclear waste storage costs. On the other hand, measures to mitigate global warming, such as a carbon tax or carbon emissions trading, may favor the economics of nuclear power.

Nuclear power plants

Just as many conventional thermal power stations generate electricity by harnessing the thermal energy released from burning fossil fuels, nuclear power plants convert the energy released from the nucleus of an atom via nuclear fission that takes place in a nuclear reactor. The heat is removed from the reactor core by a cooling system that uses the heat to generate steam, which drives a steam turbine connected to a generator producing electricity

Life cycle of nuclear fuel

A nuclear reactor is only part of the life-cycle for nuclear power. The process starts with mining (see Uranium mining). Uranium mines are underground, open-pit, or in-situ leach mines. In any case, the uranium ore is extracted, usually converted into a stable and compact form such as yellowcake, and then transported to a processing facility. Here, the yellowcake is converted to uranium hexafluoride, which is then enriched using various techniques. At this point, the enriched uranium, containing more than the natural 0.7% U-235, is used to make rods of the proper composition and geometry for the particular reactor that the fuel is destined for. The fuel rods will spend about 3 operational cycles (typically 6 years total now) inside the reactor, generally until about 3% of their uranium has been fissioned, then they will be moved to a spent fuel pool where the short lived isotopes generated by fission can decay away. After about 5 years in a spent fuel pool the spent fuel is radioactively and thermally cool enough to handle, and it can be moved to dry storage casks or reprocessed.

Conventional fuel resources

Uranium is a fairly common element in the Earth's crust. Uranium is approximately as common as tin or germanium in the Earth's crust, and is about 40 times more common than silver.^[190] Uranium is present in trace concentrations in most rocks, dirt, and ocean water, but can be economically extracted currently only where it is present in high concentrations. Still, the world's present measured resources of uranium, economically recoverable at the arbitrary price ceiling of 130 USD/kg, are enough to last for between 70 and 100 years.^{[191][192][193]}

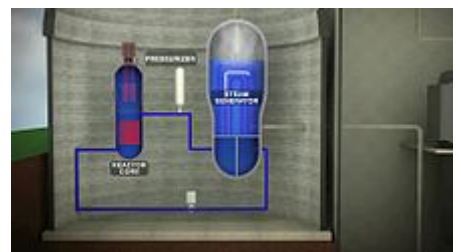
According to the OECD in 2006, there was an expected 85 years worth of uranium in already identified resources, when that uranium is used in present reactor technology, in the OECD's red book of 2011, due to increased exploration, known uranium resources have grown by 12.5% since 2008, with this increase translating into greater than a century of uranium available if the metals usage rate were to continue at the 2011 level.^{[194][195]} The OECD also estimate 670 years of economically recoverable uranium in total conventional resources and phosphate ores, while also using present reactor technology, a resource that is recoverable from between 60–100 US\$/kg of Uranium.^[196] In a similar manner to every other



George W. Bush signing the Energy Policy Act of 2005, which was designed to promote the US nuclear power industry, through incentives and subsidies, including cost-overrun support up to a total of \$2 billion for six new nuclear plants.^[137] However, as of 2014 some electric utilities have rebuffed the loan package, including South Carolina Electric and Gas which operates Summer Station (the location of 2 new builds), noting instead that "it was easier to raise [loan] money commercially"^[180]



The Ikata Nuclear Power Plant, a pressurized water reactor that cools by utilizing a secondary coolant heat exchanger with a large body of water, an alternative cooling approach to large cooling towers.



Play media

An animation of a Pressurized water reactor in operation.

natural metal resource, for every tenfold increase in the cost per kilogram of uranium, there is a three-hundredfold increase in available lower quality ores that would then become economical.^[197] As the OECD note:

Even if the nuclear industry expands significantly, sufficient fuel is available for centuries. If advanced breeder reactors could be designed in the future to efficiently utilize recycled or depleted uranium and all actinides, then the resource utilization efficiency would be further improved by an additional factor of eight.

For example, the OECD have determined that with a pure fast reactor fuel cycle with a burn up of, and recycling of, all the Uranium and actinides, actinides which presently make up the most hazardous substances in nuclear waste, there is 160,000 years worth of Uranium in total conventional resources and phosphate ore, at the price of 60–100 US\$/kg of Uranium.^[198]

Current light water reactors make relatively inefficient use of nuclear fuel, mostly fissioning only the very rare uranium-235 isotope. Nuclear reprocessing can make this waste reusable, and more efficient reactor designs, such as the currently under construction Generation III reactors achieve a higher efficiency burn up of the available resources, than the current vintage generation II reactors, which make up the vast majority of reactors worldwide.^[199]

Breeding

As opposed to current light water reactors which use uranium-235 (0.7% of all natural uranium), fast breeder reactors use uranium-238 (99.3% of all natural uranium). It has been estimated that there is up to five billion years' worth of uranium-238 for use in these power plants.^[200]

Breeder technology has been used in several reactors, but the high cost of reprocessing fuel safely, at 2006 technological levels, requires uranium prices of more than 200 USD/kg before becoming justified economically.^[201] Breeder reactors are however being pursued as they have the potential to burn up all of the actinides in the present inventory of nuclear waste while also producing power and creating additional quantities of fuel for more reactors via the breeding process.^{[202][203]}

As of 2017, there are only two breeder reactors producing commercial power: the BN-600 reactor and the BN-800 reactor, both in Russia. The BN-600, with a capacity of 600 MW, was built in 1980 in Beloyarsk and is planned to produce power until 2025. The BN-800 is an updated version of the BN-600, and started operation in 2016 with a net electrical capacity of 789 MW. The technical design of a yet larger breeder, the BN-1200 reactor was originally scheduled to be finalized in 2013, with construction slated for 2015 but has since been delayed.^[204] The Phénix breeder reactor in France was powered down in 2009 after 36 years of operation. Japan's Monju breeder reactor restarted (having been shut down in 1995) in 2010 for 3 months, but shut down again after equipment fell into the reactor during reactor checkups^[205] and it is now planned to be decommissioned. Both China and India are building breeder reactors. The Indian 500 MWe Prototype Fast Breeder Reactor is under construction, with plans to build five more by 2020.^[206] The China Experimental Fast Reactor began producing power in 2011.^[207]

Another alternative to fast breeders is thermal breeder reactors that use uranium-233 bred from thorium as fission fuel in the thorium fuel cycle. Thorium is about 3.5 times more common than uranium in the Earth's crust, and has different geographic characteristics. This would extend the total practical fissionable resource base by 450%.^[208] India's three-stage nuclear power programme features



Unlike fossil fuel power plants the only substance leaving the cooling towers of nuclear power plants is non-radioactive water vapour and thus does not pollute the air or cause global warming.



The nuclear fuel cycle begins when uranium is mined, enriched, and manufactured into nuclear fuel, (1) which is delivered to a nuclear power plant. After usage in the power plant, the spent fuel is delivered to a reprocessing plant (2) or to a final repository (3) for geological disposition. In reprocessing 95% of spent fuel can potentially be recycled to be returned to usage in a power plant (4).

the use of a thorium fuel cycle in the third stage, as it has abundant thorium reserves but little uranium.

Solid waste

The most important waste stream from nuclear power plants is spent nuclear fuel. It is primarily composed of unconverted uranium as well as significant quantities of transuranic actinides (plutonium and curium, mostly). In addition, about 3% of it is fission products from nuclear reactions. The actinides (uranium, plutonium, and curium) are responsible for the bulk of the long-term radioactivity, whereas the fission products are responsible for the bulk of the short-term radioactivity^[209]

High-level radioactive waste

High-level radioactive waste management concerns management and disposal of highly radioactive materials created during production of nuclear power. The technical issues in accomplishing this are daunting, due to the extremely long periods radioactive wastes remain deadly to living organisms. Of particular concern are two long-lived fission products, Technetium-99 (half-life 220,000 years) and Iodine-129 (half-life 15.7 million years),^[212] which dominate spent nuclear fuel radioactivity after a few thousand years. The most troublesome transuranic elements in spent fuel are Neptunium-237 (half-life two million years) and Plutonium-239 (half-life 24,000 years).^[213] Consequently, high-level radioactive waste requires sophisticated treatment and management to successfully isolate it from the biosphere. This usually necessitates treatment, followed by a long-term management strategy involving permanent storage, disposal or transformation of the waste into a non-toxic form.^[214]

Governments around the world are considering a range of waste management and disposal options, usually involving deep-geologic placement, although there has been limited progress toward implementing long-term waste management solutions.^[215] This is partly because the timeframes in question when dealing with radioactive waste range from 10,000 to millions of years,^{[216][217]} according to studies based on the effect of estimated radiation doses.^[218]

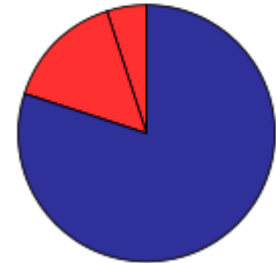
Some proposed nuclear reactor designs however such as the American Integral Fast Reactor and the Molten salt reactor can use the nuclear waste from light water reactors as a fuel, transmutating it to isotopes that would be safe after hundreds, instead of tens of thousands of years. This offers a potentially more attractive alternative to deep geological disposal.^{[219][220][221]}

Another possibility is the use of thorium in a reactor especially designed for thorium (rather than mixing in thorium with uranium and plutonium (i.e. in existing reactors). Used thorium fuel remains only a few hundreds of years radioactive, instead of tens of thousands of years.^[222]

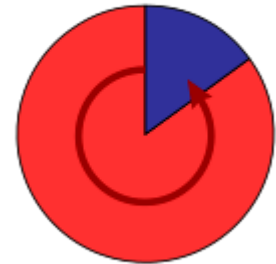
Since the fraction of a radioisotope's atoms decaying per unit of time is inversely proportional to its half-life, the relative radioactivity of a quantity of buried human radioactive waste would diminish over time compared to natural radioisotopes (such as the decay chains of 120 trillion tons of thorium and 40 trillion tons of uranium which are at relatively trace concentrations of parts per million each over the crust's 3×10^{19} ton mass).^{[223][224][225]} For instance, over a timeframe of thousands of



Natural uranium (NU)
>99.2% U-238
≤0.72% U-235



Low-enriched uranium (LEU)
(reactor grade)
<20% U-235
(typically 3-5% U-235)



Highly enriched uranium (HEU)
(weapons grade)
20-85% U-235
(≥85% U-235)

Proportions of the isotopes, uranium-238 (blue) and uranium-235 (red) found naturally versus grades that are enriched. Light water reactors require fuel enriched to (3–4%), while others such as the CANDU reactor uses natural uranium.



A nuclear fuel rod assembly bundle being inspected before entering a reactor.

years, after the most active short half-life radioisotopes decayed, burying U.S. nuclear waste would increase the radioactivity in the top 2000 feet of rock and soil in the United States (10 million km²) by $\approx$ 1 part in 10 million over the cumulative amount of natural radioisotopes in such a volume, although the vicinity of the site would have a far higher concentration of artificial radioisotopes underground than such an average.^[226]

Low-level radioactive waste

The nuclear industry also produces a large volume of low-level radioactive waste in the form of contaminated items like clothing, hand tools, water purifier resins, and (upon decommissioning) the materials of which the reactor itself is built. In the US, the Nuclear Regulatory Commission has repeatedly attempted to allow low-level materials to be handled as normal waste: landfilled, recycled into consumer items, etcetera.

Waste relative to other types

In countries with nuclear power, radioactive wastes comprise less than 1% of total industrial toxic wastes, much of which remains hazardous for long periods.^[199]

Overall, nuclear power produces far less waste material by volume than fossil-fuel based power plants.^[227] Coal-burning plants are particularly noted for producing large amounts of toxic and mildly radioactive ash due to concentrating naturally occurring metals and mildly radioactive material from the coal.^[228] A 2008 report from Oak Ridge National Laboratory concluded that coal power actually results in more radioactivity being released into the environment than nuclear power operation, and that the population effective dose equivalent, or dose to the public from radiation from coal plants is 100 times as much as from the operation of nuclear plants.^[229] Indeed, coal ash is much less radioactive than spent nuclear fuel on a weight per weight basis, but coal ash is produced in much higher quantities per unit of energy generated, and this is released directly into the environment as fly ash, whereas nuclear plants use shielding to protect the environment from radioactive materials, for example, dry cask storage vessels.^[230]

Waste disposal

Disposal of nuclear waste is often said to be the Achilles' heel of the industry.^[231] Presently, waste is mainly stored at individual reactor sites and there are over 430 locations around the world where radioactive material continues to accumulate. Some experts suggest that centralized underground repositories which are well-managed, guarded, and monitored, would be a vast improvement.^[231] There is an "international consensus on the advisability of storing nuclear waste in deep geological repositories",^[232] with the lack of movement of nuclear waste in the 2 billion year old natural nuclear fission reactors in Oklo, Gabon being cited as "a source of essential information today"^{[233][234]}

There are no commercial scale purpose built underground repositories in operation.^{[232][235][236][237]} The Waste Isolation Pilot Plant (WIPP) in New Mexico has been taking nuclear waste since 1999 from production reactors, but as the name suggests is a research and development facility. A radiation leak at WIPP in 2014 brought renewed attention to the need for R&D on disposal of radioactive waste and spent fuel.^[238]

Reprocessing

Reprocessing can potentially recover up to 95% of the remaining uranium and plutonium in spent nuclear fuel, putting it into new mixed oxide fuel. This produces a reduction in long term radioactivity within the remaining waste, since this is largely short-lived fission products, and reduces its volume by over 90%. Reprocessing of civilian fuel from power reactors is currently done in Europe, Russia, Japan, and India. The full potential of reprocessing has not been achieved because it requires breeder reactors, which are not commercially available.^{[239][240]}



Following interim storage in spent fuel pool, the bundles of used fuel assemblies of a typical nuclear power station are often stored on site in the likes of the eight dry cask storage vessels pictured above.^[210] At Yankee Rowe Nuclear Power Station, which generated 44 billion kilowatt hours of electricity over its lifetime, its complete spent fuel inventory is contained within sixteen casks.^[211]

Nuclear reprocessing reduces the volume of high-level waste, but by itself does not reduce radioactivity or heat generation and therefore does not eliminate the need for a geological waste repository. Reprocessing has been politically controversial because of the potential to contribute to nuclear proliferation, the potential vulnerability to nuclear terrorism, the political challenges of repository siting (a problem that applies equally to direct disposal of spent fuel), and because of its high cost compared to the once-through fuel cycle. Several different methods for reprocessing been tried, but many have had safety and practicality problems which have led to their discontinuation!^{[239][241]}

In the United States, the Obama administration stepped back from President Bush's plans for commercial-scale reprocessing and reverted to a program focused on reprocessing-related scientific research.^[242] Reprocessing is not allowed in the U.S.^{[243][244]} In the U.S., spent nuclear fuel is currently all treated as waste.^[245] A major recommendation of the Blue Ribbon Commission on America's Nuclear Future was that "the United States should undertake an integrated nuclear waste management program that leads to the timely development of one or more permanent deep geological facilities for the safe disposal of spent fuel and high-level nuclear waste".^[246]

Depleted uranium

Uranium enrichment produces many tons of depleted uranium (DU) which consists of U-238 with most of the easily fissile U-235 isotope removed. U-238 is a tough metal with several commercial uses—for example, aircraft production, radiation shielding, and armor—as it has a higher density than lead. Depleted uranium is also controversially used in munitions; DU penetrators (bullets or APFSDS tips) "self sharpen", due to uranium's tendency to fracture along shear bands.^{[247][248]}

Accidents, attacks and safety

Accidents

Some serious nuclear and radiation accidents have occurred. Benjamin K. Sovacool has reported that worldwide there have been 99 accidents at nuclear power plants.^[251] Fifty-seven accidents have occurred since the Chernobyl disaster, and 57% (56 out of 99) of all nuclear-related accidents have occurred in the USA.^{[251][252]}

Nuclear power plant accidents include the Chernobyl accident (1986) with approximately 60 deaths so far attributed to the accident and a predicted, eventual total death toll, of from 4000 to 25,000 latent cancers deaths. The Fukushima Daiichi nuclear disaster (2011), has not caused any radiation related deaths, with a predicted, eventual total death toll, of from 0 to 1000, and the Three Mile Island accident (1979), no causal deaths, cancer or otherwise, have been found in follow up studies of this accident.^[19] Nuclear-powered submarine mishaps include the K-19 reactor accident (1961),^[20] the K-27 reactor accident (1968),^[21] and the K-431 reactor accident (1985).^[19] International research is continuing into safety improvements such as passively safe plants,^[253] and the possible future use of nuclear fusion.



The 2011 Fukushima Daiichi nuclear disaster, the world's worst nuclear accident since 1986, displaced 50,000 households after radiation leaked into the air, soil and sea.^[249] Radiation checks led to bans of some shipments of vegetables and fish.^[250]

In terms of lives lost per unit of energy generated, nuclear power has caused fewer accidental deaths per unit of energy generated than all other major sources of energy generation. Energy produced by coal, petroleum, natural gas and hydropower has caused more deaths per unit of energy generated, from air pollution and energy accidents. This is found in the following comparisons, when the immediate nuclear related deaths from accidents are compared to the immediate deaths from these other energy sources,^[24] when the latent, or predicted, indirect cancer deaths from nuclear energy accidents are compared to the immediate deaths from the above energy sources,^{[26][27][254]} and when the combined immediate and indirect fatalities from nuclear power and all fossil fuels are compared, fatalities resulting from the mining of the necessary natural resources to power generation and to air pollution.^[22] With

these data, the use of nuclear power has been calculated to have prevented in the region of 1.8 million deaths between 1971 and 2009, by reducing the proportion of energy that would otherwise have been generated by fossil fuels, and is projected to continue to do so.^{[255][256]}

Although according to Benjamin K. Sovacool, fission energy accidents ranked first in terms of their total economic cost, accounting for 41 percent of all property damage attributed to energy accidents.^[257] Analysis presented in the international journal, *Human and Ecological Risk Assessment* found that coal, oil, Liquid petroleum gas and hydroelectric accidents (primarily due to the Banqiao dam burst) have resulted in greater economic impacts than nuclear power accidents.^[27]

Following the 2011 Japanese Fukushima nuclear disaster, authorities shut down the nation's 54 nuclear power plants, but it has been estimated that if Japan had never adopted nuclear power, accidents and pollution from coal or gas plants would have caused more lost years of life.^[258] As of 2013, the Fukushima site remains highly radioactive, with some 160,000 evacuees still living in temporary housing, and some land will be unfarmable for centuries. The difficult Fukushima disaster cleanup will take 40 or more years, and cost tens of billions of dollars.^{[259][260]}

Forced evacuation from a nuclear accident may lead to social isolation, anxiety, depression, psychosomatic medical problems, reckless behavior, even suicide. Such was the outcome of the 1986 Chernobyl nuclear disaster in Ukraine. A comprehensive 2005 study concluded that "the mental health impact of Chernobyl is the largest public health problem unleashed by the accident to date".^[261] Frank N. von Hippel, a U.S. scientist, commented on the 2011 Fukushima nuclear disaster, saying that "fear of ionizing radiation could have long-term psychological effects on a large portion of the population in the contaminated areas".^[262] A 2015 report in *Lancet* explained that serious impacts of nuclear accidents were often not directly attributable to radiation exposure, but rather social and psychological effects. Evacuation and long-term displacement of affected populations created problems for many people, especially the elderly and hospital patients.^[263]

Attacks and sabotage

Terrorists could target nuclear power plants in an attempt to release radioactive contamination into the community. The United States 9/11 Commission has said that nuclear power plants were potential targets originally considered for the September 11, 2001 attacks. An attack on a reactor's spent fuel pool could also be serious, as these pools are less protected than the reactor core. The release of radioactivity could lead to thousands of near-term deaths and greater numbers of long-term fatalities.^[264]

If nuclear power use is to expand significantly, nuclear facilities will have to be made extremely safe from attacks that could release massive quantities of radioactivity into the community. New reactor designs have features of passive safety, such as the flooding of the reactor core without active intervention by reactor operators. But these safety measures have generally been developed and studied with respect to accidents, not to the deliberate reactor attack by a terrorist group. However, the US Nuclear Regulatory Commission does now also require new reactor license applications to consider security during the design stage.^[264] In the United States, the NRC carries out "Force on Force" (FOF) exercises at all Nuclear Power Plant (NPP) sites at least once every three years.^[264] In the U.S., plants are surrounded by a double row of tall fences which are electronically monitored. The plant grounds are patrolled by a sizeable force of armed guards.^[265]

Insider sabotage regularly occurs, because insiders can observe and work around security measures. Successful insider crimes depended on the perpetrators' observation and knowledge of security vulnerabilities.^[266] A fire caused 5–10 million dollars worth of damage to New York's Indian Point Energy Center in 1971. The arsonist turned out to be a plant maintenance worker. Sabotage by workers has been reported at many other reactors in the United States: at Zion Nuclear Power Station (1974), Quad Cities Nuclear Generating Station, Peach Bottom Nuclear Generating Station, Fort St. Vrain Generating Station, Trojan Nuclear Power Plant (1974), Browns Ferry Nuclear Power Plant (1980), and Beaver Valley Nuclear Generating Station (1981). Many reactors overseas have also reported sabotage by workers.^[267]

Nuclear proliferation

Many technologies and materials associated with the creation of a nuclear power program have a dual-use capability, in that they can be used to make nuclear weapons if a country chooses to do so. When this happens a nuclear power program can become a route leading to a nuclear weapon or a public annex to a "secret" weapons program. The concern over Iran's nuclear activities is a case in point.^[268]

A fundamental goal for American and global security is to minimize the nuclear proliferation risks associated with the expansion of nuclear power. If this development is "poorly managed or efforts to contain risks are unsuccessful, the nuclear future will be dangerous".^[268] The Global Nuclear Energy Partnership is one such international effort to create a distribution network in which developing countries in need of energy, would receive nuclear fuel at a discounted rate, in exchange for that nation agreeing to forgo their own indigenous develop of a uranium enrichment program. The France-based Eurodif/European Gaseous Diffusion Uranium Enrichment Consortium was/is one such program that successfully implemented this concept, with Spain and other countries without enrichment facilities buying a share of the fuel produced at the French controlled enrichment facility, but without a transfer of technology.^[271] Iran was an early participant from 1974, and remains a shareholder of Eurodif viSofidif.

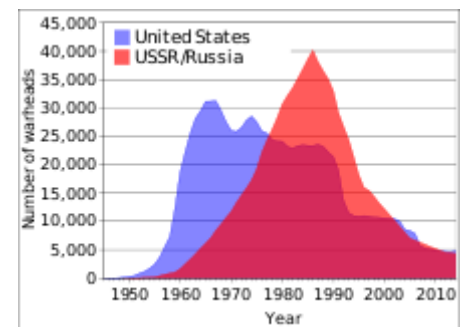
According to Benjamin K. Sovacool, a "number of high-ranking officials, even within the United Nations, have argued that they can do little to stop states using nuclear reactors to produce nuclear weapons".^[272] A 2009 United Nations report said that:

the revival of interest in nuclear power could result in the worldwide dissemination of uranium enrichment and spent fuel reprocessing technologies, which present obvious risks of proliferation as these technologies can produce fissile materials that are directly usable in nuclear weapons.^[272]

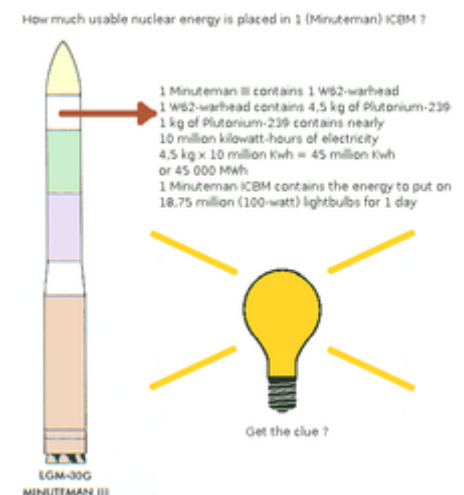
On the other hand, one factor influencing the support of power reactors is due to the appeal that these reactors have at reducing nuclear weapons arsenals through the Megatons to Megawatts Program, a program which eliminated 425 metric tons of highly enriched uranium(HEU), the equivalent of 17,000 nuclear warheads, by diluting it with natural uranium making it equivalent to low enriched uranium(LEU), and thus suitable as nuclear fuel for commercial fission reactors. This is the single most successful non-proliferation program to date.^[269]

The Megatons to Megawatts Program, the brainchild of Thomas Neff of MIT,^{[273][274]} was hailed as a major success by anti-nuclear weapon advocates as it has largely been the driving force behind the sharp reduction in the quantity of nuclear weapons worldwide since the cold war ended.^[269] However without an increase in nuclear reactors and greater demand for fissile fuel, the cost of dismantling and down blending has dissuaded Russia from continuing their disarmament.

Currently, according to Harvard professor Matthew Bunn: "The Russians are not remotely interested in extending the program beyond 2013. We've managed to set it up in a way that costs them more and profits them less than them just making new low-enriched uranium for reactors from scratch. But there are other ways to set it up that would be very profitable for them and would also serve some of their strategic interests in boosting their nuclear exports."^[275]



United States and USSR/Russian nuclear weapons stockpiles, 1945-2006. The Megatons to Megawatts Program was the main driving force behind the sharp reduction in the quantity of nuclear weapons worldwide since the cold war ended.^{[269][270]} However without an increase in nuclear reactors and greater demand for fissile fuel, the cost of dismantling has dissuaded Russia from continuing their disarmament.



Up to 2005, the Megatons to Megawatts Program had processed \$8 billion of HEU/weapons grade uranium into LEU/reactor grade uranium, with that corresponding to the elimination of 10,000 nuclear weapons.^[276]

For approximately two decades, this material generated nearly 10 percent of all the electricity consumed in the United States (about half of all US nuclear electricity generated) with a total of around 7 trillion kilowatt-hours of electricity produced.^[277] Enough energy to energize the entire United States electric grid for about two years.^[273] In total it is estimated to have cost \$17 billion, a "bargain for US ratepayers", with Russia profiting \$12 billion from the deal.^[277] Much needed profit for the Russian nuclear oversight industry, which after the collapse of the Soviet economy, had difficulties paying for the maintenance and security of the Russian Federations highly enriched uranium and warheads.^[273]

In April 2012 there were thirty one countries that have civil nuclear power plants,^[278] of which nine have nuclear weapons, with the vast majority of these nuclear weapons states having first produced weapons, before commercial fission electricity stations. Moreover, the re-purposing of civilian nuclear industries for military purposes would be a breach of the Non-proliferation treaty, of which 190 countries adhere to.

Environmental issues

Life cycle analysis (LCA) of carbon dioxide emissions show nuclear power as comparable to renewable energy sources. Emissions from burning fossil fuels are many times higher^{[279][281][282]}

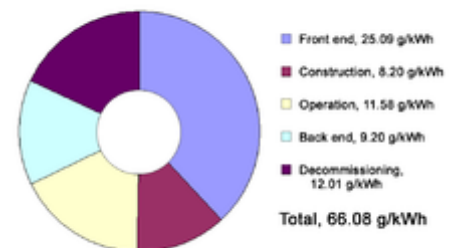
According to the United Nations (UNSCEAR), regular nuclear power plant operation including the nuclear fuel cycle causes radioisotope releases into the environment amounting to 0.0002 millisieverts (mSv) per year of public exposure as a global average.^[283] (Such is small compared to variation in natural background radiation, which averages 2.4 mSv/a globally but frequently varies between 1 mSv/a and 13 mSv/a depending on a person's location as determined by UNSCEAR).^[283] As of a 2008 report, the remaining legacy of the worst nuclear power plant accident (Chernobyl) is 0.002 mSv/a in global average exposure (a figure which was 0.04 mSv per person averaged over the entire populace of the Northern Hemisphere in the year of the accident in 1986, although far higher among the most affected local populations and recovery workers).^[283]

Climate change

Climate change causing weather extremes such as heat waves, reduced precipitation levels and droughts can have a significant impact on all thermal power station infrastructure, including large biomass-electric and fission-electric stations alike, if cooling in these power stations, namely in the steam condenser is provided by certain freshwater sources.^[284] While many thermal stations use indirect seawater cooling or cooling towers that in comparison use little to no freshwater, those that were designed to heat exchange with rivers and lakes, can run into economic problems.

This presently infrequent generic problem may become increasingly significant over time.^[284] This can force nuclear reactors to be shut down, as happened in France during the 2003 and 2006 heat waves. Nuclear power supply was severely diminished by low river flow rates and droughts, which meant rivers had reached the maximum temperatures for cooling reactors.^[284] During the heat waves, 17 reactors had to limit output or shut down. 77% of French electricity is produced by nuclear power and in 2009 a similar situation created a 8GW shortage and forced the French government to import electricity.^[284] Other cases have been reported from Germany, where extreme temperatures have reduced nuclear power production only 9 times due to high temperatures between 1979 and 2007.^[284] In particular:

Carbon emissions from nuclear power
Sovacool life cycle study survey, 2008



Mean value of carbon dioxide emissions from qualified life cycle studies among 103 surveyed. Includes results of 1997 Vattenfall study.

A 2008 synthesis of 103 studies, published by Benjamin K. Sovacool, estimated that the value of CO₂ emissions for nuclear power over the lifecycle of a plant was 66.08 g/kW·h. Comparative results for various renewable powersources were 9–32 g/kW·h.^[279] A 2012 study by Yale University arrived at a different value, with the mean value, depending on which Reactor design was analyzed, ranging from 11 to 25 g/kW·h of total life cycle nuclear power CO₂ emissions.^[280]

- the Unterweser nuclear power plant reduced output by 90% between June and September 2003^[284]
- the Isar nuclear power plant cut production by 60% for 14 days due to excess river temperatures and low stream flow in the river Isar in 2006^[284] However the more modern Isar II station did not have to cut production, as unlike its sister station Isar I, Isar II was built with a cooling tower

Similar events have happened elsewhere in Europe during those same hot summers.^[284] If global warming continues, this disruption is likely to increase or alternatively, station operators could instead retro-fit other means of cooling, like cooling towers, despite these frequently being large structures and therefore sometimes unpopular with the public.

Comparison with renewable energy

There is an ongoing debate on the relative benefits of nuclear power compared to renewable ~~energy~~ sources for the generation of low-carbon electricity. Proponents of renewable energy argue that wind power and solar power are already cheaper and safer than nuclear power. Nuclear power proponents argue that renewable energy sources such as wind and solar do not offer the scalability necessary for a large scale decarbonization of the electric grid, mainly due to their intermittency.^{[285][286]} Although the majority of installed renewable energy across the world is currently in the form of hydro power, solar and wind power are growing at a much higher pace, especially in developed countries.

Several studies report that it is in principle possible to cover most of energy generation with renewable sources. The Intergovernmental Panel on Climate Change (IPCC) has said that if governments were supportive, and the full complement of renewable energy technologies were deployed, renewable energy supply could account for almost 80% of the world's energy use within forty years.^[287] Rajendra Pachauri, chairman of the IPCC, said the necessary investment in renewables would cost only about 1% of global GDP annually. This approach could contain greenhouse gas levels to less than 450 parts per million, the safe level beyond which climate change becomes catastrophic and irreversible.^[287]

However, other studies suggest that solar and wind energy are not cost-effective compared to nuclear power. The Brookings Institution published *The Net Benefits of Low and No-Carbon Electricity Technologies* in 2014 which states, after performing an energy and emissions cost analysis, that "The net benefits of new nuclear, hydro, and natural gas combined cycle plants far outweigh the net benefits of new wind or solar plants", with the most cost effective low carbon power technology being determined to be nuclear power.^{[288][289][290]}

Nuclear power is also proposed as a tested and practical way to implement a low-carbon energy infrastructure, as opposed to renewable sources. Analysis in 2015 by Professor and Chair of Environmental Sustainability Barry W. Brook and his colleagues on the topic of replacing fossil fuels entirely, from the electric grid of the world, has determined that at the historically modest and proven-rate at which nuclear energy was added to and replaced fossil fuels in France and Sweden during each nation's building programs in the 1980s, nuclear energy could displace or remove fossil fuels from the electric grid completely within 10 years, "allow[ing] the world to meet the most stringent greenhouse-gas mitigation targets."^[175] In a similar analysis, Brook had earlier determined that 50% of all global energy, that is not solely electricity, but transportation synfuels etc. could be generated within approximately 30 years, if the global nuclear fission build rate was identical to each of these nation's already proven decadal rates (in units of installed nameplate capacity, GW per year, per unit of global GDP (GW/year/\$)).^[176]

This is in contrast to the conceptual studies for a 100% renewable energy world, which would require an orders of magnitude more costly global investment per year, which has no historical precedent,^{[177][178]} along with far greater land that would have to be devoted to the wind, wave and solar projects, and the inherent assumption that humanity will use less, and not more, energy in the future.^{[176][177][179]} As Brook notes, the "principal limitations on nuclear fission are not technical, economic or fuel-related, but are instead linked to complex issues of societal acceptance, fiscal and political inertia, and inadequate critical evaluation of the real-world constraints facing [the other] low-carbon alternatives."^[176]

Several studies conclude that wind and solar power have costs that are comparable or lower than nuclear power, when considering price per kWh. The cost of constructing established nuclear power reactor designs has followed an increasing trend due to regulations and court cases whereas the levelized cost of electricity (LCOE) is declining for wind and solar power.^[291] In 2010 a report from Solar researchers at Duke University suggested that solar power is already cheaper than nuclear power.^{[292][293]} However they state

that if subsidies were removed for solar power, the crossover point would be delayed by years.^[294] Data from the EIA in 2011 estimated that in 2016, solar will have a levelized cost of electricity almost twice as expensive as nuclear (21¢/kWh for solar, 11.39¢/kWh for nuclear), and wind somewhat less expensive than nuclear (9.7¢/kWh).^[295]

However, the US EIA has also cautioned that levelized costs of intermittent sources such as wind and solar are not directly comparable to costs of "dispatchable" sources (those that can be adjusted to meet demand), as intermittent sources need costly large-scale back-up power supplies for when the weather changes.^[296]

A 2010 study by the Global Subsidies Initiative compared global relative energy subsidies, or government financial aid to different energy sources, with this aid not solely funnelled into research and development but into bribing or "incentivizing" utilities to pursue renewable energy systems, over other options. Results show that fossil fuels receive about 1 US cents per kWh of energy they produce, nuclear energy receives 1.7 cents / kWh, renewable energy (excluding hydroelectricity) receives 5.0 cents / kWh and biofuels receive 5.1 cents / kWh in subsidies.^{[297][298]}

As opposed to renewable energy, conventional designs for nuclear reactors also produce intensely radioactive spent fuel that needs to be stored or reprocessed.^[299] A nuclear plant also needs to be disassembled and removed and much of the disassembled nuclear plant needs to be stored as low level nuclear waste for a few decades.^[300] However, from a safety stand point, nuclear power, in terms of lives lost per unit of electricity delivered, is comparable to, and in some cases lower, than many renewable energy sources.^{[22][24][301]}

Nuclear decommissioning

The financial costs of every nuclear power plant continues for some time after the facility has finished generating its last useful electricity. Once no longer economically viable, nuclear reactors and uranium enrichment facilities are generally decommissioned, returning the facility and its parts to a safe enough level to be entrusted for other uses, such as greenfield status. After a cooling-off period that may last decades, reactor core materials are dismantled and cut into small pieces to be packed in containers for interim storage or transmutation experiments. The consensus on how to approach the task is one that is relatively inexpensive, but it has the potential to be hazardous to the natural environment as it presents opportunities for human error, accidents or sabotage.^[302]

In the USA a Nuclear Waste Policy Act and Nuclear Decommissioning Trust Fund is legally required, with utilities banking 0.1 to 0.2 cents/kWh during operations to fund future decommissioning. They must report regularly to the Nuclear Regulatory Commission (NRC) on the status of their decommissioning funds. About 70% of the total estimated cost of decommissioning all US nuclear power reactors has already been collected (on the basis of the average cost of \$320 million per reactor steam turbine unit).^{[303][304]}

In the U.S. in 2011, there are 13 reactors that had permanently shut down and are in some phase of decommissioning.^[302] With Connecticut Yankee Nuclear Power Plant and Yankee Rowe Nuclear Power Station having completed the process in 2006–2007, after ceasing commercial electricity production circa 1992. The majority of the 15 years, was used to allow the station to naturally cool-down on its own, which makes the manual disassembly process both safer and cheaper. Decommissioning at nuclear sites which have experienced a serious accident are the most expensive and time-consuming.

Working under an insurance framework that limits or structures accident liabilities in accordance with the Paris convention on nuclear third-party liability, the Brussels supplementary convention, and the Vienna convention on civil liability for nuclear damage^[305] and in the U.S. the Price-Anderson Act. It is often argued that this potential shortfall in liability represents an external cost not included in the cost of nuclear electricity; but the cost is small, amounting to about 0.1% of the levelized cost of electricity, according to a CBO study.^[306]

These beyond-regular insurance costs for worst-case scenarios are not unique to nuclear power, as hydroelectric power plants are similarly not fully insured against a catastrophic event such as the Banqiao Dam disaster, where 11 million people lost their homes and from 30,000 to 200,000 people died, or large dam failures in general. As private insurers base dam insurance premiums on limited scenarios, major disaster insurance in this sector is likewise provided by the state.^[307]

Debate on nuclear power

The nuclear power debate concerns the controversy^{[13][14][63]} which has surrounded the deployment and use of nuclear fission reactors to generate electricity from nuclear fuel for civilian purposes. The debate about nuclear power peaked during the 1970s and 1980s, when it "reached an intensity unprecedented in the history of technology controversies", in some countries.^{[64][308]}

Proponents of nuclear energy contend that nuclear power is a sustainable energy source that reduces carbon emissions and increases energy security by decreasing dependence on imported energy sources.^[15] Proponents claim that nuclear power produces virtually no conventional air pollution, such as greenhouse gases and smog, in contrast to the chief viable alternative of fossil fuel.^[309] Nuclear power can produce base-load power unlike many renewables which are intermittent energy sources lacking large-scale and cheap ways of storing energy.^[310] M. King Hubbert saw oil as a resource that would run out, and proposed nuclear energy as a replacement energy source.^[311] Proponents claim that the risks of storing waste are small and can be further reduced by using the latest technology in newer reactors, and the operational safety record in the Western world is excellent when compared to the other major kinds of power plants.^[312]

Opponents believe that nuclear power poses many threats to people and the environment.^{[16][17][18]} These threats include the problems of processing, transport and storage of radioactive nuclear waste, the risk of nuclear weapons proliferation and terrorism, as well as health risks and environmental damage from uranium mining.^{[313][314]} They also contend that reactors themselves are enormously complex machines where many things can and do go wrong; and there have been serious nuclear accidents.^{[315][316]} Critics do not believe that the risks of using nuclear fission as a power source can be fully offset through the development of new technology. In years past, they also argued that when all the energy-intensive stages of the nuclear fuel chain are considered, from uranium mining to nuclear decommissioning nuclear power is neither a low-carbon nor an economical electricity source.^{[317][318][319]}

Arguments of economics and safety are used by both sides of the debate.

Use in space

Both fission and fusion appear promising for space propulsion applications, generating higher mission velocities with less reaction mass. This is due to the much higher energy density of nuclear reactions: some 7 orders of magnitude (10,000,000 times) more energetic than the chemical reactions which power the current generation of rockets.

Radioactive decay has been used on a relatively small scale (few kW), mostly to power space missions and experiments by using radioisotope thermoelectric generators such as those developed at Idaho National Laboratory

Research

Advanced concepts

Current fission reactors in operation around the world are second or third generation systems, with most of the first-generation systems having been retired some time ago. Research into advanced generation IV reactor types was officially started by the Generation IV International Forum (GIF) based on eight technology goals, including to improve nuclear safety, improve proliferation resistance, minimize waste, improve natural resource utilization, the ability to consume existing nuclear waste in the production of electricity, and decrease the cost to build and run such plants. Most of these reactors differ significantly from current operating light water reactors, and are generally not expected to be available for commercial construction before 2030.^[320]

The nuclear reactors to be built at Vogtle are new AP1000 third generation reactors, which are said to have safety improvements over older power reactors.^[107] However, John Ma, a senior structural engineer at the NRC, is concerned that some parts of the AP1000 steel skin are so brittle that the "impact energy" from a plane strike or storm driven projectile could shatter the wall.^[321] Edwin Lyman, a senior staff scientist at the Union of Concerned Scientists, is concerned about the strength of the steel containment vessel and the concrete shield building around the AP1000.^{[321][322]}

The Union of Concerned Scientists has referred to the EPR (nuclear reactor), currently under construction in China, Finland and France, as the only new reactor design under consideration in the United States that "...appears to have the potential to be significantly safer and more secure against attack than today's reactors".^[323]

One disadvantage of any new reactor technology is that safety risks may be greater initially as reactor operators have little experience with the new design. Nuclear engineer David Lochbaum has explained that almost all serious nuclear accidents have occurred with what was at the time the most recent technology. He argues that "the problem with new reactors and accidents is twofold: scenarios arise that are impossible to plan for in simulations; and humans make mistakes".^[324] As one director of a U.S. research laboratory put it, "fabrication, construction, operation, and maintenance of new reactors will face a steep learning curve: advanced technologies will have a heightened risk of accidents and mistakes. The technology may be proven, but people are not".^[324]

Hybrid nuclear fusion-fission

Hybrid nuclear power is a proposed means of generating power by use of a combination of nuclear fusion and fission processes. The concept dates to the 1950s, and was briefly advocated by Hans Bethe during the 1970s, but largely remained unexplored until a revival of interest in 2009, due to delays in the realization of pure fusion. When a sustained nuclear fusion power plant is built, it has the potential to be capable of extracting all the fission energy that remains in spent fission fuel, reducing the volume of nuclear waste by orders of magnitude, and more importantly, eliminating all actinides present in the spent fuel, substances which cause security concerns.^[325]

Nuclear fusion

Nuclear fusion reactions have the potential to be safer and generate less radioactive waste than fission.^{[326][327]} These reactions appear potentially viable, though technically quite difficult and have yet to be created on a scale that could be used in a functional power plant. Fusion power has been under theoretical and experimental investigation since the 1950s.

Construction of the ITER facility began in 2007, but the project has run into many delays and budget overruns. The facility is now not expected to begin operations until the year 2027 – 11 years after initially anticipated.^[328] A follow on commercial nuclear fusion power station, DEMO, has been proposed.^{[329][330]} There are also suggestions for a power plant based upon a different fusion approach, that of an inertial fusion power plant

Fusion powered electricity generation was initially believed to be readily achievable, as fission-electric power had been. However, the extreme requirements for continuous reactions and plasma containment led to projections being extended by several decades. In 2010, more than 60 years after the first attempts, commercial power production was still believed to be unlikely before 2050.^[329]

See also

-
- | | |
|---|--------------------------------------|
| ▪ <u>List of nuclear power stations</u> | ▪ <u>Thorium-based nuclear power</u> |
| ▪ <u>List of nuclear reactors</u> | ▪ <u>Uranium mining debate</u> |
| ▪ <u>Nuclear power by country</u> | ▪ <u>World energy consumption</u> |
| ▪ <u>Nuclear weapons debate</u> | |

References

-
1. Nuclear Energy: Statistics, Dr Elizabeth Ervin (<http://home.olemiss.edu/~cmchengs/Global%20Warming/Session%2017%20Nuclear%20Energy%20-%20Statistics/Nuclear%20Energy.pdf>)
 2. "An oasis filled with grey water"(<http://www.neimagazine.com/features/featurean-oasis-filled-with-grey-water/>) *NEI Magazine*. 2013-06-25.
 3. Topical issues of infrastructure developmentIAEA 2012 (<https://www.iaea.org/NuclearPower/Downloadable/Meeting%20s/2012/2012-01-TM-WS-Vienna/Day-4/3.Motazavi-PVNGS.pdf>)

4. "2014 Key World Energy Statistics"(<http://www.iea.org/publications/freepublications/publication/KeyWorld2014.pdf>) (PDF). International Energy Agency 2014. p. 24. Archived (<https://www.webcitation.org/6YIEFsQ6b?url=http://www.iea.org/publications/freepublications/publication/KeyWorld2014.pdf>) (PDF) from the original on 2015-05-05.
5. "Nuclear Energy" (https://web.archive.org/web/20110226114158/http://www.energyeducation.tx.gov/energy/section_1/topics/forms_of_energy/nuclear_energy.html). *Energy Education is an interactive curriculum supplement for secondary-school science students, funded by the U. S. Department of Energy and the Texas State Energy Conservation Office (SECO) U. S. Department of Energy and the Texas State Energy Conservation Office (SECO)*. July 2010. Archived from the original (http://www.energyeducation.tx.gov/energy/section_1/topics/forms_of_energy/nuclear_energy.html) on 2011-02-26 Retrieved 2010-07-10.
6. Prompt and Delayed Neutrons *The fact the neutron is produced via this type of decay and this happens orders of magnitude later compared to the emission of the prompt neutrons, plays an extremely important role in the control of the reactor.* (<http://www.nuclear-power.net/nuclear-power/fission/prompt-neutrons/>)
7. "Collectively, life cycle assessment literature shows that nuclear power is similar to other renewable and much lower than fossil fuel in total life cycle GHG emissions."(https://web.archive.org/web/20130702205635/http://www.nrel.gov/analysis/sustain_lca_nuclear.html). Nrel.gov. 2013-01-24. Archived from the original (http://www.nrel.gov/analysis/sustain_lca_nuclear.html) on 2013-07-02 Retrieved 2013-06-22.
8. Life Cycle Assessment Harmonization Results and Findings. Figure 1 (http://www.nrel.gov/analysis/sustain_lca_results.html) Archived (https://web.archive.org/web/20170506114117/http://www.nrel.gov/analysis/sustain_lca_results.html) 2017-05-06 at the Wayback Machine
9. "IPCC Working Group III – Mitigation of Climate Change, Annex II I: Technology – specific cost and performance parameters" (https://web.archive.org/web/20141215013236/http://report.mitigation2014.org/report/ipcc_wg3_ar5_annex-iii.pdf) (PDF). IPCC. 2014. p. 10. Archived from the original (http://report.mitigation2014.org/report/ipcc_wg3_ar5_annex-iii.pdf) (PDF) on 2014-12-15 Retrieved 2014-08-01.
10. "IPCC Working Group III – Mitigation of Climate Change, Annex II Metrics and Methodology pp 37 to 40, 41" (https://web.archive.org/web/20150908235241/http://report.mitigation2014.org/report/ipcc_wg3_ar5_annex-ii.pdf) (PDF). Archived from the original (http://report.mitigation2014.org/report/ipcc_wg3_ar5_annex-ii.pdf) (PDF) on 2015-09-08.
11. Kharecha Pushker A (2013). "Prevented Mortality and Greenhouse Gas Emissions from Historical and Projected Nuclear Power – global nuclear power has prevented an average of 1.84 million air pollution-related deaths and 64 gigatonnes of CO₂-equivalent (GtCO₂-eq) greenhouse gas (GHG) emissions that would have resulted from fossil fuel burning". *Environmental Science Pubs.acs.org*. **47**: 4889–4895. Bibcode:2013EnST...47.4889K (<http://adsabs.harvard.edu/abs/2013EnST...47.4889K>). doi:10.1021/es3051197 (<https://doi.org/10.1021/es3051197>)
12. Union-Tribune Editorial Board (2011-03-27). "The nuclear controversy" (<http://www.signonsandiego.com/news/2011mar/27/nuclear-controversy/>) *Union-Tribune*. San Diego.
13. James J. MacKenzie. Review of The Nuclear Power Controversy (<https://www.jstor.org/stable/2823429>) by Arthur W. Murphy *The Quarterly Review of Biology* Vol. 52, No. 4 (Dec., 1977), pp. 467–468.
14. In February 2010 the nuclear power debate played out on the pages of *The New York Times*, see *A Reasonable Bet on Nuclear Power* (<https://www.nytimes.com/2010/02/18/opinion/18thur2.html?scp=1&sq=a%20reasonable%20bet%20on%20nuclear%20power&st=cse>) and *Revisiting Nuclear Power: A Debate* (<https://www.nytimes.com/2010/02/20/opinion/20nuclear.html>) and *A Comeback for Nuclear Power?* (<http://roomfordebate.blogs.nytimes.com/2010/02/16/a-comeback-for-nuclear-power/>)
15. U.S. Energy Legislation May Be 'Renaissance' for Nuclear Power (<https://www.bloomberg.com/apps/news?pid=10000103&sid=aXb5iuqdZoD4&refer=us>) Archived (<https://web.archive.org/web/20090626182130/http://www.bloomberg.com/apps/news?pid=10000103>) 2009-06-26 at the Wayback Machine.
16. Share. "Nuclear Waste Pools in North Carolina" (<https://web.archive.org/web/20100725030831/http://www.projectcensored.org/top-stories/articles/4-nuclear-waste-pools-in-north-carolina/>) Projectcensored.org. Archived from the original (<http://www.projectcensored.org/top-stories/articles/4-nuclear-waste-pools-in-north-carolina/>) on 2010-07-25 Retrieved 2010-08-24.
17. "Nuclear Power" (<http://www.ncwarn.org/?cat=18>) Nc Warn. Retrieved 2013-06-22.
18. Sturgis, Sue. "Investigation: Revelations about Three Mile Island disaster raise doubts over nuclear plant safety" (<https://web.archive.org/web/20100418063024/http://www.southernstudies.org/2009/04/post-4.html>) Southernstudies.org. Archived from the original (<http://www.southernstudies.org/2009/04/post-4.html>) on 2010-04-18 Retrieved 2010-08-24.
19. iPad iPhone Android TIME TV Populist The Page (2009-03-25). "The Worst Nuclear Disasters" (<http://www.time.com/time/photogallery/0,29307,1887705,00.html>) Time.com. Retrieved 2013-06-22.

20. Strengthening the Safety of Radiation Sources(<http://www.iaea.org/Publications/Magazines/Bulletin/Bull413/article1.pdf>) Archived (<https://www.webcitation.org/5hO7gbe9a?url=http://www.iaea.org/Publications/Magazines/Bulletin/Bull413/article1.pdf>) 2009-06-08 at WebCite p. 14.
21. Johnston, Robert (2007-09-23)."Deadliest radiation accidents and other events causing radiation casualties"(<http://www.johnstonsarchive.net/nuclear/radevent&radevents1.html>) Database of Radiological Incidents and Related Events.
22. Markandya, A.; Wilkinson, P (2007). "Electricity generation and health" *Lancet*. **370** (9591): 979–990. doi:10.1016/S0140-6736(07)61253-7(<https://doi.org/10.1016%2FS0140-6736%2807%2961253-7>) PMID 17876910 (<https://www.ncbi.nlm.nih.gov/pubmed/17876910>). - Nuclear power has lower electricity related health risks than Coal, Oil, & gas. ...the health burdens are appreciably smaller for generation from natural gas, and lower still for nuclear power. This study includes the latent or indirect fatalities, for example those caused by the inhalation of fossil fuel created particulate matter, smog induced Cardiopulmonary events, black lung etc. in its comparison.)
23. Gohlke JM et al. Environmental Health Perspectives (2008)"Health, Economy and Environment: Sustainable Energy Choices for a Nation"(<https://www.ncbi.nlm.nih.gov/pmc/articles/PMC2430245>). *Environmental Health Perspectives*. **116** (6): A236–A237. doi:10.1289/ehp.11602(<https://doi.org/10.1289%2Fehp.11602>) PMC 2430245 (<https://www.ncbi.nlm.nih.gov/pmc/articles/PMC2430245>) PMID 18560493 (<https://www.ncbi.nlm.nih.gov/pubmed/18560493>).
24. "Dr. MacKay Sustainable Energy without the hot air" (http://www.inference.phycam.ac.uk/withouthotair/c24/page_168.shtml). Data from studies by the Paul Scherrer Institute including non EU data p. 168. Retrieved 2012-09-15.
25. <https://www.forbes.com/sites/jamesconca/2012/06/10/energys-deathprint-a-price-always-paid/> With Chernobyl's total predicted linear no-threshold cancer deaths included, nuclear power is safer when compared to many alternative energy sources' immediate, death rate.
26. Brendan Nicholson (2006-06-05)."Nuclear power 'cheaper safer' than coal and gas" (<http://www.theage.com.au/news/national/nuclear-power-cheaper-safer-than-coal-and-gas/2006/06/04/1149359609052.html>) Melbourne: The Age. Retrieved 2008-01-18.
27. Burgherr, P.; Hirschberg, S. (2008)."A Comparative Analysis of Accident Risks in Fossil, Hydro, and Nuclear Energy Chains" (http://gabe.web.psi.ch/pdfs/_2012_LEA_Audit/A01.pdf) (PDF). *Human and Ecological Risk Assessment: an International Journal* **14** (5): 947. doi:10.1080/10807030802387556(<https://doi.org/10.1080%2F10807030802387556>). Page 962 to 965. Comparing Nuclear's latent cancer deaths, such as cancer with other energy sources immediate deaths per unit of energy generated(GW_{yr}). This study does not include Fossil fuel related cancer and other indirect deaths created by the use of fossil fuel consumption in its "severe accident", an accident with more than 5 fatalities, classification.
28. The Database on Nuclear Power Reactors. The Power Reactor Information System (PRIS), developed and maintained by the IAEA for over four decades, is a comprehensive database focusing on nuclear power plants worldwide (<https://www.iaea.org/pris/>)
29. "GIF Portal – Home – Public"(https://www.gen-4.org/gif/jcms/c_9260/public). *www.gen-4.org*. Retrieved 2016-07-25.
30. "Moonshine" (<http://www.atomicarchive.com/History/mp/1s2.shtml>). Atomicarchive.com Retrieved 2013-06-22
31. "The Atomic Solar System"(<http://www.atomicarchive.com/History/mp/1s1.shtml>). Atomicarchive.com Retrieved 2013-06-22
32. taneya says: "What do you mean by Induced Radioactivity?"(<http://www.thebigger.com/chemistry/nuclear-and-radiation-chemistry/what-do-you-mean-by-induced-radioactivity-2/>)Thebigger.com. Retrieved 2013-06-22
33. "Neptunium" (<http://www.vanderkrogt.net/elements/element.php?sym=Np>) Vanderkrogt.net Retrieved 2013-06-22
34. "Otto Hahn, The Nobel Prize in Chemistry1944" (http://nobelprize.org/nobel_prizes/chemistry/laureates/1944/hahn-bio.html). Nobelprize.org Retrieved 2007-11-01
35. "Otto Hahn, Fritz Strassmann, and Lise Meitner"(<https://www.sciencehistory.org/historical-profile/otto-hahn-lise-meitner-and-fritz-strassmann>) Science History Institute Retrieved March 20, 2018.
36. "Otto Robert Frisch"(http://www.nuclearfiles.org/menu/library/biographies/bio_frisch-otto.htm) Nuclearfiles.org Retrieved 2007-11-01
37. "The Einstein Letter"(<http://www.atomicarchive.com/History/mp/introduction.shtml>) Atomicarchive.com Retrieved 2013-06-22
38. *The Atomic Age Opens* ALSOS digital library of nuclear issues. "The book does not always clearly indicate which words are being quoted rather than edited or added"(<http://alsos.wlu.edu/information.aspx?id=279>)

39. THE ATOMIC AGE OPENS. Prepared by the Editors of Pocket Books. 252 pages. New York: Pocket Books, Inc. August 1945. QC173 .P55 1945 FIRST EDITION, first issue, of the first mass market account of the atomic bomb (http://scarc.library.oregonstate.edu/coll/energycatalogue/energy2_1-100.html)
40. Bain, Alastair S.; et al. (1997). *Canada enters the nuclear age: a technical history of Atomic Energy of Canada* Magill-Queen's University Press. p. ix. ISBN 0-7735-1601-8
41. "Reactors Designed by Argonne National Laboratory: Fast Reactor Technology" (<http://www.ne.anl.gov/About/reactors/frt.shtml>). U.S. Department of Energy Argonne National Laboratory. 2012. Retrieved 2012-07-25.
42. "Reactor Makes Electricity" (<https://books.google.com/books?id=yNwDAAAAMBAJ&pg=PA105&dq=1954+Popular+Mechanics+January#v=onepage&q&f=true>) *Popular Mechanics*, March 1952, p. 105.
43. "STR (Submarine Thermal Reactor) in "Reactors Designed by Argonne National Laboratory: Light Water Reactor Technology Development" (<http://www.ne.anl.gov/About/reactors/lwr3.shtml#fragment-2>) U.S. Department of Energy, Argonne National Laboratory 2012. Retrieved 2012-07-25.
44. "From Obninsk Beyond: Nuclear Power Conference Looks to Future" (<http://www.iaea.org/NewsCenter/News/2004/obninsk.html>). *International Atomic Energy Agency* Retrieved 2006-06-27.
45. "Nuclear Power in Russia" (<http://world-nuclear.org/info/inf45.htm>) *World Nuclear Association* Retrieved 2006-06-27.
46. "This Day in Quotes: SEPTEMBER 16 – Too cheap to meter: the great nuclear quote debate" (<http://www.thisdayinquotes.com/2009/09/too-cheap-to-meter-nuclear-quote-debate.html>) This day in quotes. 2009 Retrieved 2009-09-16.
47. Pfau, Richard (1984) *No Sacrifice Too Great: The Life of Lewis L. Strauss* University Press of Virginia, Charlottesville, Virginia, p. 187 (<https://www.amazon.com/dp/0813910382>) ISBN 978-0-8139-1038-3
48. David Bodansky (2004). *Nuclear Energy: Principles, Practices, and Prospects* (<https://books.google.com/?id=qBqbr8uV9c8C&pg=PA32&dq=strauss+son+cheap+meter>). Springer. p. 32. ISBN 978-0-387-20778-0 Retrieved 2008-01-31
49. Kragh, Helge (1999). *Quantum Generations: A History of Physics in the Twentieth Century*. Princeton NJ: Princeton University Press. p. 286. ISBN 0-691-09552-3
50. "On This Day: October 17" (http://news.bbc.co.uk/onthisday/hi/dates/stories/october/17/newsid_3147000/3147145.stm). BBC News. 1956-10-17. Retrieved 2006-11-09.
51. "50 Years of Nuclear Energy" (http://www.iaea.org/About/Policy/GC/GC48/Documents/gc48inf-4_ftn3.pdf) (PDF). International Atomic Energy Agency Retrieved 2006-11-09.
52. McKeown, William (2003). *Idaho Falls: The Untold Story of America's First Nuclear Accident* Toronto: ECW Press. ISBN 978-1-55022-562-4
53. *The Changing Structure of the Electric Power Industry* (<https://books.google.com/books?id=C5W8uxwMqdUC&pg=PA110&lpg=PA110&dq=%22nuclear+power+industry%22+history+u.s.>) p. 110.
54. Bernard L. Cohen (1990). *The Nuclear Energy Option: An Alternative for the 90s* (<http://www.phyast.pitt.edu/~blc/book/chapter9.html>). New York: Plenum Press. ISBN 978-0-306-43567-6
55. "Evolution of Electricity Generation by Fuel" (http://www.iea.org/textbase/stats/pdf_graphs/FRELEC.pdf) (PDF). (39.4 KB)
56. Sharon Beder, *The Japanese Situation* (<http://www.herinst.org/sbeder/privatisation/japan.html>), English version of conclusion of Sharon Beder "Power Play: The Fight to Control the World's Electricity", Soshisha, Japan, 2006.
57. Garb Paula (1999). "Review of Critical Masses" (http://jpe.library.arizona.edu/volume_6/wellackvol6.htm). *Journal of Political Ecology*. 6.
58. Rüdiger, Wolfgang, ed. (1990). *Anti-nuclear Movements: A World Survey of Opposition to Nuclear Energy* (<https://books.google.com/books?id=ZXwfAQAIAAJ>) Detroit, MI: Longman Current Affairs. p. 1. ISBN 0-8103-9000-0.
59. Brian Martin. *Opposing nuclear power: past and present* (<http://www.bmartin.cc/pubs/07sa.html>) *Social Alternatives*, Vol. 26, No. 2, Second Quarter 2007, pp. 43-47.
60. Stephen Mills and Roger Williams (1986) *Public Acceptance of New Technologies* (<https://books.google.com/books?id=SeMNAAAQAAJ&dq=%22public+acceptance+of+new+technologies%22&printsec=frontcover#PA376,M1>) Routledge, pp. 375–376.
61. Robert Gottlieb (2005). *Forcing the Spring: The Transformation of the American Environmental Movement* (<https://books.google.com/books?id=IR0n6oqMNPkC&dq=transformation+of+the+american+environmental+gottlieb+revised&pg=PP1#PPA237,M1>), Revised Edition, Island Press, USA, p. 237.

62. Falk, Jim (1982). *Global Fission: The Battle Over Nuclear Power* Melbourne: Oxford University Press. pp. 95–96. ISBN 978-0-19-554315-5
63. Walker, J. Samuel (2004). *Three Mile Island: A Nuclear Crisis in Historical Perspective* (<https://books.google.com/books?id=tf0AfoynG-EC&dq=Three+Mile+Island:+A+Nuclear+Crisis+in+Historical+Perspective&printsec=frontcover#v=onepage&q=&f=false>) (Berkeley: University of California Press), pp. 10–11.
64. Herbert P. Kitschelt (1986). "Political Opportunity and Political Protest: Anti-Nuclear Movements in Four Democracies" (<http://www.marcuse.org/harold/hmimages/sabrook/861KitscheltAntiNuclear4Democracies.pdf>) (PDF). *British Journal of Political Science* **16** (1): 57. doi:10.1017/s000712340000380x (<https://doi.org/10.1017%2Fs000712340000380x>)
65. Herbert P. Kitschelt (1986). "Political Opportunity and Political Protest: Anti-Nuclear Movements in Four Democracies" (<http://www.marcuse.org/harold/hmimages/sabrook/861KitscheltAntiNuclear4Democracies.pdf>) (PDF). *British Journal of Political Science* **16** (1): 71. doi:10.1017/s000712340000380x (<https://doi.org/10.1017%2Fs000712340000380x>)
66. Social Protest and Policy Change (<https://books.google.com/books?id=Kn6YhNtyigC&pg=PA45&lpg=PA45&dq=%22three+mile+island%22+anti-nuclear+protests+demonstrations#PA45,M1>) p. 45.
67. "The Political Economy of Nuclear Energy in the United States" (https://web.archive.org/web/20071103011953/http://www3.brookings.edu/~media/Files/rc/papers/2004/09environment_nivola/pb138.pdf) (PDF). *Social Policy*. The Brookings Institution. 2004. Archived from the original (http://www.brookings.edu/~media/Files/rc/papers/2004/09environment_nivola/pb138.pdf) (PDF) on 2007-11-03 Retrieved 2006-11-09.
68. Nuclear Power: Outlook for New U.S. Reactors (<https://fas.org/sgp/crs/misc/RL33442.pdf>) p. 3.
69. "Nuclear Follies". *Forbes magazine*. 1985-02-11.
70. "Backgrounder on Chernobyl Nuclear Power Plant Accident" (<https://www.nrc.gov/reading-rm/doc-collections/fact-sheets/chernobyl-bg.html>) *Nuclear Regulatory Commission* Retrieved 2006-06-28.
71. "RBMK Reactors | reactor bolshoy moshchnosty kanalny | Positive void coefficient" (<http://www.world-nuclear.org/info/inf31.html>). World-nuclear.org. 2009-09-07. Retrieved 2013-06-14.
72. "Italy rejoins the nuclear family" (http://www.world-nuclear-news.org/NP_Italy_rejoins_the_nuclear_family_1007091.html). World Nuclear News. 2009-07-10 Retrieved 2009-07-17.
73. "Italy puts one year moratorium on nuclear" (<http://www.businessweek.com/ap/financialnews/D9M504RG0.htm>) 2011-03-13.
74. "Italy nuclear: Berlusconi accepts referendum blow" (<http://www.bbc.co.uk/news/world-europe-13741105>). *BBC News*. 2011-06-14.
75. "Olkiluoto pipe welding 'deficient', says regulator" (http://www.world-nuclear-news.org/NN-Olkiluoto_pipe_welding_deficient_says_regulator-1610095.html) World Nuclear News. 2009-10-16 Retrieved 2010-06-08.
76. Kinnunen, Terhi (2010-07-01). "Finnish parliament agrees plans for two reactors" (<http://uk.reuters.com/article/idUKLDE6600ED>). *Reuters*. Retrieved 2010-07-02.
77. "Olkiluoto 3 delayed beyond 2014" (http://www.world-nuclear-news.org/NN-Olkiluoto_3_delayed_beyond_2014-1707124.html). *World Nuclear News* 2012-07-17. Retrieved 2012-07-24.
78. "Finland's Olkiluoto 3 nuclear plant delayed again" (<http://www.bbc.co.uk/news/world-europe-1862422>). *BBC*. 2012-07-16. Retrieved 2012-08-10.
79. "PRIS - Trend reports - Electricity Supplied" (<https://www.iaea.org/PRIS/WorldStatistics/WorldTrendinElectricalProduction.aspx>). *www.iaea.org*. Retrieved 11 December 2017.
80. "The Nuclear Renaissance" (<http://www.world-nuclear.org/info/inf104.html>) World Nuclear Association Retrieved 2014-01-24.
81. Trevor Findlay (2010). *The Future of Nuclear Energy to 2030 and its Implications for Safety, Security and Nonproliferation: Overview* (<http://www.cigionline.org/sites/default/files/Nuclear%20Energy%20Futures%20Overview.pdf>) Archived (<https://web.archive.org/web/20130512210155/http://www.cigionline.org/sites/default/files/Nuclear%20Energy%20Futures%20Overview.pdf>) 2013-05-12 at the *Wayback Machine*, The Centre for International Governance Innovation (CIGI), Waterloo, Ontario, Canada, pp. 10–11.
82. Mycle Schneider, Steve Thomas, Antony Froggatt, and Doug Koplow (August 2009). *The World Nuclear Industry Status Report 2009* (http://www.bmu.de/english/nuclear_safety/downloads/doc/44832.php) Archived (https://web.archive.org/web/20110424000745/http://www.bmu.de/english/nuclear_safety/downloads/doc/44832.php) 2011-04-24 at the *Wayback Machine* Commissioned by German Federal Ministry of Environment, Nature Conservation and Reactor Safety, p. 5.

83. Sylvia Westall & Fredrik Dahl (2011-06-24). "IAEA Head Sees Wide Support for Stricter Nuclear Plant Safety" (<http://archive.is/20110625042535/http://www.scientificamerican.com/article.cfm?id=iaea-head-sees-wide-support>) *Scientific American* Archived from the original (<http://www.scientificamerican.com/article.cfm?id=iaea-head-sees-wide-support>) on 2011-06-25.
84. Nuclear Renaissance Threatened as Japan's Reactor Struggles (<https://www.bloomberg.com/news/2011-0313/nuclear-renaissance-threatened-as-japan-fights-meltdown-at-quake-hit-plant.html>) Bloomberg, published March 2011, accessed 2011-03-14
85. Analysis: Nuclear renaissance could fizzle after Japan quake (<https://www.reuters.com/article/2011/03/14/us-japan-quake-nuclear-analysis-idUSTRE72C41W20110314>) Reuters, published 2011-03-14, accessed 2011-03-14
86. Japan nuclear woes cast shadow over U.S. energy policy (<https://www.reuters.com/article/2011/03/13/us-nuclear-usa-idUSTRE72C2UW20110313>) Reuters, published 2011-03-13, accessed 2011-03-14
87. Nuclear winter? Quake casts new shadow on reactors (<http://www.marketwatch.com/story/nuclear-winter-2011-03-14>) MarketWatch, published 2011-03-14, accessed 2011-03-14
88. Will China's nuclear nerves fuel a boom in green energy? (<http://www.channel4.com/news/will-chinas-nuclear-nerves-fuel-a-boom-in-green-energy>) Channel 4, published 2011-03-17, accessed 2011-03-17
89. Jo Chandler (2011-03-19). "Is this the end of the nuclear revival?" (<http://www.smh.com.au/world/is-this-the-end-of-the-nuclear-revival-20110318-1c0i9.html>) *The Sydney Morning Herald*
90. Aubrey Belford (2011-03-17). "Indonesia to Continue Plans for Nuclear Power" (<https://www.nytimes.com/2011/03/18/business/global/18atomic.html?partner=rss&emc=rss>) *The New York Times*.
91. Israel Prime Minister Netanyahu: Japan situation has "caused me to reconsider" nuclear power (<http://piersmorgan.blogs.cnn.com/2011/03/17/israel-prime-minister-netanyahu-japan-situation-has-caused-me-to-reconsider-nuclear-power/>) Piers Morgan on CNN, published 2011-03-17, accessed 2011-03-17
92. Israeli PM cancels plan to build nuclear plant (http://news.xinhuanet.com/english2010/world/2011-03/18/c_13784578.htm) xinhuanet.com, published 2011-03-18, accessed 2011-03-17
93. "Gauging the pressure" (http://www.economist.com/node/18621367?story_id=18621367) *The Economist*. 2011-04-28.
94. European Environment Agency (2013-01-23). "Late lessons from early warnings: science, precaution, innovation: Full Report" (<http://www.eea.europa.eu/publications/latelessons-2>). p. 476.
95. "Turkey Prepares to Host First ATMEA 1 Nuclear Reactors" (<http://www.powermag.com/turkey-prepares-to-host-first-atmea-1-nuclear-reactors/>) *PowerMag*. Electric Power. Retrieved 2015-05-24.
96. "Startup of Sendai Nuclear Power Unit No.1" (http://www.kyuden.co.jp/en_information_15011.html). *Kyushu Electric Power Company Inc* 2015-08-11.
97. WNA (2013-06-20). "Nuclear power down in 2012" (http://www.world-nuclear-news.org/NN_Nuclear_power_down_in_2012_2006131.html) *World Nuclear News*
98. "IAEA sees slow nuclear growth post Japan" (http://www.upi.com/Business_News/EnergyResources/2011/09/23/IAEA-sees-slow-nuclear-growth-post-Japan/UPI-87041316777856/) *UPI*. 2011-09-23.
99. "News Analysis: Japan crisis puts global nuclear expansion in doubt" (<http://www.platts.com/RSSFeedDetailedNews/RSSFeed/ElectricPower/6925550>) *Platts*. 2011-03-21.
100. <https://www.progress-energy.com/assets/www/docs/company/02172010-platts.pdf>
101. "Nuclear power: When the steam clears" (<http://www.economist.com/node/18441163>) *The Economist* 2011-03-24.
102. <https://www.theguardian.com/environment/2012/may/03/nuclear-power-solution-climate-change>
103. Paton J (2011-04-04). "Fukushima crisis worse for atomic power than Chernobyl, USB says" (<https://www.bloomberg.com/news/2011-04-04/fukushima-crisis-worse-for-nuclear-power-industry-than-chernobyl-ubs-says.html>) *Bloomberg.com*. Retrieved 2014-08-17.
104. "The 2011 Inflection Point for Energy Markets: Health, Safety, Security and the Environment" (https://institutional.deutscheawm.com/content/_media/Inflection_Point_Research_Note.pdf) PDF). *DB Climate Change Advisors Deutsche Bank Group*. 2011-05-02.
105. "Siemens to quit nuclear industry" (<http://www.bbc.co.uk/news/business-1496375>). *BBC News*. 2011-09-18.
106. John Broder (2011-10-10). "The Year of Peril and Promise in Energy Production" (<https://www.nytimes.com/2011/10/11/business/energy-environment/the-year-of-peril-and-promise-in-energy-production.html?src=un&feedurl=http%3A%2F%2Fjson8.nytimes.com%2Fpages%2Fbusiness%2Fglobal%2Findex.jsonp>) *The New York Times*.

107. Hsu, Jeremy (2012-02-09). "First Next-Gen US Reactor Designed to Avoid Fukushima Repeat" (<https://news.yahoo.com/first-next-gen-us-reactor-designed-avoid-fukushima-005203660.html>) Live Science (hosted on Yahoo!). Retrieved 2012-02-09.
108. Ayesha Rascoe (2012-02-09). "U.S. approves first new nuclear plant in a generation" (<https://www.reuters.com/article/2012/02/09/us-usa-nuclear-nrc-idUSTRE8182J720120209>) Reuters.
109. Kristi E. Swartz (2012-02-16). "Groups sue to stop Vogtle expansion project" (<http://www.ajc.com/business/groups-sue-to-stop-1351830.html>) *The Atlanta Journal-Constitution*
110. <http://chronicle.augusta.com/news/business/2012-07-12/court-rejects-legal-challenge-plant-vogtle-construction-license?v=1342114200>
111. Mark Cooper (2013-06-18). "Nuclear aging: Not so graceful" (<http://www.thebulletin.org/nuclear-aging-notso-graceful>) *Bulletin of the Atomic Scientists*
112. Matthew Wald (2013-06-14). "Nuclear Plants, Old and Uncompetitive, Are Closing Earlier Than Expected" (<https://www.nytimes.com/2013/06/15/business/energy-environment/aging-nuclear-plants-are-closing-but-for-economic-reasons.html?ref=matthewwald>) *The New York Times*.
113. World Nuclear Association "Plans for New Reactors Worldwide" (<http://www.world-nuclear.org/info/current-and-future-generation/plans-for-new-reactors-worldwide/>), October 2015.
114. Duroyan Fertil (2011-06-05). "Germany: Nuclear power to be phased out by 2022" (<http://www.greenleft.org.au/node/47834>). *Green Left*
115. <http://www.iea.org/newsroomandevents/news/2015/january/taking-a-fresh-look-at-the-future-of-nuclear-power.html>
116. "Ten New Nuclear Power Reactors Connected to Grid in 2015, Highest Number Since 1990" (<https://www.iaea.org/newscenter/news/ten-new-nuclear-power-reactors-connected-to-grid-in-2015-highest-number-since-1990>) Retrieved May 22, 2016.
117. "China Nuclear Power | Chinese Nuclear Energy – World Nuclear Association" (<http://www.world-nuclear.org/information-library/country-profiles/countries-a-f/china-nuclear-power.aspx>). *www.world-nuclear.org*.
118. "World doubles new build reactor capacity in 2015" (<http://www.world-nuclear-news.org/NP-World-starts-up-10-shuts-down-eight-nuclear-reactors-in-2015-411601.html>) London, UK: World Nuclear News. 4 January 2016. Retrieved 7 March 2016.
119. "Grid Connection for Fuqing-2 in China 7 August 2015" (<http://www.worldnuclearreport.org/Grid-Connection-for-Fuqing-2-in-China.html>) Worldnuclearreport.org Retrieved 2015-08-12
120. "World's First APR-1400 Connected to Grid" (<http://www.nei.org/News-Media/News/Milestones>). Washington DC, USA: NEI (Nuclear Energy Institute). 21 January 2016 Retrieved 7 March 2016.
121. South Korea's Shin-Wolsong-2 Enters Commercial Operation (<http://www.nucnet.org/all-the-news/2015/0724/south-korea-s-shin-wolsong-2-enters-commercial-operation>)
122. Blau, Max (2016-10-20). "First new US nuclear reactor in 20 years goes live" (<http://www.cnn.com/2016/10/20/us/tennessee-nuclear-power-plant/index.html>) CNN.com. Cable News Network. Turner Broadcasting System, Inc. Retrieved 2016-10-20.
123. "Bruce Power's Unit 2 sends electricity to Ontario grid for first time in 17 years" (<https://archive.is/20130102114510/http://www.brucepower.com/6926/news/bruce-power%E2%80%99s-unit-2-sends-electricity-to-ontario-grid-for-first-time-in-17-years/>). Bruce Power. 2012-10-16. Archived from the original (<http://www.brucepower.com/6926/news/bruce-power%E2%80%99s-unit-2-sends-electricity-to-ontario-grid-for-first-time-in-17-years/>) on 2013-01-02 Retrieved 2014-01-24.
124. <http://world-nuclear.org/information-library/current-and-future-generation/nuclear-power-in-the-world-today.aspx>
125. James Conca, "China shows how to build nuclear reactors fast and cheap" (<https://www.forbes.com/sites/jamesconca/2015/10/22/china-shows-how-to-build-nuclear-reactors-fast-and-cheap/#75c618694d0b>) Forbes, 22 Oct. 2015.
126. "Nuclear power plant builders see new opportunities in India" (<http://asia.nikkei.com/magazine/20160616-POWER-PERFORMERS-of-the-Asia300/Business/Nuclear-power-plant-builders-see-new-opportunities-in-India>) Nikkei, 16 June 2016.
127. "The problem with Britain's (planned) nuclear power station" (<https://www.economist.com/blogs/economist-explains/2016/08/economist-explains-5>) *The Economist*, 7 Aug. 2016.
128. "Japan reactor restarts in post-Fukushima nuclear push" (<http://www.abc.net.au/news/2016-08-12/japan-reactor-restarts-in-post-fukushima-nuclear-push/7729892>) ABC News, 12 Aug. 2016.

129. Kidd, Steve (30 January 2018). "Nuclear new build - where does it stand today?" (<http://www.neimagazine.com/opinion/opinionnuclear-new-build-where-does-it-stand-today-6041240/>) Nuclear Engineering International Retrieved 12 February 2018.
130. "Korea's nuclear phase-out policy takes shape" (<http://www.world-nuclear-news.org/NP-Korea-s-nuclear-phase-out-policy-takes-shape-1906174.html>) World Nuclear News. 19 June 2017 Retrieved 12 February 2018.
131. Taking a fresh look at the future of nuclear power (<http://www.iea.org/newsroomandevents/news/2015/january/taking-a-fresh-look-at-the-future-of-nuclear-power.html>), International Energy Agency 29 Jan. 2015.
132. International Energy outlook 2016 (<http://www.eia.gov/forecasts/aeo/data/browser/#/?id=31-IEO2016&sourcekey=0>) US Energy Information Administration, accessed 17 Aug. 2016.
133. James Kanter (2009-05-28). "In Finland, Nuclear Renaissance Runs Into Trouble" (<https://www.nytimes.com/2009/05/29/business/energy-environment/29nuke.html?ref=global-home>) *The New York Times*.
134. James Kanter (2009-05-29). "Is the Nuclear Renaissance Fizzling?" (<http://greeninc.blogs.nytimes.com/2009/05/29/is-the-nuclear-renaissance-fizzling/>) *Green*.
135. Rob Broomby (2009-07-08). "Nuclear dawn delayed in Finland" (<http://news.bbc.co.uk/2/hi/europe/8138869.stm>) *BBC News*.
136. Jeff McMahon (2013-11-10). "New-Build Nuclear Is Dead: Morningstar" (<https://www.forbes.com/sites/jefmcmahon/2013/11/10/new-build-nuclear-is-dead-morningstar/>) *Forbes*.
137. John Quiggin (2013-11-08). "Reviving nuclear power debates is a distraction. We need to use less energy" (<https://www.theguardian.com/commentisfree/2013/nov/08/reviving-nuclear-power-debates-is-a-distraction-we-need-to-use-less-energy>) *The Guardian*.
138. Hannah Northey (2011-03-18). "Former NRC Member Says Renaissance is Dead, for Now" (<https://www.nytimes.com/gwire/2011/03/18/18greenwire-former-nrc-member-says-renaissance-is-dead-for-n-961.html>) *The New York Times*.
139. Ian Lowe (2011-03-20). "No nukes now, or ever" (<http://www.theage.com.au/opinion/politics/no-nukes-now-or-ever-20110319-1c1ed.html>) *The Age*. Melbourne.
140. Leo Hickman (2012-11-28). "Nuclear lobbyists wined and dined senior civil servants, documents show" (<https://www.theguardian.com/environment/2012/nov/28/nuclear-lobbyists-senior-civil-servants>) *The Guardian*. London.
141. Diane Farseta (2008-09-01). "The Campaign to Sell Nuclear" (<http://thebulletin.org/2008/sepember/campaign-sell-nuclear>). *Bulletin of the Atomic Scientists* 64 (4): 38–56. doi:10.2968/064004009 (<https://doi.org/10.2968/064004009>)
142. Jonathan Leake (2005-05-23). "The Nuclear Charm Offensive" (<http://www.newstatesman.com/node/150675>). *New Statesman*.
143. "Nuclear Industry Spent Hundreds of Millions of Dollars Over the Last Decade to Sell Public, Congress on New Reactors, New Investigation Finds" (https://web.archive.org/web/20131127112542/http://www.ucsusa.org/news/media_alerts/nuclear-industry-spent-millions-to-sell-congress-on-new-reactors-0343.html) *Union of Concerned Scientists*. 2010-02-01. Archived from the original (http://www.ucsusa.org/news/media_alerts/nuclear-industry-spent-millions-to-sell-congress-on-new-reactors-0343.html) on 2013-11-27.
144. "Nuclear group spent \$460,000 lobbying in 4Q" (<http://www.businessweek.com/ap/financialnews/D9EHS0580.htm>) *Business Week*. 2010-03-19.
145. "Nuclear Power in China" (<http://www.world-nuclear.org/information-library/country-profiles/countries-a-f/china-nuclear-power.aspx>). London, UK: World Nuclear Association. March 2016. Retrieved 7 March 2016.
146. "Nuclear Power in China" (<http://www.world-nuclear.org/info/inf63.html>) *World Nuclear Association* 2010-12-10.
147. "China is Building the World's Largest Nuclear Capacity" (<https://web.archive.org/web/20120306125100/http://en.21cbh.com/HTML/2010-9-21/yMMDAwMDE5ODcyMA.html>). *21cbh.com*. 2010-09-21. Archived from the original (<http://en.21cbh.com/HTML/2010-9-21/yMMDAwMDE5ODcyMA.html>) on 2012-03-06.
148. "China Should Control Pace of Reactor Construction, Outlook Says" (<https://www.bloomberg.com/news/2011-0111/china-should-control-pace-of-reactor-construction-outlook-says.html>) *Bloomberg News* 2011-01-11.
149. "Nuclear Power in the USA" (<http://www.world-nuclear.org/info/inf41.html#licence>) *World Nuclear Association* June 2008. Retrieved 2008-07-25.
150. Matthew L. Wald (2010-12-07). "Nuclear 'Renaissance' Is Short on Largess" (<http://green.blogs.nytimes.com/2010/12/07/nuclear-renaissance-is-short-on-largess/>) *The New York Times*.
151. "NRC/DOE Life After 60 Workshop Report" (<http://www.energetics.com/nrcdoefeb08/pdfs/Life%20After%2060%20Workshop%20Report.pdf>) (PDF). 2008. Retrieved 2009-04-01.

152. Sherrell R. Greene, "Centurion Reactors – Achieving Commercial Power Reactors With 100+yr Operating Lifetimes", Oak Ridge National Laboratory published in transactions of Winter 2009 American Nuclear Society National Meeting, November 2009, Washington, D.C.
153. New nuclear build – sufficient supply capability? (<http://www.neimagazine.com/story.asp?sectioncode=147&storyCode=2052302>) Archived (<https://web.archive.org/web/20110613104418/http://www.neimagazine.com/story.asp?sectioncode=147&storyCode=2052302>) 2011-06-13 at the [Wayback Machine](http://www.archive.org) Steve Kid, Nuclear Engineering International, 3/3/2009
154. Bloomberg exclusive: Samurai-Sword Maker's Reactor Monopoly May Cool Nuclear Revival (<https://www.bloomberg.com/apps/news?pid=20601109&sid=aaVMzCTMz3ms&s=polyhood>) By Yoshifumi Takemoto and Alan Katz, bloomberg.com, 3/13/08.
155. Plans For New Reactors Worldwide (<http://world-nuclear.org/info/inf17.html>), World Nuclear Association
156. "Nuclear Energy's Role in Responding to the Energy Challenges of the 21st Century" (http://nuclear.inl.gov/docs/papers-presentations/ga_tech_woodruff_3-4.pdf) (PDF). *Idaho National Engineering and Environmental Laboratory* Retrieved 2008-06-21.
157. "Westinghouse files for bankruptcy" (<http://www.neimagazine.com/news/news/westinghouse-files-for-bankruptcy-5773901>). Nuclear Engineering International. 29 March 2017 Retrieved 4 April 2017.
158. Bershidsky, Leonid (30 March 2017). "U.S. Nuclear Setback Is a Boon to Russia, China" (<https://www.bloomberg.com/view/articles/2017-03-30/u-s-nuclear-setback-is-a-boon-to-russia-china>) Bloomberg. Retrieved 21 April 2017.
159. "Reactor suppliers face governance challenge" (<http://www.world-nuclear-news.org/NP-Reactor-suppliers-face-governance-challenge-20041701.html>) World Nuclear News. 20 April 2017 Retrieved 21 April 2017.
160. "Key World Energy Statistics 2012" (<https://www.iea.org/publications/freepublications/publication/kwes.pdf>) (PDF). International Energy Agency 2012. Retrieved 2012-12-16.
161. Nicola Armaroli, Vincenzo Balzani, *Towards an electricity-powered world* In: *Energy and Environmental Science* 4, (2011), 3193–3222, p. 3200, doi:10.1039/c1ee01249e (<https://doi.org/10.1039/c1ee01249e>)
162. REN 21. RENEWABLES 2014 GLOBAL STATUS REPORT (http://www.ren21.net/Portals/0/documents/Resources/GSR/2014/GSR2014_KeyFindings_low%20res.pdf)
163. "PRIS – Home" (<http://www.iaea.org/pris/>). *iaea.org*. Retrieved 2013-06-14.
164. "World Nuclear Power Reactors 2007–08 and Uranium Requirements" (<https://web.archive.org/web/20080303234143/http://www.uic.com.au/reactors.htm>) World Nuclear Association. 2008-06-09. Archived from the original (<http://www.uic.com.au/reactors.htm>) on 2008-03-03 Retrieved 2008-06-21.
165. "Japan approves two reactor restarts" (<http://www.taipeitimes.com/News/front/archives/2012/06/17/2003535527>) Taipei Times. 2013-06-07. Retrieved 2013-06-14.
166. "What is Nuclear Power Plant – How Nuclear Power Plants work | What is Nuclear Power Reactor - types of Nuclear Power Reactors" (<http://www.engineersgarage.com/articles/nuclear-power-plants?page=2>) EngineersGarage Retrieved 2013-06-14.
167. "Nuclear-Powered Ships | Nuclear Submarines" (<http://www.world-nuclear.org/info/Non-Power-Nuclear-Applications/Transport/Nuclear-Powered-Ships/#.UV5yQspyJM>). World-nuclear.org. Retrieved 2013-06-14.
168. "Archived copy" (<https://web.archive.org/web/20150226055625/http://www.ewp.rpi.edu/hartford/~ernesto/F2010/EP2/Materials4Students/Misiaszek/NuclearMarinePropulsion.pdf>) (PDF). Archived from the original (<http://www.ewp.rpi.edu/hartford/~ernesto/F2010/EP2/Materials4Students/Misiaszek/NuclearMarinePropulsion.pdf>) (PDF) on 2015-02-26. Retrieved 2015-06-04. Naval Nuclear Propulsion, Magdi Ragheb As of 2001, about 235 naval reactors had been built
169. "Summary status for the US" (<http://www.eia.doe.gov/cneaf/electricity/epa/depates.html>). Energy Information Administration. 2010-01-21 Retrieved 2010-02-18.
170. Eleanor Beardsley (2006-05-01). "France Presses Ahead with Nuclear Power" (<https://www.npr.org/templates/story/story.php?storyId=5369610>) NPR. Retrieved 2006-11-08.
171. "Gross electricity generation, by fuel used in power-stations" (https://web.archive.org/web/20061017154500/http://ep.eurostat.ec.europa.eu/portal/page?_pageid=1996%2C39140985&_dad=portal&_schema=PORTAL&screen=detailref&language=en&product=sdi_cc&root=sdi_cc%2Fsdi_cc%2Fsdi_cc_ene%2Fsdi_cc2300) Eurostat 2006. Archived from the original (http://ep.eurostat.ec.europa.eu/portal/page?_pageid=1996,39140985&_dad=portal&_schema=PORTAL&screen=detailref&language=en&product=sdi_cc&root=sdi_cc/sdi_cc/sdi_cc_ene/sdi_cc2300) on 2006-10-17. Retrieved 2007-02-03.

172. Issues in Science & Technology Online; "Promoting Low-Carbon Electricity Production"(<http://www.issues.org/23.3/apt.html>) Archived (<https://web.archive.org/web/20130927013232/http://www.issues.org/23.3/apt.html>)2013-09-27 at the Wayback Machine
173. The European Strategic Energy Technology Plan SET-Plan Towards a low-carbon future 2010. Nuclear power provides "2/3 of the EU's low carbon energy" pg 6(http://ec.europa.eu/energy/publications/doc/2010_setplan_brochure.pdf) Archived (https://web.archive.org/web/20140211100220/http://ec.europa.eu/energy/publications/doc/2010_setplan_brochure.pdf)2014-02-11 at the Wayback Machine
174. "Nuclear Icebreaker Lenin"(https://web.archive.org/web/20071015031630/http://www.bellona.org/english_import_area/international/russia/civilian_nuclear_vessels/icebreakers/30131)Bellona. 2003-06-20. Archived from the original (http://www.bellona.org/english_import_area/international/russia/civilian_nuclear_vessels/icebreakers/30131) on October 15, 2007. Retrieved 2007-11-01.
175. Potential for Worldwide Displacement of Fossil-Fuel Electricity by Nuclear Energy in Three Decades Based on Extrapolation of Regional Deployment Data. Barry W Brook et al. <https://dx.doi.org/10.1371/journal.pone.0124074> (<http://journals.plos.org/plosone/article?id=10.1371/journal.pone.0124074>)
176. Brook Barry W (2012). "Could nuclear fission energy etc., solve the greenhouse problem? The affirmative case" (<http://www.sciencedirect.com/science/article/pii/S0301421511009189>) *Energy Policy*. **42**: 4–8. doi:10.1016/j.enpol.2011.11.041(<https://doi.org/10.1016%2Fj.enpol.2011.11.041>)
177. Loftus; et al. (2014). "A critical review of global decarbonization scenarios: what do they tell us about feasibility?,". *WIREs Clim Change* **6**: 93–112. doi:10.1002/wcc.324 (<https://doi.org/10.1002%2Fwcc.324>)
178. A critical review of global decarbonization scenarios: what do they tell us about feasibility? Open access PDF Figure 6 (<http://www.qualenergia.it/sites/default/files/articolo-doc/wcc324-1.pdf>)
179. A critical review of global decarbonization scenarios: what do they tell us about feasibility? Open access PDF (<http://www.qualenergia.it/sites/default/files/articolodoc/wcc324-1.pdf>)
180. Loan Program for Reactors Is Fizzling(https://www.nytimes.com/2014/02/19/business/energy-environment/loan-program-for-reactors-is-fizzling.html?_r=3)
181. Load-following with nuclear power plants by A. Lokhov(<https://www.oecd-neo.org/nea-news/2011/2-2/nea-news-29-2-load-following-e.pdf>)
182. Gore, Al (2009). *Our Choice: A Plan to Solve the Climate Crisis* Emmaus, PA: Rodale. ISBN 978-1-59486-734-7.
183. "What does nuclear power actually cost #peakoil"(<http://northdenvernews.com/what-does-nuclear-power-actually-cost-peakoil/>). *North Denver News* 19 May 2015.
184. Kidd, Steve (2011-01-21). "New reactors—more or less?"(<https://web.archive.org/web/20111212195417/http://www.neimagazine.com/story.asp?sectioncode=147&storyCode=2058653>) *Nuclear Engineering International* Archived from the original (<http://www.neimagazine.com/story.asp?sectioncode=147&storyCode=2058653>) on 2011-12-12.
185. Henry Fountain (2014-12-22). "Nuclear: Carbon Free, but Not Free of Unease"(<https://www.nytimes.com/2014/12/23/science/nuclear-carbon-free-but-not-free-of-unease-.html>) *The New York Times*. Retrieved 2014-12-23. "the plant had become unprofitable in recent years, a victim largely of lower energy prices resulting from a glut of natural gas used to fire electricity plants"
186. Ed Crooks (2010-09-12). "Nuclear: New dawn now seems limited to the east"(<http://www.ft.com/cms/s/0/ad15fcfe-bc71-11df-a42b-00144feab49a.html>) *Financial Times*. Retrieved 2010-09-12
187. United States Nuclear Regulatory Commission, 1983. The Price-Anderson Act: the Third Decade, NUREG-0957
188. *The Future of Nuclear Power*(<http://web.mit.edu/nuclearpower/>) Massachusetts Institute of Technology. 2003. ISBN 0-615-12420-8 Retrieved 2006-11-10.
189. Massachusetts Institute of Technology (2011). "The Future of the Nuclear Fuel Cycle"(http://web.mit.edu/mitei/research/studies/documents/nuclear-fuel-cycle/The_Nuclear_Fuel_Cycle-all.pdf) (PDF). p. xv.
190. "uranium Facts, information, pictures | Encyclopedia.com articles about uranium"(<http://www.encyclopedia.com/topic/uranium.aspx>) Encyclopedia.com. 2001-09-11 Retrieved 2013-06-14.
191. "Second Thoughts About Nuclear Power"(https://web.archive.org/web/20130116084833/http://spp.nus.edu.sg/docs/policy-briefs/201101_RSU_PolicyBrief_1-2nd_Thought_Nuclear-Sovacool.pdf) (PDF). *A Policy Brief – Challenges Facing Asia*. January 2011. Archived from the original (http://www.spp.nus.edu.sg/docs/policy-briefs/201101_RSU_PolicyBrief_1-2nd_Thought_Nuclear-Sovacool.pdf) (PDF) on January 16, 2013.

192. "Uranium resources sufficient to meet projected nuclear energy requirements long into the future"(https://web.archive.org/web/20081205121250/http://www.nea.fr/html/general/press/2008/2008-02.html) Nuclear Energy Agency (NEA). 2008-06-03. Archived from the original (http://www.nea.fr/html/general/press/2008/2008-02.html) on 2008-12-05. Retrieved 2008-06-16.
193. *Uranium 2007 – Resources, Production and Demand*(https://web.archive.org/web/20090130092151/http://www.oecdbookshop.org/oecd/display.asp?sf1=identifiers&st1=9789264047662) Nuclear Energy Agency, Organisation for Economic Co-operation and Development 2008-06-10. ISBN 978-92-64-04766-2 Archived from the original (http://www.oecdbookshop.org/oecd/display.asp?sf1=identifiers&st1=9789264047662) on 2009-01-30.
194. "Uranium 2011 – OECD Online Bookshop"(http://www.oecdbookshop.org/oecd/display.asp?lang=EN&sf1=identifiers&st1=978-92-64-17803-8) Oecdbookshop.org Retrieved 2013-06-14.
195. "Global Uranium Supply Ensured For Long Term, New Report Shows"(http://www.oecd-neo.org/press/2012/2012-05.html). Oecd-neo.org. 2012-07-26 Retrieved 2013-06-14.
196. "Energy Supply" (https://web.archive.org/web/20071215202932/http://www.ipcc.ch/pdf/assessment-report/ar4/wg3/ar4-wg3-chapter4.pdf)(PDF). p. 271. Archived from the original (https://www.ipcc.ch/pdf/assessment-report/ar4/wg3/ar4-wg3-chapter4.pdf)(PDF) on 2007-12-15. and table 4.10.
197. Deffeyes KS, MacGregor ID (1980). "World uranium resources". *Scientific American* **242** (1): 66–76. Bibcode:1980SciAm.242a..66D (http://adsabs.harvard.edu/abs/1980SciAm.242a..66D) doi:10.1038/scientificamerican0180-66 (https://doi.org/10.1038/scientificamerican0180-66)
198. "Energy Supply" (https://web.archive.org/web/20071215202932/http://www.ipcc.ch/pdf/assessment-report/ar4/wg3/ar4-wg3-chapter4.pdf)(PDF). p. 271. Archived from the original (https://www.ipcc.ch/pdf/assessment-report/ar4/wg3/ar4-wg3-chapter4.pdf)(PDF) on 2007-12-15. and figure 4.10.
199. "Waste Management in the Nuclear Fuel Cycle" (http://www.world-nuclear.org/info/inf04.html) *Information and Issue Briefs*. World Nuclear Association. 2006 Retrieved 2006-11-09.
200. John McCarthy (2006). "Facts From Cohen and Others"(https://web.archive.org/web/20070410165316/http://www-formal.stanford.edu/jmc/progress/cohen.html) *Progress and its Sustainability* Stanford. Archived from the original (http://www-formal.stanford.edu/jmc/progress/cohen.html) on 2007-04-10. Retrieved 2006-11-09. Citing Breeder reactors: A renewable energy source *American Journal of Physics* vol. 51, (1), Jan. 1983.
201. "Advanced Nuclear Power Reactors"(http://www.world-nuclear.org/info/inf08.html) *Information and Issue Briefs* World Nuclear Association. 2006 Retrieved 2006-11-09.
202. "Synergy between Fast Reactors and Thermal Breeders for Safe, Clean, and Sustainable Nuclear Power"(https://web.archive.org/web/20110110121245/http://worldenergy.org/documents/p001515.pdf)(PDF). *World Energy Council* Archived from the original (http://www.worldenergy.org/documents/p001515.pdf)(PDF) on 2011-01-10.
203. Rebecca Kessler. "Are Fast-Breeder Reactors A Nuclear Power Panacea? by Fred Pearce: *The Environment* 360" (http://e360.yale.edu/feature/are_fast-breeder_reactors_a_nuclear_power_panacea/2557/) *E360.yale.edu* Retrieved 2013-06-14.
204. "Large fast reactor approved for Beloyarsk"(http://www.world-nuclear-news.org/NN-Large_fast_reactor_approved_for_Beloyarsk-2706124.html) World-nuclear-news.org. 2012-06-27 Retrieved 2013-06-14.
205. "Atomic agency plans to restart Monju prototype fast breeder reactor – AJW by The Asahi Shimbun"(https://web.archive.org/web/20130614042451/http://ajwasahi.com/article/0311disaster/fukushima/AJ201211090056) Ajw.asahi.com. Archived from the original (http://ajw.asahi.com/article/0311disaster/fukushima/AJ201211090056) on 2013-06-14. Retrieved 2013-06-14.
206. "India's breeder reactor to be commissioned in 2013"(https://web.archive.org/web/20130426141852/http://www.hindustantimes.com/India-news/NewDelhi/India-s-breeder-reactor-to-be-commissioned-in-2013/Article1-814183.aspx) Hindustan Times. Archived from the original (http://www.hindustantimes.com/India-news/NewDelhi/India-s-breeder-reactor-to-be-commissioned-in-2013/Article1-814183.aspx) on 2013-04-26. Retrieved 2013-06-14.
207. "China makes nuclear power development – Xinhua | English.news.cn"(http://news.xinhuanet.com/english/business/2012-10/31/c_131942867.htm) News.xinhuanet.com Retrieved 2013-06-14.
208. "Thorium" (http://www.world-nuclear.org/info/inf62.html) *Information and Issue Briefs* World Nuclear Association. 2006. Retrieved 2006-11-09.
209. M. I. Ojovan, W.E. Lee. *An Introduction to Nuclear Waste Immobilisation*, Elsevier Science Publishers B.V, Amsterdam, 315pp. (2005).
210. "NRC: Dry Cask Storage"(https://www.nrc.gov/waste/spent-fuel-storage/dry-cask-storage.html) Nrc.gov. 2013-03-26. Retrieved 2013-06-22.

211. "Yankee Nuclear Power Plant"(<http://www.yankeerowe.com/>) Yankeerowe.com Retrieved 2013-06-22
212. "Environmental Surveillance, Education and Research Program"(<https://web.archive.org/web/20081121041307/http://www.stoller-eser.com/Quarterlies/iodine.htm>) Idaho National Laboratory Archived from the original (<http://www.stoller-eser.com/Quarterlies/iodine.htm>) on 2008-11-21 Retrieved 2009-01-05.
213. Vandenbosch 2007, p. 21.
214. Ojovan, M. I.; Lee, WE. (2005). *An Introduction to Nuclear Waste Immobilisation*. Amsterdam: Elsevier Science Publishers. p. 315. ISBN 0-08-044462-8
215. Brown, Paul (2004-04-14). "Shoot it at the sun. Send it to Earth's core. What to do with nuclear waste?"(<https://www.theguardian.com/uk/2004/apr/14/nucleargreenpolitics>). *The Guardian*. London.
216. National Research Council (1995). *Technical Bases for Yucca Mountain Standards*(<https://books.google.com/?id=1DLyAtgVPy0C&pg=PA91>). Washington, D.C.: National Academy Press. p. 91. ISBN 0-309-05289-0.
217. "The Status of Nuclear Waste Disposal" (<http://www.aps.org/units/fps/newsletters/2006/january/article1.html>) The American Physical Society January 2006 Retrieved 2008-06-06.
218. "Public Health and Environmental Radiation Protection Standards for Yucca Mountain, Nevada; Proposed Rule"(<http://www.epa.gov/radiation/docs/yucca/70fr4013.pdf>) (PDF). United States Environmental Protection Agency 2005-08-22. Retrieved 2008-06-06.
219. Duncan Clark (2012-07-09). "Nuclear waste-burning reactor moves a step closer to reality | Environment | [theguardian.co.uk](https://www.theguardian.com/environment/2012/jul/09/nuclear-waste-burning-reactor)" (<https://www.theguardian.com/environment/2012/jul/09/nuclear-waste-burning-reactor>) London: Guardian. Retrieved 2013-06-14.
220. "George Monbiot – A Waste of Waste" (<http://www.monbiot.com/2011/12/05/a-waste-of-waste/>). Monbiot.com Retrieved 2013-06-14.
221. "Energy From Thorium: A Nuclear Waste Burning Liquid Salt Thorium Reactor"(<https://www.youtube.com/watch?v=AZR0UKxNPh8>) YouTube. 2009-07-23 Retrieved 2013-06-14.
222. NWT magazine, October 2012
223. Sevier M. (2006). "Considerations for nuclear power in Australia"(<http://www.informaworld.com/smpp/content+db=all~content=a767886528>)(PDF). *International Journal of Environmental Studies* 63 (6): 859–872. doi:10.1080/00207230601047255(<https://doi.org/10.1080%2F00207230601047255>)
224. Thorium Resources In Rare Earth Elements(<https://wayback.archive-it.org/all/20121218195159/https://netfiles.uiuc.edu/mragheb/www/NPRE%20402%20ME%20405%20Nuclear%20Power%20Engineering/Thorium%20Resources%20in%20%20Rare%20Earth%20Elements.pdf>)
225. American Geophysical Union, Fall Meeting 2007, abstract #V33A-1161 *Mass and Composition of the Continental Crust* (<http://adsabs.harvard.edu/abs/2007AGUFM.V33A1161P>)
226. Interdisciplinary Science Reviews 23:193–203;1998. Dr Bernard L. Cohen, University of Pittsburgh *Perspectives on the High Level Waste Disposal Problem*(http://www.phyast.pitt.edu/~blc/Perspectives_on_HLW.htm)
227. "The Challenges of Nuclear Power"(<http://nuclearinfo.net/Nuclearpower/TheRisksOfNuclearPower>)
228. "Coal Ash Is More Radioactive than Nuclear Waste" (<http://www.scientificamerican.com/article.cfm?id=coal-ash-is-more-radioactive-than-nuclear-waste>) *Scientific American* 2007-12-13.
229. Alex Gabbard (2008-02-05). "Coal Combustion: Nuclear Resource or Danger"(<https://web.archive.org/web/20070205103749/http://www.ornl.gov/info/ornlreview/rev26-34/text/colmain.html>) Oak Ridge National Laboratory Archived from the original (<http://www.ornl.gov/info/ornlreview/rev26-34/text/colmain.html>) on February 5, 2007. Retrieved 2008-01-31.
230. "Coal ash is *not* more radioactive than nuclear waste"(<https://web.archive.org/web/20090827045039/http://www.cejournal.net/?p=410>) *CE Journal*. Center for Environmental Journalism. 2008-12-31. Archived from the original (<http://www.cejournal.net/?p=410>) on 2009-08-27.
231. Montgomery, Scott L. (2010). *The Powers That Be* University of Chicago Press, p. 137.
232. Gore, Al (2009). *Our Choice: A Plan to Solve the Climate Crisis* Emmaus, PA: Rodale. pp. 165–166. ISBN 978-1-59486-734-7.
233. "international Journal of Environmental Studies, The Solutions for Nuclear waste, December 2005"(<http://www.efn.org.au/NucWaste-Comby.pdf>) (PDF). Retrieved 2013-06-22

234. "Oklo: Natural Nuclear Reactors"(<https://web.archive.org/web/20090825013752/http://www.ocrwm.doe.gov/factsheets/doeymp0010.shtml>) U.S. Department of Energy Office of Civilian Radioactive Waste Management, Yucca Mountain Project, DOE/YMP-0010. November 2004. Archived from the original (<http://www.ocrwm.doe.gov/factsheets/doeymp0010.shtml>) on 2009-08-25. Retrieved 2009-09-15.
235. "A Nuclear Power Renaissance?"(<http://www.sciam.com/article.cfm?id=a-nuclear-renaissance&print=true>) *Scientific American*. 2008-04-28. Retrieved 2008-05-15.
236. von Hippel, Frank N. (April 2008). "Nuclear Fuel Recycling: More Trouble Than It's Worth" (<http://www.sciam.com/article.cfm?id=rethinking-nuclear-fuel-recycling>) *Scientific American*. Retrieved 2008-05-15.
237. Is the Nuclear Renaissance Fizzling? (<http://greeninc.blogs.nytimes.com/2009/05/29/is-the-nuclear-renaissance-fizzling/>)
238. Jeff Tollefson (4 March 2014). "US seeks waste-research revival: Radioactive leak brings nuclear repositories into the spotlight" (<http://www.nature.com/news/us-seeks-waste-research-revival-1.14804>) *Nature*.
239. R. Stephen Berry and George S. Tolley, *Nuclear Fuel Reprocessing* (<http://franke.uchicago.edu/energy2013/group6.pdf>), The University of Chicago, 2013.
240. *IEEE Spectrum: Nuclear Wasteland* (<http://www.spectrum.ieee.org/feb07/4891>) Retrieved on 2007-04-22
241. Harold Feiveson; et al. (2011). "Managing nuclear spent fuel: Policy lessons from a 10-country study" (<http://www.thebulletin.org/web-edition/features/managing-nuclear-spent-fuel-policy-lessons-10-country-study>) *Bulletin of the Atomic Scientists*
242. "Adieu to nuclear recycling". *Nature*. **460** (7252): 152. 2009. Bibcode:2009Natur.460R.152. (<http://adsabs.harvard.edu/abs/2009Natur.460R.152>). doi:10.1038/460152b (<https://doi.org/10.1038%2F460152b>) PMID 19587715 (<https://www.ncbi.nlm.nih.gov/pubmed/19587715>)
243. "Nuclear Fuel Reprocessing: U.S. Policy Development" (<https://fas.org/sgp/crs/nuke/RS22542.pdf>) (PDF). Retrieved 2009-07-25.
244. "Adieu to nuclear recycling" (<http://www.nature.com/nature/journal/v460/i7252/full/460152b.html>) *Nature*. **460** (7252): 152. 2009. Bibcode:2009Natur.460R.152. (<http://adsabs.harvard.edu/abs/2009Natur.460R.152>). doi:10.1038/460152b (<https://doi.org/10.1038%2F460152b>) PMID 19587715 (<https://www.ncbi.nlm.nih.gov/pubmed/19587715>).
245. Processing of Used Nuclear Fuel for Recycling (<http://www.world-nuclear.org/info/inf69.html>) WNA
246. Blue Ribbon Commission on America's Nuclear Future "Disposal Subcommittee Report to the Full Commission" (http://www.brc.gov/sites/default/files/documents/disposal_report_updated_final.pdf) (PDF). Retrieved 1 January 2016.
247. Hambling, David (2003-07-30). "'Safe' alternative to depleted uranium revealed" (<https://www.newscientist.com/article/dn4004-safe-alternative-to-depleted-uranium-revealed.html>) *New Scientist*. Retrieved 2008-07-16.
248. Stevens, J. B.; R. C. Batra. "Adiabatic Shear Banding in Axisymmetric Impact and Penetration Problems" (<https://web.archive.org/web/20081007233308/http://www.sv.vt.edu/research/batra-stevens/pent.html>) Virginia Polytechnic Institute and State University Archived from the original (<http://www.sv.vt.edu/research/batra-stevens/pent.html>) on 2008-10-07. Retrieved 2008-07-16.
249. Tomoko Yamazaki & Shunichi Ozasa (2011-06-27). "Fukushima Retiree Leads Anti-Nuclear Shareholders at Aepco Annual Meeting" (<https://www.bloomberg.com/news/2011-0626/fukushima-retiree-to-lead-anti-nuclear-motion.html>) *Bloomberg*.
250. Mari Saito (2011-05-07). "Japan anti-nuclear protesters rally after PM call to close plant" (<https://www.reuters.com/article/2011/05/07/us-japan-nuclear-idUSTRE74610J20110507>) *Reuters*.
251. Benjamin K. Sovacool (August 2010). "A Critical Evaluation of Nuclear Power and Renewable Electricity in Asia" (<http://www.informaworld.com/smpp/content~content=a923050767~db=all~jumptype=rss>) *Journal of Contemporary Asia*. **40** (3): 393–400. doi:10.1080/00472331003798350 (<https://doi.org/10.1080%2F00472331003798350>)
252. Benjamin K. Sovacool (2009). The Accidental Century - Prominent Energy Accidents in the Last 100 Years (<http://www.touchoilandgas.com/ebooks/A1ioj0/eandpv07iss2/resources/134.htm>) Archived (<https://web.archive.org/web/20120821162134/http://www.touchoilandgas.com/ebooks/A1ioj0/eandpv07iss2/resources/134.htm>) August 21, 2012, at the Wayback Machine
253. David Baurac (2002). "Passively safe reactors rely on nature to keep them cool" (<http://www.ne.anl.gov/About/hn/logs-winter02-psr.shtml>). *Logos*. Argonne National Laboratory **20** (1). Retrieved 2012-07-25.
254. <https://www.forbes.com/sites/jamesconca/2012/06/10/energys-deathprint-a-price-always-paid/> with and without Chernobyl's total predicted, by the Linear no-threshold cancer deaths included.

255. "Nuclear Power Prevents More Deaths Than It Causes | Chemical & Engineering News"<http://cen.acs.org/articles/91/web/2013/04/Nuclear-Power-Prevents-Deaths-Causes.html>)Cen.acs.org. Retrieved 2014-01-24.
256. Kharecha, P. A.; Hansen, J. E. (2013). "Prevented Mortality and Greenhouse Gas Emissions from Historical and Projected Nuclear Power".*Environmental Science & Technology*. **47** (9): 4889. Bibcode:2013EnST...47.4889K (<http://adsabs.harvard.edu/abs/2013EnST...47.4889K>). doi:10.1021/es3051197 (<https://doi.org/10.1021/es3051197>)
257. Sovacool, B. K. (2008). "The costs of failure: A preliminary assessment of major energy accidents, 1907–2007".*Energy Policy*. **36** (5): 1802–1820. doi:10.1016/j.enpol.2008.01.040 (<https://doi.org/10.1016/j.enpol.2008.01.040>)
258. Dennis Normile (2012-07-27). "Is Nuclear Power Good for You?" (<https://www.webcitation.org/6EPZQYUB0?url=http://news.sciencemag.org/scienceinsider/2012/07/is-nuclear-power-good-for-you.html>)*Science*. **337** (6093): 395. doi:10.1126/science.337.6093.395-b(<https://doi.org/10.1126/science.337.6093.395-b>)Archived from the original (<http://news.sciencemag.org/scienceinsider/2012/07/is-nuclear-power-good-for-you.html>) on 2013-02-13.
259. Richard Schiffman (2013-03-12). "Two years on, America hasn't learned lessons of Fukushima nuclear disaster"(<https://www.theguardian.com/commentisfree/2013/mar/12/fukushima-nuclear-accident-lessons-for-us>)*The Guardian*. London.
260. Martin Fackler (2011-06-01). "Report Finds Japan Underestimated Tsunami Danger" (https://www.nytimes.com/2011/06/02/world/asia/02japan.html?_r=1&ref=world)*The New York Times*.
261. Andrew C. Revkin (2012-03-10). "Nuclear Risk and Fear from Hiroshima to Fukushima" (<http://dotearth.blogs.nytimes.com/2012/03/10/nuclear-risk-and-fear-from-hiroshima-to-fukushima/>)*The New York Times*.
262. Frank N. von Hippel (September–October 2011). "The radiological and psychological consequences of the Fukushima Daiichi accident"(<http://bos.sagepub.com/content/67/5/27.full>)*Bulletin of the Atomic Scientists* **67** (5): 27–36. doi:10.1177/0096340211421588(<https://doi.org/10.1177/0096340211421588>)
263. Arifumi Hasegawa, Koichi Tanigawa, Akira Ohtsuru, Hirooki Yabe, Masaharu Maeda, Jun Shigemura, et alHealth effects of radiation and other health problems in the aftermath of nuclear accidents, with an emphasis on Fukushima ([http://www.thelancet.com/pdfs/journals/lancet/PIIS0140-6736\(15\)61106-0.pdf](http://www.thelancet.com/pdfs/journals/lancet/PIIS0140-6736(15)61106-0.pdf)) *The Lancet*, 1 August 2015.
264. Charles D. Ferguson & Frank A. Settle (2012). "The Future of Nuclear Power in the United States"(https://fas.org/pubs/_docs/Nuclear_Energy_Report-lowres.pdf) (PDF). *Federation of American Scientists*
265. U.S. NRC: "Nuclear Security – Five Years After 9/11" (<https://www.nrc.gov/reading-rm/doc-collections/fact-sheets/security-enhancements.html>) Accessed 23 July 2007
266. Matthew Bunn & Scott Sagan (2014). "A Worst Practices Guide to Insider Threats Lessons from Past Mistakes"(<https://www.amacad.org/content/publications/publicContent.aspx?d=1427>) The American Academy of Arts & Sciences.
267. Amory Lovins (2001). *Brittle Power* (http://www.natcapsolutions.org/publications_files/BrittlePower/BrittlePower_Part123.pdf) (PDF). pp. 145–146.
268. Steven E. Miller & Scott D. Sagan (Fall 2009). "Nuclear power without nuclear proliferation?"*Dædalus*. **138** (4): 7. doi:10.1162/daed.2009.138.4.7(<https://doi.org/10.1162/daed.2009.138.4.7>)
269. "The Bulletin of atomic scientists support the megatons to megawatts program"(<https://web.archive.org/web/20110708162741/http://www.thebulletin.org/web-edition/op-eds/support-of-the-megatons-to-megawatts-program>)Archived from the original (<http://www.thebulletin.org/web-edition/op-eds/support-of-the-megatons-to-megawatts-program>) on 2011-07-08. Retrieved 2012-09-15.
270. "home" (<https://web.archive.org/web/20130621223711/http://www.usec.com/>). usec.com. 2013-05-24. Archived from the original (<http://www.usec.com/>) on 2013-06-21. Retrieved 2013-06-14.
271. <http://www.world-nuclear.org/info/Nuclear-Fuel-Cycle/Conversion-Enrichment-and-Fabrication/Uranium-Enrichment/>
272. Sovacool, Benjamin (2011). *Contesting the Future of Nuclear Power A Critical Global Assessment of Atomic Energy*. Hackensack, NJ: World Scientific p. 190. ISBN 978-981-4322-75-1
273. A Farewell to Arms, 2014. (<http://www.technologyreview.com/article/529861/a-farewell-to-arms/>)
274. From Warheads to Cheap Energy Thomas L. Nef's Idea Turned Russian Warheads Into American Electricity Jan 2014 (https://www.nytimes.com/2014/01/28/science/thomas-l-nefs-idea-turned-russian-warheads-into-american-electricity.html?_r=0)
275. "Future Unclear For 'Megatons to Megawatts' Program" (<https://www.npr.org/templates/story/story.php?storyId=121125743>). *All Things Considered* NPR. 2009-12-05 Retrieved 2013-06-22.

276. "Megatons to Megawatts Eliminates Equivalent of 10,000 Nuclear Warheads" (<https://web.archive.org/web/20130426130245/http://www.usec.com/news/megatonsmegawatts-eliminates-equivalent-10000-nuclear-warheads>) Usec.com. 2005-09-21. Archived from the original (<http://www.usec.com/news/megatons-megawatts-eliminates-equivalent-10000-nuclear-warheads>) on 2013-04-26 Retrieved 2013-06-22.
277. Dawn Stover (2014-02-21). "More megatons to megawatts" (<http://thebulletin.org/more-megatons-megawatts>) *The Bulletin*.
278. "Nuclear Power in the World Today" (<http://www.world-nuclear.org/info/inf01.html>) World-nuclear.org. Retrieved 2013-06-22.
279. Benjamin K. Sovacool. Valuing the greenhouse gas emissions from nuclear power: A critical survey (http://www.nirs.org/climate/background/sovacool_nuclear_ghg.pdf) *Energy Policy*, Vol. 36, 2008, p. 2950.
280. Warner, E. S.; Heath, G. A. (2012). "Life Cycle Greenhouse Gas Emissions of Nuclear Electricity Generation". *Journal of Industrial Ecology* **16**: S73. doi:10.1111/j.1530-9290.2012.00472.x (<https://doi.org/10.1111%2Fj.1530-9290.2012.00472.x>)
281. "Energy Balances and CO2 Implications" (<http://www.world-nuclear.org/info/inf100.html>) World Nuclear Association. November 2005 Retrieved 2014-01-24.
282. "Life-cycle emissions analyses" (<http://www.nei.org/keyissues/protectingtheenvironment/lifecycleemissionsanalysis/>) Nei.org. Retrieved 2010-08-24.
283. "UNSCEAR 2008 Report to the General Assembly" (http://www.unscear.org/docs/reports/2008/09-86753_Report_2008_GA_Report_corr2.pdf) (PDF). United Nations Scientific Committee on the Effects of Atomic Radiation. 2008.
284. Dr. Frauke Urban and Dr Tom Mitchell 2011. Climate change, disasters and electricity generation (<http://www.odi.org.uk/resources/details.asp?id=5792&title=climate-change-disasters-electricity-generation>) Archived (<https://web.archive.org/web/20120920024704/http://www.odi.org.uk/resources/details.asp?id=5792&title=climate-change-disasters-electricity-generation>) 2012-09-20 at the Wayback Machine. London: Overseas Development Institute and Institute of Development Studies
285. Kloor, Keith (2013-01-11). "The Pro-Nukes Environmental Movement" (http://www.slate.com/articles/health_and_science/nuclear_power/2013/01/nuclear_energy_and_climate_change_environmentalists_debate_how_to_stop_global.html). *Slate.com "The Big Questions" Blog* The Slate Group Retrieved 2013-03-11
286. Smil, Vaclav (2012-06-28). "A Skeptic Looks at Alternative Energy" (<http://spectrum.ieee.org/energy/renewables/a-skeptic-looks-at-alternative-energy/0>) *IEEE Spectrum*. Retrieved 2014-01-24.
287. Fiona Harvey (2011-05-09). "Renewable energy can power the world, says landmark IPCC study" (<https://www.theguardian.com/environment/2011/may/09/ipcc-renewable-energy-power-world>) *The Guardian*. London.
288. Economist magazine article "Sun, wind and rain Wind and solar power are even more expensive than is commonly thought Jul 26th 2014" (<https://www.economist.com/news/finance-and-economics/21608646-wind-and-solar-power-are-even-more-expensive-commonly-thought-sun-wind-and>)
289. THE NET BENEFITS OF LOW AND NO-CARBON ELECTRICITY TECHNOLOGIES. MA 2014, Charles Frank PDF (<https://www.brookings.edu/wp-content/uploads/2016/06/Net-Benefits-Final.pdf>)
290. Comparing the Costs of Intermittent and Dispatchable Electricity-Generating Technologies", by Paul Joskow Massachusetts Institute of Technology, September 2011 (<http://economics.mit.edu/files/6317>)
291. [1] (<http://eetd.lbl.gov/ea/ems/reports/wind-energy-costs-2-2012.pdf>) Archived (<https://web.archive.org/web/20121021062622/http://eetd.lbl.gov/ea/ems/reports/wind-energy-costs-2-2012.pdf>) October 21, 2012, at the Wayback Machine.
292. Powers, Diana S. (26 July 2010). "Nuclear Energy Loses Cost Advantage" (<https://www.nytimes.com/2010/07/27/business/global/27iht-renuke.html>) *The New York Times*.
293. "Solar and Nuclear Costs — The Historic Crossover" (http://www.ncwarn.org/wp-content/uploads/2010/07/NCW-SolarReport_final1.pdf) (PDF). NC WARN. July 2010. Retrieved 2013-01-16.
294. "Is solar power cheaper than nuclear power?" (<http://phys.org/news200578033.html>) 2010-08-09. Retrieved 2013-01-04.
295. "Levelized Cost of New Generation Resources in the Annual Energy Outlook 2011" (https://web.archive.org/web/20121104092151/http://www.eia.gov/oiaf/aeo/electricity_generation.html) *U.S. Energy Information Administration* November 2010. Archived from the original (http://www.eia.gov/oiaf/aeo/electricity_generation.html) on 2012-11-04 Retrieved 2013-01-16.

296. Chris Namovicz (2013-06-17). "Assessing the Economic Value of New Utility-Scale Renewable Generation Projects" (<http://www.eia.gov/conference/2013/pdf/presentations/namovicz.pdf>) (PDF). *US Energy Information Administration Energy Conference*
297. "Relative Subsidies to Energy Sources: GSI estimates 19 APRIL 2010" (https://web.archive.org/web/20130513055956/http://www.iisd.org/gsi/sites/default/files/relative_energy_subsidies.pdf) (PDF). Archived from the original (http://www.iisd.org/gsi/sites/default/files/relative_energy_subsidies.pdf) (PDF) on 13 May 2013.
298. EIA Releases New Subsidy Report: Subsidies for Renewables Increase 186 Percent August 3, 2011 (<http://instituteoforenergyresearch.org/analysis/eia-releases-new-subsidy-report-subsidies-for-renewables-increase-186-percent/>)
299. David Biello (2009-01-28). "Spent Nuclear Fuel: A Trash Heap Deadly for 250,000 Years or a Renewable Energy Source?" (<http://www.scientificamerican.com/article.cfm?id=nuclear-waste-lethal-trash-or-renewable-energy-source>) *Scientific American*. Retrieved 2014-01-24.
300. "Closing and Decommissioning Nuclear Power Plants" (http://arquivo.pt/wayback/20160518164428/http://www.unep.org/yearbook/2012/pdfs/UYB_2012_CH_3.pdf) (PDF). *United Nations Environment Programme* 2012-03-07. Archived from the original (http://www.unep.org/yearbook/2012/pdfs/UYB_2012_CH_3.pdf) (PDF) on 2016-05-18.
301. Nils Starfelt; Carl-Erik Wikdahl. "Economic Analysis of Various Options of Electricity Generation – Taking into Account Health and Environmental Effects" (https://web.archive.org/web/20070927230434/http://manhaz.cyf.gov.pl/manhaz/strona_konferencja_EAE-2001/15%20-%20Polenp~1.pdf) (PDF). Archived from the original (http://manhaz.cyf.gov.pl/manhaz/strona_konferencja_EAE-2001/15%20-%20Polenp~1.pdf) (PDF) on 2007-09-27. Retrieved 2012-09-08.
302. Sovacool, Benjamin (2011). *Contesting the Future of Nuclear Power A Critical Global Assessment of Atomic Energy*. Hackensack, NJ: World Scientific pp. 118–119. ISBN 978-981-4322-75-1
303. Decommissioning Nuclear Facilities (<http://www.world-nuclear.org/information-library/nuclear-fuel-cycle/nuclear-wastes/decommissioning-nuclear-facilities.aspx>)
304. Backgrounder on Decommissioning Nuclear Power Plants. NRC (<https://www.nrc.gov/reading-rm/doc-collections/fact-sheets/decommissioning.html>)
305. Publications: Vienna Convention on Civil Liability for Nuclear Damage (<http://www.iaea.org/Publications/Documents/Conventions/liability.html>). International Atomic Energy Agency
306. Nuclear Power's Role in Generating Electricity (<http://www.cbo.gov/sites/default/files/05-02nuclear.pdf>) Congressional Budget Office, May 2008.
307. Availability of Dam Insurance (<http://www.damsafety.org/media/Documents/FEMA/AvailabilityOfDamInsurance.pdf>) Archived (<https://web.archive.org/web/20160108185336/http://www.damsafety.org/media/documents/fema/availabilityofdaminsurance.pdf>) 2016-01-08 at the Wayback Machine 1999
308. Falk, Jim (1982). *Global Fission: The Battle Over Nuclear Power* Melbourne: Oxford University Press. ISBN 978-0-19-554315-5
309. Patterson, Thom (2013-11-03). "Climate change warriors: It's time to go nuclear" (<http://www.cnn.com/2013/11/03/world/nuclear-energy-climate-change-scientists/index.html>) CNN.
310. "Renewable Energy and Electricity" (<http://www.world-nuclear.org/info/inf10.html>) World Nuclear Association. June 2010. Retrieved 2010-07-04.
311. M. King Hubbert (June 1956). "Nuclear Energy and the Fossil Fuels 'Drilling and Production Practice'" (<https://web.archive.org/web/20080527233843/http://www.hubbertpeak.com/hubbert/1956/1956.pdf>) (PDF). API. p. 36. Archived from the original (<http://www.hubbertpeak.com/hubbert/1956/1956.pdf>) (PDF) on 2008-05-27. Retrieved 2008-04-18.
312. Bernard L. Cohen (1990). *The Nuclear Energy Option: An Alternative for the 90s* (<http://www.phyast.pitt.edu/~blc/book/BOOK.html>). New York: Plenum Press. ISBN 978-0-306-43567-6
313. Greenpeace International and European Renewable Energy Council (January 2007) *Energy Revolution: A Sustainable World Energy Outlook* (http://www.energyblueprint.info/fileadmin/media/documents/energy_revolution.pdf) Archived (https://web.archive.org/web/20090806121526/http://www.energyblueprint.info/fileadmin/media/documents/energy_revolution.pdf) 2009-08-06 at the Wayback Machine, p. 7.
314. Giugni, Marco (2004). *Social Protest and Policy Change: Ecology Antinuclear, and Peace Movements* (<https://books.google.com/books?id=Kn6YhNtyVgC&pg=PA44&lpg=PA44&dq=shoreham+nuclear+power+plant+protests>)
315. Sovacool Benjamin K. (2008). "The costs of failure: A preliminary assessment of major energy accidents, 1907–2007". *Energy Policy*. **36**: 1802–1820. doi:10.1016/j.enpol.2008.01.040 (<https://doi.org/10.1016%2Fj.enpol.2008.01.040>).
316. Stephanie Cooke (2009). *In Mortal Hands: A Cautionary History of the Nuclear Age* Black Inc., p. 280.

317. Kurt Kleiner. Nuclear energy: assessing the emissions(<http://www.nature.com/climate/2008/0810/pdf/climate.2008.9.pdf>) *Nature Reports*, Vol. 2, October 2008, pp. 130–131.
318. Mark Diesendorf (2007). *Greenhouse Solutions with Sustainable Energy* University of New South Wales Press, p. 252.
319. Mark Diesendorf. Is nuclear energy a possible solution to global warming?(<http://www.ceem.unsw.edu.au/content/userDocs/NukesSocialAlternativesMD.pdf>) Archived (<https://web.archive.org/web/20120722213838/http://www.ceem.unsw.edu.au/content/userDocs/NukesSocialAlternativesMD.pdf>) July 22, 2012, at the Wayback Machine
320. "4th Generation Nuclear Power — OSS Foundation"(<http://ossfoundation.us/projects/energy/nuclear>) Ossfoundation.us Retrieved 2014-01-24.
321. Adam Piore (June 2011). "Nuclear energy: Planning for the Black Swan"*Scientific American*
322. Matthew L. Wald (2010-04-22). "Critics Challenge Safety of New Reactor Design"(<http://green.blogs.nytimes.com/2010/04/21/critics-challenge-safety-of-new-nuclear-reactor-design/?src=busln>)*The New York Times*.
323. "Nuclear Power in a Warming World" (http://www.ucsusa.org/assets/documents/nuclear_power/nuclear-power-in-a-warming-world.pdf) (PDF). *Union of Concerned Scientists* Retrieved 2008-10-01.
324. Benjamin K. Sovacool (August 2010). "A Critical Evaluation of Nuclear Power and Renewable Electricity in Asia"(<http://www.informaworld.com/smpp/content~content=a923050767~db=all~jumptype=rss>) *Journal of Contemporary Asia*. **40** (3): 381.
325. Gerstner, E. (2009). "Nuclear energy: The hybrid returns"(<http://www.nature.com/news/2009/090701/pdf/460025a.pdf>) (PDF). *Nature*. **460** (7251): 25–8. doi:10.1038/460025a(<https://doi.org/10.1038%2F460025a>) PMID 19571861 (<https://www.ncbi.nlm.nih.gov/pubmed/19571861>).
326. *Introduction to Fusion Energy* J. Reece Roth, 1986.
327. T. Hamacher & A.M. Bradshaw (October 2004). "Fusion as a Future Power Source: Recent Achievements and Prospects" (https://web.archive.org/web/20040506065141/http://www.worldenergy.org/wec-geis/publications/default/tech_papers/18th_Congress/downloads/ds/ds6/ds6_5.pdf) (PDF). World Energy Council. Archived from the original (http://www.worldenergy.org/wec-geis/publications/default/tech_papers/18th_Congress/downloads/ds/ds6/ds6_5.pdf) (PDF) on 2004-05-06.
328. W Wayt Gibbs (2013-12-30). "Triple-threat method sparks hope for fusion"(<http://www.nature.com/news/triple-threat-method-sparks-hope-for-fusion-1.14445>) *Nature*.
329. "Beyond ITER" (<https://web.archive.org/web/20061107220145/http://www.iter.org/Future-beyond.htm>) *The ITER Project*. Information Services, Princeton Plasma Physics Laboratory Archived from the original (<http://www.iter.org/Future-beyond.htm>) on 2006-11-07. Retrieved 2011-02-05. – Projected fusion power timeline
330. "Overview of EFDA Activities"(https://web.archive.org/web/20061001123645/http://www.efda.org/about_efda/downloads/EFDAoverviewppt). *EFDA European Fusion Development Agreement* Archived from the original (http://www.efda.org/about_efda/downloads/EFDAoverviewppt) on 2006-10-01 Retrieved 2006-11-11.

Further reading

- Armstrong, Robert C., Catherine Wolfram, Robert Gross, Nathan S. Lewis, and M.V. Ramana et al. *The Frontiers of Energy*, *Nature Energy*, Vol 1, 11 January 2016.
- Clarfield, Gerald H. and William M. Wiecek (1984) *Nuclear America: Military and Civilian Nuclear Power in the United States 1940–1980* Harper & Row
- Cooke, Stephanie (2009). *In Mortal Hands: A Cautionary History of the Nuclear Age* Black Inc.
- Cravens, Gwyneth (2007). *Power to Save the World: the Truth about Nuclear Energy*. New York: Knopf. ISBN 0-307-26656-7.
- Elliott, David (2007). *Nuclear or Not? Does Nuclear Power Have a Place in a Sustainable Energy Future?* Palgrave.
- Ferguson, Charles D., (2007). *Nuclear Energy: Balancing Benefits and Risks* Council on Foreign Relations
- Garwin, Richard L. and Charpak, Georges (2001) *Megawatts and Megatons A Turning Point in the Nuclear Age?*, Knopf.
- Herbst, Alan M. and George W Hopley (2007). *Nuclear Energy Now: Why the Time has come for the World's Most Misunderstood Energy Source* Wiley.
- Schneider, Mycle, Steve Thomas, Antony Froggatt, Doug Koplow (2016). *The World Nuclear Industry Status Report World Nuclear Industry Status as of 1 January 2016*
- Walker, J. Samuel (1992). *Containing the Atom: Nuclear Regulation in a Changing Environment, 1993-1971* Berkeley: University of California Press.
- Weart, Spencer R. *The Rise of Nuclear Fear* Cambridge, MA: Harvard University Press, 2012 ISBN 0-674-05233-1

External links

- [Alsos Digital Library for Nuclear Issues — Annotated Bibliography on Nuclear Power](#) a partnership between the [National Science Foundation](#), [National Science Digital Library](#), [Washington and Lee University](#) and [Nuclear Pathways](#)
- [Energy Information Administration](#) provides statistics and information
- [The World Nuclear Industry Status Reports website](#) by [Mycale Schneider](#) and others

Introduction

- [Nuclear Tourist.com](#), nuclear power information

Retrieved from 'https://en.wikipedia.org/w/index.php?title=Nuclear_power&oldid=833997945

This page was last edited on 3 April 2018, at 11:58.

Text is available under the [Creative Commons Attribution-ShareAlike License](#); additional terms may apply. By using this site, you agree to the [Terms of Use](#) and [Privacy Policy](#). Wikipedia® is a registered trademark of the [Wikimedia Foundation, Inc.](#), a non-profit organization.