Nuclear power

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Sustainable development Portal

The Susquehanna Steam Electric Station. The nuclear reactors are located inside the rectangular containment buildings towards the front of the cooling towers. The towers in the background vent water vapor.

Nuclear technology Portal

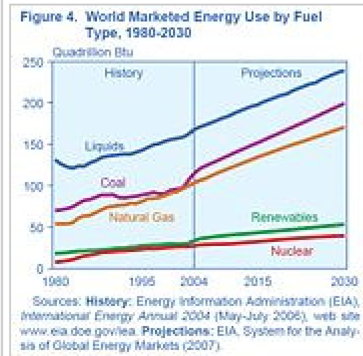
Energy Portal

Nuclear power is a type of nuclear technology involving the controlled use of nuclear fission to release energy for work including propulsion, heat, and the generation of electricity. Nuclear energy is produced by a controlled nuclear chain reaction and creates heat—which is used to boil water, produce steam, and drive a steam turbine. The turbine can be used for mechanical work and also to generate electricity.

Contents

Use

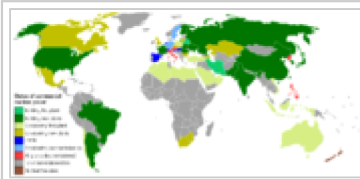
See also: Nuclear power by country and List of nuclear reactors



Historical and projected world energy use by energy source, 1980-2030, Source: International Energy Outlook 2007, EIA.

As of 2004, nuclear power provided 6.5% of the world's energy and 15.7% of the world's electricity, with the U.S., France, and Japan together accounting for 57% of all nuclear generated electricity.[1] As of 2007, the IAEA reported there are 439 nuclear power reactors in operation in the world,[2] operating in 31 different countries.[3]

The United States produces the most nuclear energy, with nuclear power providing 20% of the electricity it consumes, while France produces the highest percentage of its electrical energy from nuclear reactors—80% as of 2006.[4][5] In the European Union as a whole, nuclear energy provides 30% of the electricity.[6] Nuclear energy policy differs between European Union countries, and some, such as Austria and Ireland, have no active nuclear power stations. In comparison France has a large number of these plants, with 16 currently in use.



The status of nuclear power globally. Nations in dark green have reactors and are constructing new reactors, those in light green are constructing their first reactor, those in dark yellow are considering new reactors, those in light yellow are considering their first reactor, those in blue have reactors but are not constructing or decommissioning, those in light blue are considering decommissioning and those in red have decommissioned all their commercial reactors. Brown indicates that the country has declared itself free of nuclear power and weapons.

Many military and some civilian (such as some icebreaker) ships use nuclear marine propulsion, a form of nuclear propulsion[7]

International research is ongoing into different safety improvements such as passively safe plants[8], the use of nuclear fusion, and additional uses of produced heat such as the hydrogen production (in support of a hydrogen economy), for desalinating sea water, and for use in district heating systems.

History

Origins

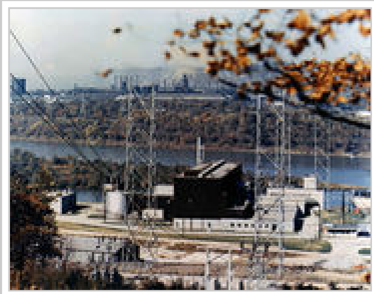
Nuclear fission was first experimentally achieved by Enrico Fermi in 1934 when his team bombarded uranium with neutrons[9]. In 1938, German chemists Otto Hahn[10] and Fritz Strassmann, along with Austrian physicists Lise Meitner[11] and Meitner's nephew, Otto Robert Frisch[12], conducted experiments with the products of neutron-bombarded uranium. They determined that the relatively tiny neutron split the nucleus of the massive uranium atoms into two roughly equal pieces--an incredible result. Numerous scientists (Leo Szilard being one of the first) recognized that if the fission reactions released additional neutrons, a self-sustaining nuclear chain reaction could result. This spurred scientists in many countries (including the United States, the United Kingdom, France, Germany, and the Soviet Union) to petition their government for support of nuclear fission research.

In the United States, where Fermi and Szilard 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, which built giant reactors at Hanford, Washington in order to breed plutonium for use in the first nuclear weapons. (A parallel uranium enrichment effort was also pursued.)

After World War II, the fear that reactor research would encourage the rapid spread of nuclear weapons and nuclear "know-how", combined with what many scientists thought would be a long road of development, created a situation in which reactor research was kept under very strict government control and classification. Additionally, most reactor research centered on purely military purposes. 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 (the Arco Reactor was also the first to experience partial meltdown, in 1955). In 1952, a report by the Paley Commission (*The President's Materials Policy Commission*) for President Harry Truman made a "relatively pessimistic" assessment of nuclear power, and called for "aggressive research in the whole field of solar energy".[13] A December 1953 speech by President Dwight Eisenhower, "Atoms for Peace", emphasized the useful harnessing of the atom and set the U.S. on a course of strong government support for international use of nuclear power.

Early years

In 1954, Lewis Strauss, then chairman of the United States Atomic Energy Commission (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."[14] While few doubt he was thinking of atomic energy when he made the statement, he may have been referring to hydrogen fusion, rather than uranium fission. [8] Actually, the consensus of government and business at the time was that nuclear (fission) power might eventually become merely economically competitive with conventional power sources.



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

On June 27, 1954, the USSRs Obninsk Nuclear Power Plant became the world's first nuclear power plant to generate electricity for a power grid, and produced around 5 megawatts electric power.[15][16]

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).

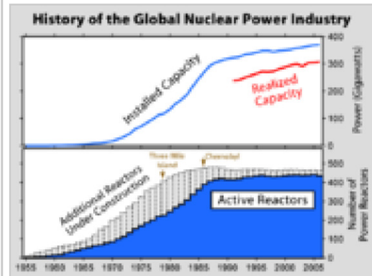
The world's first commercial nuclear power station, Calder Hall in Sellafield, England was opened in 1956 with an initial capacity of 50 MW (later 200 MW).[17] The first commercial nuclear generator to become operational in the United States was the Shippingport Reactor (Pennsylvania, December, 1957).

One of the first organizations to develop nuclear power was the U.S. Navy, for the purpose of propelling submarines and aircraft carriers. It has a good record in nuclear safety, perhaps because of the stringent demands of Admiral Hyman G. Rickover, who was the driving force behind nuclear marine propulsion as well as the Shippingport Reactor. The U.S. Navy has operated more nuclear reactors than any other entity, including the Soviet Navy, with no publicly known major incidents. The first nuclear-powered submarine, USS *Nautilus* (SSN-571), was put to sea in December 1954.[18] Two U.S. nuclear submarines, USS *Scorpion* and *Thresher*, have been lost at sea.

Enrico Fermi and Leó Szilárd in 1955 shared U.S. Patent 2,708,656 for the nuclear reactor, belatedly granted for the work they had done during the Manhattan Project.

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 capacity has risen much more slowly, reaching 366 GW in 2005, with the largest expansion being in China. Between around 1970 and 1990, more than 50 GW of capacity was under construction (peaking at over 150 GW in the late 70s and early 80s) — 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.[18]



History of the use of nuclear power (top) and the number of active nuclear power plants (bottom).

During the 1970s and 1980s rising economic costs (related to extended construction times largely due to regulatory changes and pressure-group litigation) 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.

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

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% and 73% respectively) to invest in nuclear power.[19][20] Today, nuclear power supplies about 80% and 30% of the electricity in those countries, respectively.

A general movement against nuclear power arose during the last third of the 20th century, based on the fear of a possible nuclear accident, fears of radiation, nuclear proliferation, and on the opposition to nuclear waste production, transport and final storage. Perceived risks on the citizens' health and safety, the 1979 accident at Three Mile Island and the 1986 Chernobyl disaster played a part in stopping new plant construction in many countries,[21] although the Brookings Institution suggests that new nuclear units have not been ordered in the U.S. primarily for economic reasons rather than fears of accidents.[22]

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 containment buildings.[23] 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, New Zealand 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.

Future of the industry

See also: Nuclear energy policy, Mitigation of global warming, and Economics of new nuclear power plants

As of 2007, Watts Bar 1, which came on-line in Feb. 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. However, political resistance to nuclear power has only ever been successful in parts of Europe, New Zealand, the Philippines and in the United States. Even in the U.S. and throughout Europe, investment in research and in the nuclear fuel cycle has continued, and some experts predict that 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 will renew the demand for nuclear power plants.

Many countries remain active in developing nuclear power, including Japan, China and India, all actively developing both fast and thermal technology, South Korea and the United States, developing thermal technology only, and South Africa and China, developing versions of the Pebble Bed Modular Reactor (PBMR). Finland, France and Romania actively pursue nuclear programs (the only 3 countries in the EU to do so); Finland has a new European Pressurized Reactor under construction by Areva, which is currently two years behind schedule. Japan has an active nuclear construction program with new units brought on-line in 2005. In the U.S., three consortia responded in 2004 to the U.S. Department of Energy's solicitation under the Nuclear Power 2010 Program and were awarded matching funds—the Energy Policy Act of 2005 authorized loan guarantees for up to six new reactors, and authorized the Department of Energy to build a reactor based on the Generation IV Very-High-Temperature Reactor concept to produce both electricity and hydrogen. As of the early 21st century, nuclear power is of particular interest to both China and India to serve their rapidly growing economies—both are developing fast breeder reactors. See also energy development. In the energy policy of the United Kingdom it is recognized that there is a likely future energy supply shortfall, which may have to be filled by either new nuclear plant construction or maintaining existing plants beyond their programmed lifetime.

On December 20, 2002 the Bulgarian Council of Ministers voted to restart construction of the Belene Nuclear Power Plant. The plant's foundations were laid in 1987, however construction was abandoned in 1990, with the first reactor being 40% ready. It is expected that the first reactor should go on-line in 2013, and the second in 2014.[24]

On September 22, 2005 it was announced that two sites in the U.S. had been selected to receive new power reactors (exclusive of the new power reactor scheduled for INL).

In August 2007 TVA was approved to restart construction of Watts Bar 2. The reactor is scheduled to be completed and come online in 2013.

In October 2007, two new plants have been scheduled to build in Texas. They should be online by 2014.

Nuclear reactor technology

Conventional thermal power plants all have a fuel source to provide heat. Examples are gas, coal, or oil. For a nuclear power plant, this heat is provided by nuclear fission inside the nuclear reactor. When a relatively large fissile atomic nucleus is struck by a neutron it forms two or more smaller nuclei as fission products, releasing energy and neutrons in a process called nuclear fission. The neutrons then trigger further fission, and so on. When this nuclear chain reaction is controlled, the energy released can be used to heat water, produce steam and drive a turbine that generates electricity. While a nuclear power plant uses the same fuel, uranium-235 or plutonium-239, a nuclear explosive involves an uncontrolled chain reaction, and the rate of fission in a reactor is not capable of reaching sufficient levels to trigger a nuclear explosion because commercial reactor grade nuclear fuel is not enriched to a high enough level. Naturally found uranium is less than 1% U-235, the rest being U-238. Most reactor fuel is enriched to only 3-4%, but some designs use natural uranium or highly enriched uranium. Reactors for nuclear submarines and large naval surface ships, such as aircraft carriers, commonly use highly enriched uranium. Although highly enriched uranium is more expensive, it reduces the frequency of refueling, which is very useful for military vessels. CANDU reactors are able to use unenriched uranium because the heavy water they use as a moderator and coolant does not absorb neutrons like light water does.

The chain reaction is controlled through the use of materials that absorb and moderate neutrons. In uranium-fueled reactors, neutrons must be moderated (slowed down) because slow neutrons are more likely to cause fission when colliding with a uranium-235 nucleus. Light water reactors use ordinary water to moderate and cool the reactors. When at operating temperatures if the temperature of the water increases, its density drops, and fewer neutrons passing through it are slowed enough to trigger further reactions. That negative feedback stabilizes the reaction rate.

The current types of plants (and their common components) are discussed in the article nuclear reactor technology.

A number of other designs for nuclear power generation, the Generation IV reactors, are the subject of active research and may be used for practical power generation in the future. A number of the advanced nuclear reactor designs could also make critical fission reactors much cleaner, much safer and/or much less of a risk to the proliferation of nuclear weapons.

Safety

See also: Nuclear safety in the U.S.

The topic of nuclear safety covers:

- The research and testing of the possible incidents/events at a nuclear power plant,
- What equipment and actions are designed to prevent those incidents/events from having serious consequences,
- The calculation of the probabilities of multiple systems and/or actions failing thus allowing serious consequences,
- The evaluation of the worst-possible timing and scope of those serious consequences (the worst-possible in extreme cases being a release of radiation),
- The actions taken to protect the public during a release of radiation,
- The training and rehearsals performed to ensure readiness in case an incident/event occurs.

Many different safety features have been added to nuclear power plants and in the United States, the NRC has responsible over nuclear safety.

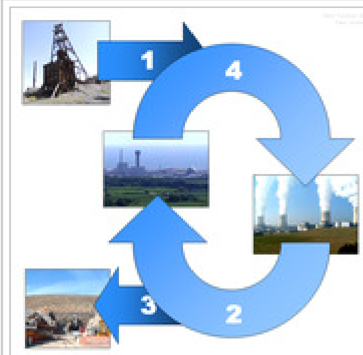
Economics

This is a controversial subject, since multi-billion dollar investments ride on the choice of an energy source.

Which power source (generally coal, natural gas, nuclear or wind) is most cost-effective depends on the assumptions used in a particular study—several are quoted in the main article.

Life cycle

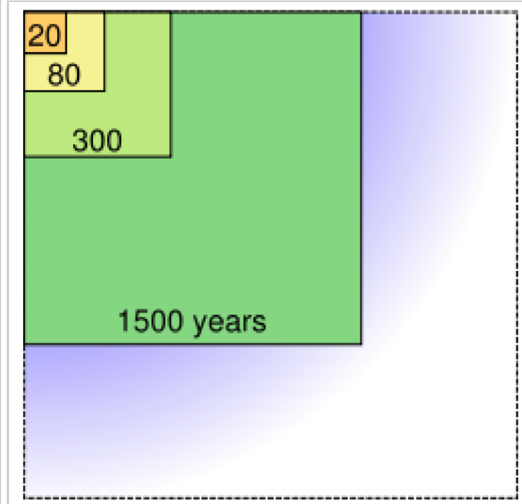
A nuclear reactor is only part of the life-cycle for nuclear power. The process starts with mining. Generally, uranium mines are either open-pit strip mines, or in-situ leach mines. In either case, the uranium ore is extracted, usually converted into a stable and compact form such as yellowcake, and 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 years 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 cooling pond, the spent fuel is radioactively and thermally cool enough to handle, and it can be moved to dry storage casks or reprocessed.



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 be recycled to be returned to usage in a power plant (4).

Fuel resources

Uranium is a fairly common element in the Earth's crust. Uranium is approximately as common as tin or germanium in Earth's crust, and is about 35 times as common as silver. Uranium is a constituent of most rocks, dirt, and of the oceans. The world's present measured resources of uranium, economically recoverable at a price of 130 USD/kg, are enough to last for some 70 years at current consumption. This represents a higher level of assured resources than is normal for most minerals. On the basis of analogies with other metallic minerals, a doubling of price from present levels could be expected to create about a tenfold increase in measured resources, over time. The fuel's contribution to the overall cost of the electricity produced is relatively small, so even a large fuel price escalation will have relatively little effect on final price. For instance, typically a doubling of the uranium market price would increase the fuel cost for a light water reactor by 26% and the electricity cost about 7%, whereas doubling the price of natural gas would typically add 70% to the price of electricity from that source. At high enough prices, eventually extraction from sources such as granite and seawater become economically feasible.[28][29]



The Estimate of Available Uranium depends on what resources are included in the estimate. The squares represent relative sizes of different estimates, whereas the numbers at the lower edge show how long the given resource would last at present consumption.

Reserves in current mines [25]
Known economic reserves [26]
Conventional undiscovered resources [27]
Total ore resources at 2004 prices [25]
Unconventional resources (at least 4 billion tons, could last for millennia) [27]

Current light water reactors make relatively inefficient use of nuclear fuel, fissioning only the very rare uranium-235 isotope. Nuclear reprocessing can make this waste reusable and more efficient reactor designs allow better use of the available resources.[30]

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[31], at present levels of usage.

Breeder technology has been used in several reactors, but the high cost of reprocessing fuel safely requires prices of more than 200 USD/kg before becoming justified economically.[32] As of December 2005, the only breeder reactor producing power is BN-600 in Beloyarsk, Russia. The electricity output of BN-600 is 600 MW — Russia has planned to build another unit, BN-800, at Beloyarsk nuclear power plant. Also, Japan's Monju reactor is planned for restart (having been shut down since 1995), and both China and India intend to build breeder reactors.

Another alternative would be to use uranium-233 bred from thorium as fission fuel in the thorium fuel cycle. Thorium is about 3.5 times as common as uranium in the Earth's crust, and has different geographic characteristics. This would extend the total practical fissionable resource base by 450%. [33] Unlike the breeding of U-238 into plutonium, fast breeder reactors are not necessary — it can be performed satisfactorily in more conventional plants. India has looked into this technology, as it has abundant thorium reserves but little uranium.

Fusion power commonly propose the use of deuterium, an isotope of hydrogen, as fuel and in many current designs also lithium. Assuming a fusion energy output equal to the current global output and that this does not increase in the future, then the known current lithium reserves would last 3000 years, lithium from sea water would last 60 million years, and a more complicated fusion process using only deuterium from sea water would have fuel for 150 billion years.[34]

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 making bullets and armor — as it has a higher density than lead. There are concerns that U-238 may lead to health problems in groups exposed to this material excessively, like tank crews and civilians living in areas where large quantities of DU ammunition have been used.

Solid waste

For more details on this topic, see Radioactive waste.

The safe storage and disposal of nuclear waste is a significant challenge. The most important waste stream from nuclear power plants is spent fuel. A large nuclear reactor produces 3 cubic metres (25-30 tonnes) of spent fuel each year.[35] 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 made of fission products. 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[36].

Spent fuel is highly radioactive and needs to be handled with great care and forethought. However, spent nuclear fuel becomes less radioactive over time. After 40 years, the radiation flux is 99.9% lower than it was the moment the spent fuel was removed, although still dangerously radioactive.[30]

Spent fuel rods are stored in shielded basins of water (spent fuel pools), usually located on-site. The water provides both cooling for the still-decaying uranium, and shielding from the continuing radioactivity. After a few decades some on-site storage involves moving the now cooler, less radioactive fuel to a dry-storage facility or dry cask storage, where the fuel is stored in steel and concrete containers until its radioactivity decreases naturally ("decays") to levels safe enough for other processing. This interim stage spans years or decades, depending on the type of fuel. Most U.S. waste is currently stored in temporary storage sites requiring oversight, while suitable permanent disposal methods are discussed.

As of 2003, the United States had accumulated about 49,000 metric tons of spent nuclear fuel from nuclear reactors. Underground storage at Yucca Mountain in U.S. has been proposed as permanent storage. After 10,000 years of radioactive decay, according to United States Environmental Protection Agency standards, the spent nuclear fuel will no longer pose a threat to public health and safety.

The amount of waste can be reduced in several ways, particularly reprocessing. Even so, the remaining waste will be substantially radioactive for at least 300 years even if the actinides are removed, and for up to thousands of years if the actinides are left in. Even with separation of all actinides, and using fast breeder reactors to destroy by transmutation some of the longer-lived non-actinides as well, the waste must be segregated from the environment for one to a few hundred years, and therefore this is properly categorized as a long-term problem. Subcritical reactors or fusion reactors could also reduce the time the waste has to be stored.[37] It has been argued that the best solution for the nuclear waste is above ground temporary storage since technology is rapidly changing. The current waste may well become a valuable resource in the future.

The nuclear industry also produces a 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 United States, the Nuclear Regulatory Commission has repeatedly attempted to allow low-level materials to be handled as normal waste: landfilled, recycled into consumer items, et cetera. Most low-level waste releases very low levels of radioactivity and is only considered radioactive waste because of its history. For example, according to the standards of the NRC, the radiation released by coffee is enough to treat it as low level waste.

In countries with nuclear power, radioactive wastes comprise less than 1% of total industrial toxic wastes, which remain hazardous indefinitely unless they decompose or are treated so that they are less toxic or, ideally, completely non-toxic.[30] Overall, nuclear power produces far less waste material than fossil-fuel based power plants. Coal-burning plants are particularly noted for producing large amounts of toxic and mildly radioactive ash due to concentrating naturally occurring metals and radioactive material from the coal. Contrary to popular belief, coal power actually results in more radioactive waste being released into the environment than nuclear power. The population effective dose equivalent from radiation from coal plants is 100 times as much as nuclear plants.[38]

Fusion energy makes nuclear waste of a type that must be stored and could be reused after some 100 years, not the tens of thousands of years of fission waste.

Reprocessing

For more details on this topic, see Nuclear 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 would produce 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 on large scale in Britain, France and (formerly) Russia, will be in China and perhaps India, and is being done on an expanding scale in Japan. The full potential of reprocessing has not been achieved because it requires breeder reactors, which are not yet commercially available. France is generally cited as the most successful reprocessor, but it presently only recycles 28% (by mass) of the yearly fuel use, 7% within France and another 21% in Russia.[39]

Unlike other countries, the US has stopped civilian reprocessing as one part of US non-proliferation policy, since reprocessed material such as plutonium can be used in nuclear weapons. Spent fuel is all currently treated as waste.[40] In February, 2006, a new U.S. initiative, the Global Nuclear Energy Partnership was announced. It would be an international effort to reprocess fuel in a manner making nuclear proliferation unfeasible, while making nuclear power available to developing countries.[41]

Debate on nuclear power

Critics claim that nuclear power is an uneconomic and potentially dangerous energy source with a limited fuel supply compared to renewable energy, and dispute whether the costs and risks can be reduced through new technology. Critics also point to the problem of storing radioactive waste, the potential for possibly severe radioactive contamination by accident or sabotage, the possibility of nuclear proliferation and the disadvantages of centralized electrical production.

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

Proponents of nuclear energy claim that nuclear power is a sustainable energy source that reduces carbon emissions and increases energy security by decreasing dependence on foreign countries for energy sources.[42] Proponents also claim that the risks of storing waste are small and can be further reduced by the technology in the new reactors and the operational safety record is already good when compared to the other major kinds of power plants. Many go on to argue that renewables are limited to a minority share of energy production because they are intermittent power sources and have questionable economics themselves as well as demanding too much money for development.

Pros and Cons - an overview

France is one of the world's most densely populated countries. According to a 2007 story broadcast on *60 Minutes*, nuclear power gives France the cleanest air of any industrialized country, and the cheapest electricity in all of Europe.[43] France reprocesses its nuclear waste to reduce its mass and make more energy.[44] However, the article continues, "Today we stock containers of waste because currently scientists don't know how to reduce or eliminate the toxicity, but maybe in 100 years perhaps scientists will ... Nuclear waste is an enormously difficult political problem which to date no country has solved. It is, in a sense, the Achilles heel of the nuclear industry ... If France is unable to solve this issue, says Mandil, then 'I do not see how we can continue our nuclear program.'" Further, reprocessing itself has its critics, such as the Union of Concerned Scientists [9] PDF (113 KiB).

In the U.S., which does not reprocess nuclear waste, nuclear power has its own set of problems such as what to do with all the radioactive waste. "Already more than 80,000 tonnes of highly radioactive waste sits in cooling pools next to the 103 US nuclear power plants, awaiting transportation to a storage facility yet to be found. This dangerous material will be an attractive target for terrorist sabotage as it travels through 39 states on roads and railway lines for the next 25 years"[45]. Even keeping track of it all has proved to be a problem [10]. In fact fears have been expressed that terrorists could get hold of some of it to make nuclear bombs[46]. Additionally many point to the possibility of a catastrophic accident at one of these plants which could affect many thousands or even millions. Greenpeace has produced a report titled *An American Chernobyl: Nuclear "Near Misses" at U.S. Reactors Since 1986* which "reveals that nearly two hundred "near misses" to nuclear meltdowns have occurred in the United States". At almost 450 nuclear plants in the world that risk is greatly magnified they say. This is not to mention numerous incidents[47], many unreported, that have occurred. Another report called Nuclear Reactor Hazards: Ongoing Dangers of Operating Nuclear Technology in the 21st Century concludes that risk of a major accident has increased in the past years. See also [11].

Underlying much of the distrust is the fact that it has unfortunately often been the case that populations are not informed of hazards from various technologies that may impact on them. For example Brookhaven National Laboratory's leaking of radioactive tritium into community groundwater for up to 12 years which angered the local community [12], dangerous coverups at the Rocky Flats Nuclear Weapons Plant [13] or the pollution of Anniston, Alabama and other locations by Monsanto that went unreported for four decades [14]. For these reasons many feel the risks outweigh the benefits.

However, some people claim that the problems of nuclear waste do not come anywhere close to approaching the problems of fossil fuel waste.[48][49]. A 2004 article from the BBC states: "The World Health Organization (WHO) says 3 million people are killed worldwide by outdoor air pollution annually from vehicles and industrial emissions, and 1.6 million indoors through using solid fuel."[15] In the U.S. alone, fossil fuel waste kills 20,000 people each year.[50] A coal power plant releases 100 times as much radiation as a nuclear power plant of the same wattage.[51] In addition, fossil fuel waste causes global warming, which leads to increased deaths from hurricanes, flooding, and other weather events.

Accidents

The International Nuclear Event Scale (INES), developed by the International Atomic Energy Agency (IAEA), is used to communicate the severity of nuclear accidents on a scale of 0 to 7. The two most well-known events are the Three Mile Island accident and the Chernobyl disaster.

The 1979 accident at Three Mile Island Unit 2 was the worst civilian nuclear accident outside the Soviet Union (INES score of 5). The reactor experienced a partial core meltdown. However, the reactor vessel and containment building were not breached and little radiation was released to the environment.[52] The event resulted in fundamental changes in how plants in the West were to be maintained and operated.

The Chernobyl disaster in 1986 at the Chernobyl Nuclear Power Plant in the Ukrainian Soviet Socialist Republic (now Ukraine) was the worst nuclear accident in history and is the only event to receive an INES score of 7. The power excursion and resulting steam explosion and fire spread radioactive contamination across large portions of Europe. A large 2005 study found that the death toll includes the 50 workers who died of acute radiation syndrome, nine children who died from thyroid cancer, and an estimated 4000 excess cancer deaths in the future. [53] Supporters of nuclear power argue that this accident occurred due to several critical design flaws in the Soviet RBMK reactors, such as lack of a containment building which would have stopped radioactive emissions from that accident, and that security in the remaining RBMK reactors have greatly improved.[16]

Design changes are being pursued to lessen the risks of fission reactors; in particular, passively safe plants (such as the ESBWR) are available to be built and inherently safe designs are being pursued. Fusion reactors which may be viable in the future theoretically have very little risk of explosive radiation-releasing accidents. (They still produce residual radioactivity, however.)

The World Nuclear Association provides a comparison of deaths due to accidents among different forms of energy production. In their comparison, deaths per TW-yr of electricity produced from 1970 to 1992 are quoted as 885 for hydropower, 342 for coal, 85 for natural gas, and 8 for nuclear[54]. Air pollution from fossil fuels is argued to cause tens of thousands of additional deaths each year in the US alone.[55] Furthermore, a 2004 news article from the BBC stated, "The World Health Organization (WHO) says 3 million people are killed worldwide by outdoor air pollution annually from vehicles and industrial emissions, and 1.6 million indoors through using solid fuel. Most are in poor countries."[56]

Vulnerability of plants to attack

Nuclear power plants are generally (although not always) considered "hard" targets. In the US, 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.[57] The NRC's "Design Basis Threat" criteria for plants is a secret, and so what size attacking force the plants are able to protect against is unknown. However, to scram a plant takes less than 5 seconds while unimpeded restart takes hours, severely hampering a terrorist force in a goal to release radioactivity.

Attack from the air is a more problematic concern. The most important barrier against the release of radioactivity in the event of an aircraft strike is the containment building and its missile shield. The NRC's Chairman has said "Nuclear power plants are inherently robust structures that our studies show provide adequate protection in a hypothetical attack by an airplane. The NRC has also taken actions that require nuclear power plant operators to be able to manage large fires or explosions—no matter what has caused them."[58]

In addition, supporters point to large studies carried out by the US Electric Power Research Institute that tested the robustness of both reactor and waste fuel storage, and found that they should be able to sustain a terrorist attack comparable to the September 11 terrorist attacks in the USA.[54] Spent fuel is usually housed inside the plant's "protected zone"[59] or a spent nuclear fuel shipping cask; stealing it for use in a "dirty bomb" is extremely difficult. Exposure to the intense radiation would almost certainly quickly incapacitate or kill any terrorists who attempt to do so.[60]

Nuclear power plants are designed to withstand threats deemed credible at the time of licensing. However, as weapons evolve it cannot be said unequivocably that within the 60 year life of a plant it will not become vulnerable. In addition, the future status of storage sites may be in doubt. Other forms of energy production are also vulnerable to attack, such as hydroelectric dams and LNG tankers.

Use of waste byproduct as a weapon

An additional concern with nuclear power plants is that if the by-products of nuclear fission—the nuclear waste generated by the plant—were to be unprotected it could be used as a radiological weapon, colloquially known as a "dirty bomb". There have been incidents of nuclear plant workers attempting to sell nuclear materials for this purpose (for example, there was such an incident in Russia in 1999 where plant workers attempted to sell 5 grams of radioactive material on the open market,[61] and an incident in 1993 where Russian workers were caught attempting to sell 4.5 kilograms of enriched uranium.[62][63][64]), and there are additional concerns that the transportation of nuclear waste along roadways or railways opens it up for potential theft. The UN has since called upon world leaders to improve security in order to prevent radioactive material falling into the hands of terrorists,[65] and such fears have been used as justifications for centralized, permanent, and secure waste repositories and increased security along transportation routes.[66]

Health effect on population near nuclear plants


A couple of fishermen near the Trojan Nuclear Power Plant.

Most of human exposure to radiation comes from natural background radiation. Most of the remaining exposure comes from medical procedures. Several large studies in the US, Canada, and Europe have found no evidence of any increase in cancer mortality among people living near nuclear facilities. For example, in 1991, the National Cancer Institute (NCI) of the National Institutes of Health announced that a large-scale study, which evaluated mortality from 16 types of cancer, found no increased incidence of cancer mortality for people living near 62 nuclear installations in the United States. The study showed no increase in the incidence of childhood leukemia mortality in the study of surrounding counties after start-up of the nuclear facilities. The NCI study, the broadest of its kind ever conducted, surveyed 900,000 cancer deaths in counties near nuclear facilities.[17]

Some areas of Britain near industrial facilities, particularly near Sellafield, have displayed elevated childhood leukemia levels, in which

The reactor dome is visible on the left, and the large cooling tower on the right.

children living locally are 10 times more likely to contract the cancer. One study of those near Sellafield has ruled out any contribution from nuclear sources, and the reasons for these increases, or clusters, are unclear. Apart from anything else, the levels of radiation at these sites are orders of magnitude too low to account for the excess incidences reported. One explanation is viruses or other infectious agents being introduced into a local community by the mass movement of migrant workers.[67][68] Likewise, small studies have found an increased incidence of childhood leukemia near some nuclear power plants has been found in Germany[69] and France.[70] Nonetheless, the results of larger multi-site studies in these countries invalidate the hypothesis of an increased risk of leukemia related to nuclear discharge. The methodology and very small samples in the studies finding an increased incidence has been criticized.[71][72][73][74] Also, one study focusing on leukemia clusters in industrial towns in England indicated a link to high-capacity electricity lines suggesting that the production or distribution of the electricity, rather than the nuclear reaction, may be a factor.

Nuclear proliferation

For more details on this topic, see Nuclear proliferation.

Nuclear proliferation is the spread of nuclear weapons and related technology to nations not recognized as "Nuclear Weapon States" by the Nuclear Nonproliferation Treaty. Since the days of the Manhattan Project it has been known that reactors could be used for weapons-development purposes—the first nuclear reactors were developed for exactly this reason—as the operation of a nuclear reactor converts U-238 into plutonium. As a consequence, since the 1950s there have been concerns about the possibility of using reactors as a dual-use technology, whereby apparently peaceful technological development could serve as an approach to nuclear weapons capability.

Original impetus for development of nuclear power came from the military nuclear programs, including the early designs of power reactors that were developed for nuclear submarines. In many countries nuclear and civilian nuclear programs are linked, at least by common research projects and through agencies such as the U.S. DOE. In the U.S., for example, the first goal of the Department of Energy is "to advance the national, economic, and energy security of the United States; to promote scientific and technological innovation in support of that mission; and to ensure the environmental cleanup of the national nuclear weapons complex."[75]

To prevent weapons proliferation, safeguards on nuclear technology were published in the Nuclear Non-Proliferation Treaty (NPT) and monitored since 1968 by the International Atomic Energy Agency (IAEA). Nations signing the treaty are required to report to the IAEA what nuclear materials they hold and their location. They agree to accept visits by IAEA auditors and inspectors to verify independently their material reports and physically inspect the nuclear materials concerned to confirm physical inventories of them in exchange for access to nuclear materials and equipment on the global market.

Several states did not sign the treaty and were able to use international nuclear technology (often procured for civilian purposes) to develop nuclear weapons (India, Pakistan, Israel, and South Africa). Of those who have signed the treaty and received shipments of nuclear paraphernalia, many states have either claimed to, or been accused of, attempting to use supposedly civilian nuclear power plants for developing weapons. Certain types of reactors may be more conducive to producing nuclear weapons materials than others, such as possible future fast breeder reactors, and a number of international disputes over proliferation have centered on the specific model of reactor being contracted for in a country suspected of nuclear weapon ambitions.

There is concern in some countries over North Korea and Iran operating research reactors and fuel enrichment plant. In 2006, North Korea detonated what they claimed was a functioning nuclear weapon, which analysis has indicated was fueled by plutonium, presumably diverted from their Yongbyon nuclear reactor.[76] North Korea has since signed a deal with the United States regarding its Yongbyon plant and has discontinued its nuclear activities. An IAEA report also recently cited "significant cooperation" by Iran and that it has slowed its enrichment of uranium. See also Nuclear program of Iran.

Aside from their plutonium-producing potential, some research reactors are considered proliferation threats because of their use of highly-enriched uranium (HEU) as their fuel. According to the IAEA, there are over 100 reactors in the world which continue to be fueled by HEU, though for decades work has pursued to convert these to operate with low-enriched uranium (LEU). In this case, the threat is not considered to be based on surrepticious weapons development, but rather that of theft of the enriched nuclear materials, which would help potential bomb makers subvert the largest hurdle in developing an enriched-uranium weapon.[77]

Floating nuclear power plants

Russia has begun building floating nuclear power plants. The £100 million ($204.9 million, 2 billion руб) vessel, the *Lomonosov*, to be completed in 2010, is the first of seven plants that Moscow says will bring vital energy resources to remote Russian regions. While producing only a small fraction of the power of a standard Russian land-based plant, it can supply power to a city of 200,000, or function as a desalination plant. The Russian atomic energy agency said that at least 12 countries were also interested in buying floating nuclear plants.[78]

Environmental groups and nuclear experts are concerned that floating nuclear plants will be more vulnerable to accidents and terrorism than land-based stations. They point to a history of naval and nuclear accidents in Russia and the former Soviet Union, including the Chernobyl disaster of 1986.[78] Russia does have 50 years of experience operating a fleet of nuclear powered icebreakers that are also used for scientific and Arctic tourism expeditions. The Russians have commented that a nuclear reactor that sinks, such as the similar reactor involved in the *Kursk* explosion, can be raised and probably put back into operation.[78] At this time it is not known what, if any, containment structure or associated missile shield will be built on the ship. According to MosNews, a Russian news outlet, there is no way an airliner striking the ship would destroy the reactor.[79]

Environmental effects

See also: Environmental concerns with electricity generation

The primary environmental impacts of nuclear power are damage through Uranium mining, radioactive effluent emissions, and waste heat. Like renewable sources, the majority of life cycle studies have found that indirect carbon emissions from nuclear power are many times less than comparable fossil fuel plants. Nuclear generation does not directly produce sulfur dioxide, nitrogen oxides, mercury or other pollutants associated with the combustion of fossil fuels (pollution from fossil fuels is blamed for 24,000 early deaths each year in the U.S. alone[80]).

Effluent emissions

Commercial nuclear power plants release gaseous and liquid radiological effluents into the environment as a byproduct of electrical generation, which are monitored in the US by the EPA and the NRC. Dose to a unaffiliated member of the public as a result of these emissions is typically on the order of 0.01 mrem.[81]

The total amount of radioactivity released through this method depends on the plant, regulatory requirements, and plant performance. Atmospheric dispersion models combined with pathway models are employed to accurately approximate the dose to a member of the public from the effluents emitted. Limits for the Canadian plants are shown below:

Regulatory limits on Radioactive Effluents from Canadian Nuclear Power Plants

Effluent	Tritium	Iodine-131	Noble Gases	Particulates	Carbon-14
Units	**(TBqb × 104)**	**(TBq)**	**(TBq-MeVc × 104)**	**(TBq)**	**(TBq × 103)**
Point Lepreau Nuclear Generating Station	43.0	9.9	7.3	5.2	3.3
Bruce Nuclear Generating Station A	38.0	1.2	25.0	2.7	2.8
Bruce B	47.0	1.3	61.0	4.8	3.0
Darlington	21.0	0.6	21.0	4.4	1.4
Pickering Nuclear Generating Station A	34.0	2.4	8.3	5.0	8.8
Pickering B	34.0	2.4	8.3	5.0	8.8
Gentilly-2	44.0	1.3	17.0	1.9	0.91

[82]

Indirect carbon emissions

Generation from nuclear power also does not directly produce carbon dioxide, which has led some environmentalists to advocate increased reliance on nuclear energy as a means to reduce greenhouse gas emissions (which contribute to global warming). Non-radioactive water vapor is the significant operating emission from nuclear power plants.[83]

According to a 2007 story broadcast on *60 Minutes*,[84] nuclear power gives France the cleanest air of any industrialized country, and the cheapest electricity in all of Europe.

Like any power source (including renewables like wind and solar energy), the facilities to produce and distribute the electricity require energy to build and subsequently decommission. Mineral ores must be collected and processed to produce nuclear fuel. These processes either are directly powered by diesel and gasoline engines, or draw electricity from the power grid, which may be generated from fossil fuels. Life cycle analyses assess the amount of energy consumed by these processes (given today's mix of energy resources) and calculate, over the lifetime of a nuclear power plant, the amount of carbon dioxide saved (related to the amount of electricity produced by the plant) vs. the amount of carbon dioxide used (related to construction and fuel acquisition).

A life cycle analysis centered around the Swedish Forsmark Nuclear Power Plant estimated carbon dioxide emissions at 3.10 g/kWh[85] and 5.05 g/kWh in 2002 for the Torness Nuclear Power Station.[86] This compares to 11 g/kWh for hydroelectric power, 950 g/kWh for installed coal, 900 g/kWh for oil and 600 g/kWh for natural gas generation in the United States in 1999[87].

UK Parliamentary Office Study

In a study conducted in 2006 by the UK's Parliamentary Office of Science and Technology (POST), nuclear power's lifecycle was evaluated to emit the least amount of carbon dioxide (very close to wind power's lifecycle emissions) when compared to the other alternatives (fossil oil, coal, and some renewable energy including biomass and PV solar panels).[88] In 2006, a UK government advisory panel, The Sustainable Development Commission, concluded that if the UK's existing nuclear capacity were doubled, it would provide an 8% decrease in total UK CO_2 emissions by 2035. This can be compared to the country's goal to reduce greenhouse gas emissions by 60 % by 2050. As of 2006, the UK government was to publish its official findings later in the year.[89][90] On 21 September 2005 the Oxford Research Group published a report, in the form of a memorandum to a committee of the British House of Commons, which argued that, while nuclear plants do not generate carbon dioxide while they operate, the other steps necessary to produce nuclear power, including the mining of uranium and the storing of waste, result in substantial amounts of carbon dioxide pollution.[91]

Storm and Smith publication

The report by Jan Willem Storm van Leeuwen and Philip Smith with the title *Is Nuclear Power Sustainable?* was prepared for circulation during the April 2001 United Nations Commission on Sustainable Development meeting, and again during the continuation in Bonn in July 2001. The report concluded that nuclear power is not sustainable because of increasing energy inputs. The report has been widely cited in arguments against nuclear power.

The report claims carbon dioxide emissions from nuclear power per kilowatt hour could range from 20% to 120% of those for natural gas-fired power stations depending on the availability of high grade ores.[92] The study was strongly criticized by the World Nuclear Association (WNA), rebutted in 2003, then dismissed by the WNA in 2006 based on its own life-cycle-energy calculation (with comparisons). The WNA also listed several other independent life cycle analyses which show similar emissions per kilowatt-hour from nuclear power and from renewables such as wind power.[93][94]

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See also

- Anti-nuclear
- Category:Nuclear power by country
- Control rod
- Electricity generation
- Energy: world resources and consumption
- Future energy development
- Nuclear contamination
- Nuclear physics
- Nuclear terrorism
- Radiation poisoning
- Radioactive contamination
- Renewable energy
- Spent nuclear fuel shipping cask
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Supportive

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