

Nuclear power development

Birth and rebirth

Towards the end of the 19th century, scientists began to look inside the atom, which had been postulated since ancient Greece to be indivisible. After learning that energy could be emitted from certain uranium minerals as radiation and later discovering that energy could in fact interchange with mass, scientists began to doubt if an atom was indeed indivisible. They began shooting electrically-charged particles into metal targets and saw that some of the atomic mass was converted into energy. However, the amount of energy emitted was far less than the energy input, and this resulted in the view that nuclear energy was only a scientific curiosity with no practical use.

It was in 1932 that the electrically-uncharged neutron as a subatomic particle was discovered. Experiments were conducted with neutrons hitting uranium targets and scientists were removing just a few particles at a time from the uranium nucleus. However in 1938, a small team of physicists were surprised that they produced from uranium the much lighter barium which needed the removal of about 100 or 40% of the particles from the uranium nucleus. It was suggested and later confirmed that the uranium atom had undergone “nuclear fission”, similar to the division of a living cell, and the process could be sustained since more neutrons than needed were released in the fission. This was verified in 1942 with a test reactor at The University of Chicago.

The practical use of nuclear energy was first driven by the development of technology to enrich the concentration of fissile uranium and to produce plutonium in a nuclear reactor for the manufacture of nuclear weapons, leading to destructive applications in 1945. While nuclear weapon technology has continued to develop afterwards, it was also recognised that the heat produced in a nuclear reactor could be harnessed as a source of thermal power. Subsequently, nuclear power was first produced in the Soviet Union in 1954, followed by commercial production in the UK in 1956 and the US in 1957. To prevent the spread of nuclear weapons and their technology, and with the aim of furthering nuclear disarmament and promoting the peaceful use of nuclear energy, the Treaty on the

Non-Proliferation of Nuclear Weapons was opened for signature by 1968 and entered into force in 1970. It has now been joined by 191 states out of 195 in the world.

Growth and setback

Various reactor prototypes were explored in different pioneering countries in the late 1950s, driven by the technology acquired by each that time. There were choices of nuclear material, reactor coolant and the material for slowing down the neutrons if necessary to enable nuclear fission. After a decade, reactor designs finally began to standardise, driven by synergy in nuclear fuel manufacture, the feedback of operating experience and regulatory requirements for improved safety equipment provision. Reactor capacity also began to increase to reach 1,000 MW per generating plant driven primarily by economies of scale.

In the late 1980s, the number of nuclear power generating units¹ in the world reached 400, but subsequently increased only marginally to slightly exceed 440 at the end of 2019. Typical capacity factor - the electricity generated by a power generating unit in a given period versus its maximum generation by design for the same period - increased from about 65% in the 1980s to about 80% in the 2000s. Figure 1 presents data which shows that annual nuclear electricity generation reached 2,800 TWh in 2006, equivalent to 14.5% of the annual electricity generation in the world.[1]

Figure 1 also shows that annual nuclear electricity generation marginally decreased in the 2010s, and with the continuous growth in world electricity generation, nuclear electricity provided a nominal 10% of the global electricity in 2019.

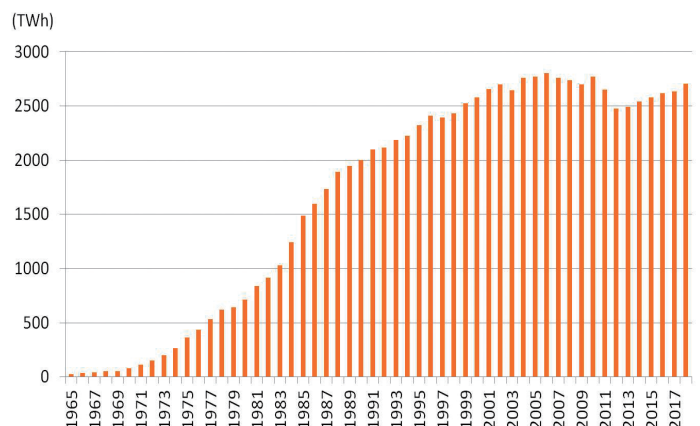


Figure 1: Nuclear electricity generation worldwide

All activities involve risks, and an operating nuclear power plant carries the risk of an accidental release of its radioactivity into the environment that may endanger public health. To address this issue, a civil nuclear facility receives oversight by a regulating body in nuclear safety and an operating licence is issued only after the necessary safety regulations are met. In the case of the US as an example, this assures the risk of the facility to the nearby public contributes only a very small fraction to overall risk. A nuclear power plant gradually incorporates more safety measures over time to address any new risks and technologies identified so as to keep risk at a level that is "as low as reasonably practicable."

While improving safety, such retroactive measures have an adverse effect on plant design and construction, as well as plant outage duration during operation. This in turn partly adds to design and operation complexity, construction project delay, budget overrun and cost increase. The need for better understanding of the physics to support engineering design and plant operations raised the complexity of such a large project that subsequently challenged nuclear electricity competitiveness particularly in an open unregulated electricity market.

There have been three notable accidents on record involving nuclear power plants in over 60 years of operation. Notwithstanding that the most severe accident that occurred in 1986 in the Soviet Union resulted in the immediate death of 35 emergency workers and some more subsequently attributable deaths, nuclear power is the safest form of established means of power generation on this count. Despite this, psychological upset and social disruption have occurred among the public and led to widespread social concern and, in some cases, outright opposition to nuclear power in some countries.

New challenges and opportunities

The increase in plant complexity with time and project unit cost measured in dollars per kilowatt can be addressed by having a larger plant, as illustrated in Figure 2 in the case of the data in the US.[2] This yields economies of scale to reduce project unit cost which restores some measure of competitiveness. However, the outcome is an increase in project complexity and the resulting engineering challenge, the size of project finance and the length of construction time. The result would raise the cost impact of any project delay and the risk of market change for the nuclear power plant. Another drawback of building a large plant, at nominally exceeding 1,000 MW each, is that it often leads to less frequent new plant construction. This is relevant particularly when supplying a more mature electricity market, and when it is attractive to extend the operating period of the plant to take advantage of the regular maintenance that has kept the plant in good condition. The general outcome is a reduced demand for equipment manufacture which weakens the sustainability of the supply chain, and in turn leads to fewer career opportunities and a greater challenge to knowledge and skill retention.

Nevertheless, the advancement of knowledge has enabled a fundamental rethink in the approach to safety, with better focus on risks and making more effective use of basic scientific principles and natural phenomena to provide safety without the need of active intervention by the plant operators or active engineering features. This new knowledge will contribute further to the safety of nuclear power plants, which will in turn facilitate regulatory and social acceptance.



Figure 2: Increase in installed capacity of a nuclear power generating unit over time in the US

To address the drawbacks of building large plants, a new approach is to return to building smaller plants, at nominally within 300 MW each. Certain designs may be made up of a cluster of smaller operable modules and manufactured in production lines that have better quality control than at construction sites. This approach will divide project finance into smaller and more manageable portions, which will enable earlier financial return by having earlier revenues from electricity sales since the construction time of a module is much shorter than that of a full plant project. The approach will also ease manufacture complexity since plant components will be much smaller. This in turn will better maintain continuous production and therefore sustain the supply chain, offering better expertise continuity and ultimately improving economic competitiveness.

Nuclear power can contribute to meeting the challenge of keeping atmospheric temperature rise to within 2°C, since it has virtually no carbon dioxide emissions. It will be interesting to see to what extent nuclear power will continue to be accepted in making a sustainable contribution to the environment and to humankind.

Note

1. It should be noted that a nuclear power plant may have more than one generating unit similar to other types of power plants.

References

- [1] BP. *Statistical Review of World Energy*. Retrieved 20 February 2020, from <https://www.bp.com/en/global/corporate/energy-economics/statistical-review-of-world-energy.html>
- [2] Nuclear Engineering International. 2011. *World Nuclear Industry Handbook 2011*.

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