NUCLEAR PLANTS

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Introduction

A nuclear power plant allows the production of steam without using fossil fuels. A nuclear reactor behaves like any boiler and the steam it generates can be used to operate a turbine connected to an electricity generator.

Nuclear reactors

In particular, the "heart" of the reactor of a fission nuclear power plant is called "core" and generally has the shape of a cylinder. The core is made of a liquid, for example water, into which cylindrical uranium bars are dipped, a couple of metres long and with a diameter of a few centimetres. At regular intervals there are control bars capable of absorbing many neutrons. Thus, the chain reaction is kept under control and stopped, if necessary. In the most common type of reactors, the water contained in the core is warmed by the fission of uranium and is circulated by means of a pump until it reaches a heat exchanger, into which it cools down producing steam which, in its turn, rotates the turbine of the plant. A reactor is classified according to the type of fuel, the type of coolant and the core's inner architecture. For example, a common distinction is made between light water and heavy water reactors.

Light water reactors

In light water reactors the fuel is made of cylinders of uranium oxide enriched with uranium 235. The water circulates among the cylinders and acts both as a controlling element and as coolant. The core is hosted in a pressurised steel container provided with the coolant intake and outlet holes. Shields to absorb the nuclear radiation are mounted around the container and the active parts of the reactor: the metal heat shield mainly absorbs gamma radiation; the concrete biological shield absorbs neutrons. Of course, the safety and emergency systems necessary to face possible nuclear accidents are paramount.

Heavy water reactors

The fuel of heavy water reactors is made of non-enriched natural uranium. There are more modern reactors called "fast" reactors, cooled by means of liquid metal and working with highly enriched fuel by converting uranium 235 into plutonium. The French Superphenix produces 1200 electric megawatt with a 40% total efficiency. However, such plants show several limitations, including the cost of the energy produced, 2-3 times higher that of a light water power plant.

The past and the future of reactors

Nuclear reactors can be classified into four generations, depending on some common characteristics and depending on the period in which they were designed and built. Currently, 440 reactors, mainly of the first and second generation, and some units of the third generation are operating.

The first generation includes prototypes and reactors for the production of electric power or plutonium for nuclear weapons, designed and built before the 70s. Generally, these reactors are characterized by low thermal power which, in the case of commercial power reactors means power generally lower than 300 MWe. In Italy, there are three nuclear power plants (Latina – 210 MWe, Garigliano – 160 MWe and Trino 270 MWe) which we can consider of the first generation. The plants were shut down in 1986 and at present are being dismantled.

The second generation mainly includes light water reactors, built and utilized starting from the 70s and 80s and which are still operating. Generally, these reactors are characterized by electric power ranging from 300 MWe to 1000 MWe. In Italy, the nuclear power plant in Caorso (860 MWe) can be considered a second generation reactor even if at present it is shut down and it is being dismantled.

The third generation refers to the advanced type of rectors which derive from the optimization, in terms of economy and safety, of the current light water reactors. Generally, third generation reactors are characterized by electric power over 1000 MWe. Often 3+ generation reactors are also mentioned. These include systems that may be introduced in the next 10-15 years, and therefore much before the fourth generation reactors, and meanwhile, these can also lead to advantages in the development of the same.

The fourth generation includes innovative nuclear systems which probably will reach a technical maturity after 2030. These nuclear systems are designed to supply energy in a very competitive manner from an economic point of view, and to extend and improve safety in case of accidents, to minimize radioactive waste, (in particular waste that remains radioactive for a long time), and to promote the rational use of natural resources (with a greater exploitation of fertile and fissile materials), to produce hydrogen directly (without having to pass through the production of electric energy) and to guarantee greater reliability.

Source: Agi Energia

Fusion reactor

The fusion reactor works according to the opposite principle to the fission reactor. The fission reactor divides the nuclei of heavy atoms and the resulting heat is released in order to heat water and activate, through the water vapour, a turbine that produces electricity. Instead in the fusion reactor, light atoms (hydrogen isotopes deuterium and tritium) are united into a helium atom (fusion). The fusion frees a bit more energy than the fission and does not produce any radioactivity.

In the fusion, only if two nuclei are located very close one to the other, the force of nuclear attraction melts them. The problem is that this force only act at very short distances, at thousand billion parts of a millimetre, and as the nuclei that are going to be melted are both positively charged, when they get closer, they tend to push back and do not melt due to another force, i.e. electrostatic repulsion, that acts on bigger distances and hamper the fusion.

In order to break that barrier, the nuclei have to be in excitement state, at more than a hundred million degrees temperature, when atoms are detached from their electron “shell”. This is the condition when the fusion naturally occurs between light atoms. The extremely high temperature that is needed to fusion plasma (the ionised hot mixture of deuterium and tritium, hydrogen isotopes), i.e. several million degrees, has not allowed to build a fusion reactor at industrial level. Nevertheless, the research is continuing to make important progress and the objective seems to be approaching.

Environment and territory

The nuclear energy is considered as one of the most environmentally friendly resources: it does not generate polluting emissions such as sulphides, dust or greenhouse gases. Moreover, its implementation allows a considerable reduction in the exploitation of the fossil fuel reserves. ***The advantages of nuclear fusion.*** One of the advantages of fusion is that the functioning of the reactor excludes any loss of control since the quantity of fuel used for the reaction and present inside the reactor is reduced (only a few grams) and the combustion only lasts a few seconds. Any minimum disturbance inside the reactor makes the plasma cool down, with subsequent spontaneous interruption of the fusion reaction. Fission reactors, instead, contain a large quantity of nuclear fuel (uranium) and, should an accident occur, the chain reaction stops, the heat produced inside can melt the core of the reactor and free the radioactive products with serious consequences. For this reason today they are extremely safe, always protected by the most sophisticated security systems and by at least two water-tightness shells. Another advantage of fusion is that it can be done almost anywhere; it does not depend on the availability of raw materials: its fuel, that is deuterium, is extracted from water. Moreover, the product of fusion is helium, i.e. that gas used to inflate balloons, and its waste looses its radioactivity in almost a hundred years (against the thousands of years needed for fission waste).

The risk of accidents

The environmental problem of nuclear power plants includes the danger involved in the process (which is dangerous in case of an accident or leak of radioactive material). As regards the operation of nuclear power plants, there is a risk connected to the possible leaks of radioactive emissions following accidents or operating defects which may lead to very alarming consequences, as happened on the occasion of the notorious "Chernobyl disaster".
Since it is very much like a normal thermoelectric power plant, the environmental impact of a nuclear power plant does not depend on its actual size, but rather on the safety of the equipment and the protection of the population. In an active nuclear reactor there are approximately 1,000 tonnes of radio, more or less the quantity which leaked out of the Chernobyl nuclear power plant. The development of nuclear energy requires that plants are at least far from densely populated areas. However, this is not enough since, in case of accident, the radioactive elements are dispersed into the atmosphere in amounts that are dangerous for human beings and can be transported by the wind for thousands of kilometres.

The INES scale

The INES scale (International Nuclear and radiological Event Scale) was developed, starting in 1989, by IAEA, the International Atomic Energy Agency, with the scope of classifying nuclear and radiological accidents and to make the public immediately aware of the gravity of each accident. The INES scale consists of 7 levels plus Level 0 under this scale, and it is subdivided into two parts: accidents (from Level 7 to Level 4), i.e. all the events that produce significant damages to people, the environment or to things, and incidents (from Level 3 to Level 1), in other words events that produce damages that are not very significant to people, the environment and to things. Level 0 is classified as a deviation. It is a logarithmic scale and the difference between one level and the next therefore, amounts to a ten-fold increase in the damages.

Level 7 – major accident. Major release, outside a large power plant, of radioactive material, over a very vast area, with consequent severe effects on the health of the population that is exposed, and severe consequences on the environment.

Examples:

- The disaster at Chernobyl, Ukraine, 1986. Overheating, up to the fusion of the core of a poorly protected nuclear reactor. Explosion (not nuclear) of the reactor and release of radioactive material in the environment.
- The disaster at Fukushima Dai-ichi (reactors 1, 2, 3) subsequent to the Sendai earthquake in March 2011, initially classified level 4, and subsequently, as the weeks passed, classified level 5, and over one month after the accident, after large losses of radioactivity, classified level 7.

Level 6 - serious accident. Significant release of radioactive material outside. The radiological equivalent amount of 1 to 10PBq iodine-131, which requires the complete implementation of planned countermeasures, which are part of an external emergency plan in order to limit the severe effects on the health of the population.

Examples:

- The accident in Kyshtym, Mayak, Russia, 1957. The breakdown of the cooling system of a nuclear fuel reprocessing plant, overheating and explosion (not nuclear) of the deposit involving release of radioactive material in the environment.

Level 5 - accident with off-site risk. Release, outside, of radioactive material - a radiological equivalent amount of 100 to 1000 TBq, requiring partial implementation of planned countermeasures. Severe damage to the reactor core or the protective barriers.

Examples:

- The accident at Three Mile Island, United States, 1979. Severe damage to the reactor core and the radiation protection barriers.
- Accident in Goiânia, Brazil, 1987. Radioactive contamination due to theft of radiotherapy equipment from an abandoned hospital.

Level 4 - accident without significant off-site risk [modification]. Accident with minor external impact, with radiological exposure of the surrounding population within the prescribed limits. Significant damage to the reactor core or the protective barriers. Exposure of a worker at the plant with fatal consequences.

Examples:

- Accident at the Windscale (currently Sellafield) reprocessing plant, United Kingdom, 1973.
- Accident at the Saint-Laurent nuclear power plant, France, 1980.

Level 3 - serious incident. Event with a very mild impact outside, with radiological exposure of the population in the surrounding area below the prescribed limits. Severe contamination in the plant and/or severe consequences on the health of the workers at the plant.

Level 2 – incident. Event with no external impact. Significant internal contamination of the plant and/or overexposure of workers at the plant.

Level 1 – anomaly. Anomaly beyond the authorized operating regime.

Level 0 – deviation. Event without consequences on safety.

The problem of nuclear waste

Another risk is connected to the disposal of radioactive waste. With reference to radioactive isotopes, it is necessary to plan a controlled storage of 500-700 years, while in the case of plutonium, it takes thousands of years.

The problems to be solved are related to the treatment of radioactive waste and the choice of geologically stable environments where waste can be deposited once it has been treated. Therefore, when a nuclear plant is going to be built, it is necessary to consider the possibility to rely on suitable deposits to store the production of radioactive waste and equipment to extract the plutonium from the irradiated material.

Actually, the quantity of waste produced from the nuclear sector is a lot lower than the quantity produced by burning fossil fuels. Many radioactive products deriving from the nuclear combustion cycle have a radioactivity that is similar or slightly higher than natural quantities. This waste is relatively easy to manage. Only a small fraction is highly radioactive and needs to be isolated.

Disposal of nuclear waste

The general considerations to be made about waste classification are:

- how long will the waste keep at a dangerous level?
- what is the concentration of radioactive material in waste?
- does the waste generate heat?

The persistence of radioactivity determines for how long the waste will have to be managed. The concentration and generation of heat indicate how they will have to be handled. These considerations also offer information on the most suitable methods to dispose of the waste.

The classification varies slightly from one country to another, but usually the internationally accepted categories are:

- extremely low radioactivity or no radioactivity;
- low radioactivity waste;
- intermediate radioactivity waste;
- high radioactivity waste.

Extremely-low radioactivity waste or not radioactive waste include neglectable quantities of radioactivity and can be treated like domestic waste.
Low-radioactivity waste includes the majority of the waste deriving from the fuel cycle. It includes paper, cloth, tools, clothes, filters and other waste that contains small quantities of radioactivity usually with a short life. It does not require any screen during handling, transport and volume reduction before the disposal. It represents 90% of the total volume, but only contain 1% of the total radioactivity.
Intermediate-radioactivity waste includes higher quantities of radioactivity and usually requires a screen. The screen can be a lead or water barrier to protect from penetrating radiations like gamma rays. Intermediate radioactivity waste essentially include resins, chemical mud, fuel metallic coating. They can be mixed with concrete or bitumen when disposed of.
High-radioactivity waste includes fission products and transuranic elements produced in the reactor, which are highly radioactive and generate heat. This waste represents more than 95% of the total radioactivity even if the quantity of material produced is modest, i.e. around 25-30 tons of extinguished fuel or three cubic metres per year of vitrified waste for a large reactor. In order to manage high-activity waste two different strategies are used: deep disposal and extended disposal. The first occurs inside stable and deep rocks and has undergone significant developments in the last ten years, especially with reference to knowledge, characterisation and modelling of natural safety barriers or artificial barriers. The second, instead, is considered by the community as an alternative to deep disposal. High-radioactive waste keeps radioactive for a long period of time, therefore it is necessary to keep it distant from people for thousands of years, until its radioactive level is reduced. Geological deposits are created between stable rocks in the countries that most use nuclear waste. Each country has the responsibility to dispose of its own radioactive waste, even though some countries (Russia, China), have declared they are ready to host in their own territory, under payment, the radioactive waste coming other countries. A geological deposit is normally located at 500 metres underground in a rock, clay or salt formation. The basic concept is the "multiple barrier" principle: radioactive waste, as oxide ceramics (irradiated fuel) or vitrified are then "immobilized". Then, they are "sealed" inside corrosion-resistant containers, such as stainless steel or copper and, finally, they are "buried" inside a stable rocky formation.
Other methods to stabilize high-activity waste are now being investigated. One of the most advanced methods is called ynroc, a ceramic that comprises three titanate minerals that are geo-chemically stable and that can include radioactive waste elements in their crystal structure, immobilizing them.

Decommissioning

Beginning from the initial planning and design stages and the identification of the site, a nuclear power plant is a very complex plant to deal with. Each stage of its realization and each successive life-cycle of the power plant must be carefully controlled in order to guarantee maximum safety. After the operating period is over, a nuclear power plant still requires a great amount of attention because it is not sufficient to "shut down" the power plant in order to cancel all possible risks. The fuel, the waste products and the plant itself continue to be dangerous as they are radioactive for a

very long period of time. The many procedures to be followed in order to dismantle a nuclear plant are known as decommissioning. The final aim is to restore the initial situation and therefore permit the destination of the area to any type of use.
The shutting down operations of a nuclear power plant are very long, complex and costly and can be summarized as follows:

- initial plant shut-down;
- decommissioning of used nuclear fuel present in the power plant;
- processing of radioactive waste accumulated during plant operation and forwarding of the same to the deposit;
- decontamination and dismantling of the equipment, plants and buildings;
- processing (if radioactive) of materials deriving from the dismantling operations and forwarding them to the deposit or disposal of the same;
- characterization, requalification and release of the site for other uses.

According to the IAEA scale, the following general decommissioning strategies can be used:

- DECON (Decontamination) – Immediately, after the plant is stopped, dismantling procedures are begun in order to complete the decommissioning operations as soon as possible. Generally, this operation is chosen when a new power plant is planned on the same site, or if the site needs to be released for other uses in a short period of time.
- SAFESTOR (Safe Storage) – The fuel and waste products are taken away and the plant is kept safe for a few decades, awaiting the decay of the radioactivity to more acceptable levels in order to carry out the dismantling operations, which are then followed by the DECON strategy.
- ENTOMB (Entombment) – The radioactive parts of the plant are confined (i.e. encased in a concrete material) awaiting decay to environmental background levels.

At present, worldwide, there is no definite choice with regard either a Decon or Safestor strategy, while the Entomb strategy is practically never carried out for the high power nuclear power plants. In fact, opting for an ENTOMB strategy is the equivalent of transforming all nuclear sites into a site for the final dismantling of radioactive waste.
In some cases, for example Chernobyl, entombment became the only possible choice. Up to date it has only been used for some demonstrative low power reactors in the United States but has never been considered for high power nuclear reactors.
In Europe and in the USA the two strategies, SAFESTOR and DECON, exist side by side. In Germany preference has been given to the DECON strategy, while in France and in the United Kingdom, usually the SAFESTOR strategy has been chosen. In the same country there can be changes in strategy during the course of time. In Italy for example, the initial strategy was SAFESTOR, but later the choice fell on DECON, which however did not lead to advantageous consequences with regard to the strategy for the management of radioactive waste.

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