NUCLEAR KNOWLEDGE

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Introduction

The atom is the smallest part of each element found in nature which preserves its chemical properties; for a long time, it was considered to be indivisible (from the Greek word *ατομος*, atomos, that which cannot be cut). In reality, it is made up of a **nucleus** (formed by protons and neutrons) surrounded by **electrons** able to promote chemical reactions that can produce energy (for example combustion reactions).

What is it

Use of nuclear energy stems from the possibility of using the considerable energy present in the atom's nucleus, much greater than the energy obtained from chemical reactions where the atom's nucleus is not involved. Nuclear power can be produced both by **nuclear fission** (separation of the nuclei of heavy radioactive materials) and by **fusion** (combination of the nuclei of lighter elements). Of the two reactions, fission is the only one that can be achieved and controlled by humans, using the necessary technical precautions linked to prevention of incidents and management of radioactive waste.
On the contrary, it is not yet possible to use fusion for sufficiently long times for continuous production of energy. Indeed, as yet there is no device able to contain hydrogen and keep it "trapped" for long enough at sufficiently high temperature to make aggregation of the nuclei possible.

What it is for

The heat generated during the transformation of nuclear energy into thermal energy, regardless of it being obtained from uranium or plutonium, can be used to obtain mechanic energy, i.e. to move a machine (e.g. a turbine). The efficiency of this transformation depends on the temperature at which the boiler can operate, i.e. the nuclear reactor. The mechanic energy is then converted into electricity by an alternator connected to a turbine. Nuclear fuels are used, for example, to produce energy on big ships and submarines. The energy provided by nuclear motors is useful both to move propellers and for the other services on board. In the past researchers studied the possibility to transform the nuclear energy directly into chemical energy or to use the heat directly for heating purposes or to allow the production of the metal industry. Today such hypotheses have been discarded since they are not economically viable and also for safety reasons. Following that decision, the operating temperature of many nuclear power plants was reduced, thus limiting dangers but also efficiency. After those modifications, a nuclear reactor today supplies heat at a lower temperature as compared to a traditional thermoelectric power plant.

Where it is

As for the other non-renewable sources of energy, such as coal, petroleum and natural gas, we must estimate how much nuclear combustible is available on the Earth and at what price. In nature an enormous quantity of natural uranium is present. The oceans, for example, contain approximately one billion cubic kilometres. In 2019, world uranium reserves amounted to 6,147,800 tons of uranium. Uranium is present in the ground at an average concentration of 4-5 milligrams per kg, while in the sea the concentration is 3-4 milligrams of uranium per ton of water – however, extraction of this uranium is not economically convenient because the concentrations are very low, and the costs would exceed 1000 dollars/kg. The largest known reserves of uranium that can be extracted are in four countries, which together account for 60% of the resources: Australia (28%), Kazakhstan (15%), Canada (9%) and Russia (8%) (*Source: World Nuclear Association*).
Also thorium is a fissile element: thorium reserves could be integrated with uranium reserves, for reactors designed for the purpose. Besides the above, self-fertilizing reactors can also produce fissile combustible. Therefore, nuclear fuel may be practically inexhaustible, in a historical perspective. It must also be pointed out that the incidence of fuel on the cost of electric energy produced from a nuclear source is approximately 15%, while the incidence of petroleum and gas is approximately 80%, even though the costs of nuclear reactors must be assessed bearing in mind the entire cycle of nuclear energy, which is much more complex than the other energy resources. In fact, these costs include the entire fuel cycle, the construction, management and safety of the power plant, including emergency conditions, waste disposal and dismantling the plant, if necessary. Furthermore, the economic characteristic and efficacy of the nuclear reactors' fuel reprocessing plants, which enable the recovery of spent uranium, must be assessed.

A bit of history

The instability of nuclei and the freeing of ionising radiation (each electromagnetic radiation capable of producing ionisation in atoms or molecules of the body it goes through, i.e. the ejection of an electron from the atomic structure with the ensuing creation of a pair of ions, positive and negative) is present naturally but it started being considered from the scientific viewpoint only on the occasion of the study of the x rays conducted by Roentgen in 1895. During the 20th century vital research was conducted leading to the atomic fission.
First of all, in 1934 Mr. and Mrs. Curie identified the first case of artificial radioactivity. In 1942, after a series of "home-made" experiments in the legendary Roman institute in Panisperna street, the Italian physic Enrico Fermi carried out the first fission experiment under controlled conditions. Thus, the first nuclear reactor was created at the University of Chicago. That research belonged to the effort made by the American scientists which three years after led them to manufacture and drop the first atomic bomb on the Japanese city of Hiroshima (80,000 killed instantly). After the world war, in 1954, the first electro-nuclear power plant – albeit moderately powerful (5 megawatt) – started operating in the Soviet Union. The first nuclear power plant aimed at the production of electric energy to be sold on the market dates back to 1956 and was built near Calder Hill, in England.

During the second half of the last century the production of electric energy from nuclear fuel increased up to 11% of the world energy production. In particular, in 2022 the world counted 440 operating nuclear power plants and 55 being built.
The birth of nuclear energy, as a tangible source of energy can be dated back to the mid-Sixties when the economic competitiveness of nuclear energy was demonstrated. Development accelerated greatly initially, but subsequently there was a slowing down due to violent protests with regard to its safety, which led to increased financial difficulties caused by the delays in granting authorizations for operation of the plants by the National Authorities for safety. In some cases, the Authorities imposed substantial changes in the operating plants, and even the total shutdown of some plants. The accidents at Three Mile Island (1979), Chernobyl (1986) and in the power plant in Fukushima in Japan (March 2011), revived controversies on the choice of nuclear energy. The last accident was by far the most dangerous, and for this reason the impact on public opinion was remarkable. In Italy, following a new popular referendum (after the referendum of 1987, following the accident in Chernobyl, nuclear power plants in the Italian territory were shut down), in June 2011, nuclear power for the production of electricity was newly abandoned.

Radioactivity

Radioactivity is indeed a physical phenomenon in which unstable nuclei are transformed into nuclei of other elements or isotopes (identical atom nuclei from the chemical viewpoint but with different mass, owing to the different number of neutrons) of the starting nuclei, by emitting nuclear radiation. The core, before decaying to a lower energy level, can remain in a radioactive state for a period of time ranging from a fraction of a second to 100 million years. Radioactivity is naturally present in the Earth's environment, it has biological effects on human beings due to its ionizing characteristics. These effects are exploited in medical diagnostics (X-rays, scintigraphy/body scans, Computer Assisted Tomography, Positron Emission Tomography etc.) and in anti-tumour therapies (radiotherapy, boron neutron capture therapy, particle or hadron therapy) but they can be harmful if they are not administered carefully. In fact, over a certain limit, radiation can become very dangerous for human health, also in relation to the time of exposure. Radioactivity is dangerous specially if the radioactive elements have a very long "half-time" (transformation into other nuclei) that can last millennia, and they become fixed permanently in the human body or in other living creatures. Radioactivity is also used for sterilization, and to examine the properties and defects of construction materials.
The production of nuclear waste, generating radiotoxic elements, is extremely important and delicate in the nuclear power production cycle and great attention must be paid so that no situation arises in which radioactive elements come into contact with human beings.

Nuclear fission

Fission is the breaking of the nucleus into two fragments through the action of neutrons on very heavy nuclei, i.e. uranium 235, thorium 232, plutonium 239, etc. The main effects of this phenomenon are: the release of a large quantity of energy and the simultaneous emission of 2-3 neutrons that activate a reaction, provoking new fissions and starting a chain reaction. During nucleus fission energy is released and, if kept carefully under control, it can be exploited to produce electricity. Some of these heavy elements, like uranium 235 (92 protons and 143 neutrons), are located in deposits and in order to obtain them it is necessary to extract them from the soil. Others, like plutonium 239 or uranium 233, are artificially produced by men. Uranium in nature is present mainly in the form of uranium-238 (not fissile) and only a small proportion of uranium-235 (0.71%).

Nuclear fusion

Nuclear fusion is the process that since ancient times has used solar and star energy to activate fusion reactions between hydrogen nuclei. Fusion reaction starts from very light nuclei that aggregate. By joining together, they become heavier and loaded with a great "binding energy". For example, a mixture of hydrogen nuclei (1 proton), deuterium and tritium (1 proton and 1 or 2 neutrons) can trigger a reaction which, through various passages, leads to the creation of carbon nuclei.

In order to let the reaction occur, the two reacting particles must have a sufficient quantity of kinetic energy to overcome the repulsive barrier created by the electric charge of the nuclei. This means that it will be necessary to reach extremely high temperatures, where the matter is in plasma state. The most studied reaction, which is also the least difficult, is “deuterium plus tritium”, with a trigger temperature of 100 million degrees centigrade. Deuterium is an isotope (atom of an element with the same number of protons, but with a different number of neutrons) of hydrogen, whose nucleus is made up of a proton and a neutron. It is present in water with the proportion of 1 out of 7,000 atoms of normal hydrogen, therefore it cannot be depleted. Tritium is another hydrogen isotope, made up of a proton and two neutrons. It is radioactive, with a half-life of 12 years and it is produced by bombing lithium by means of neutrons. Indirectly, lithium is therefore the energy raw material.

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