Atomic Power

Fission Power

More about atomic energy. Atomic energy is the same as nuclear energy. It has a bad reputation because of its radioactive waste and its association with the atom bomb. A group of major countries is seeking a safer form of nuclear power (less contamination), and has undertaken a global program on plasma fusion energy, called ITER, to meet this goal.

Today's atomic power is mainly a classical nuclear physics discipline. It is concerned with generation and capture of free neutrons, and the splitting of uranium and plutonium atoms. Generation of massive amounts of heat by uranium fission is made possible by three aspects of nuclear physics. First, the most stable nuclei are those corresponding to mid-mass elements with a mass somewhat heavier than iron. Language-wise, protons and neutrons are lumped together and called nucleons. The lowest energy arrangement of nucleons is the most stable nucleus. The iron we mine is a mixture of 4 different nuclei, each having a different mass. This is to say that iron has 4 stable isotopes. The most abundant form of iron nucleus is the iron-56 isotope, which is written ^{56}Fe. It has 56 nucleons, of which 30 are neutrons and 26 are protons. The other isotopes have the same number of protons, but a different number of neutrons. The uranium used in nuclear power plants is the uranium-235 isotope, written ^{235}U. It has 143 neutrons and 92 protons. It is a much less stable than ^{56}Fe in the sense that its binding energy per nucleon is much lower than that of ^{56}Fe and much lower than that of other elements in the mid-mass portion of the Periodic Table of elements. At the beginning of WWII it was already known that if a uranium nucleus could be split into two pieces, a lot of energy would be released.

Nuclear power became available when a way was found to split a uranium nucleus into 2 pieces. In nuclear power plants it is not the ^{235}U nucleus that splits. It is its neighbor isotope ^{236}U. When ^{235}U absorbs a neutron, it becomes ^{236}U in a highly excited state. The over-energized ^{236}U nucleus has too much vibration energy and flies apart in 2 pieces: it undergoes fission. The reason that ^{236}U is so highly excited is that even-numbered nuclei are generally much more stable than neighboring odd-numbered nuclei.

The 2 fragments produced by fission of uranium have a higher neutron/proton ratio than other nuclear configurations in the mid-mass range of elements. The excess neutron/proton ratio makes the fission fragments unstable and highly radioactive. As a result, neutrons inside the nucleus want to decay into protons plus electrons and antineutrinos, in a process called beta-decay (β-decay). The emission of β-rays (high energy electrons of nuclear origin) is frequently accompanied by emission of gamma-rays (high energy x-rays of nuclear origin). Successive conversion of neutrons into protons eventually creates stable nuclear end-products.

Plutonium-239 is a man-made nuclear fuel produced when the most common form of uranium, ^{238}U, absorbs a neutron. The ^{238}U isotope is about 140 times more plentiful than the ^{235}U isotope in mined uranium. The reaction sequence is

$$^{238}\text{U} + \text{n} \rightarrow {}^{239}\text{U} \rightarrow {}^{239}\text{Np} + \text{electron} + \text{antineutrino} + \text{gamma} \;\; ;$$

$$^{239}\text{Np} \rightarrow {}^{239}\text{Pu} + \text{electron} + \text{antineutrino} + \text{gamma} \quad ,$$

where n is a neutron, Np is Neptunium, and Pu is plutonium. ^{239}Pu is a synthetic nuclear fuel and acts much like ^{235}U.

Operation of a commercial nuclear power plant depends on a neutron chain reaction. When a ^{236}U nucleus splits in two, it produces free neutrons in the fragmentation process. On the average, more than one free neutron is produced. It would take one free neutron per fission to keep a chain reaction going if no free neutrons escaped or were lost in "sterile" absorptions that do not produce fission. But some neutrons are always absorbed in non-fission reactions. The power plant operator must ensure that just the right number of neutrons get absorbed in "sterile" absorptions. Otherwise, heat production will either increase exponentially, or die down exponentially. The power plant maintains a desired number of free neutrons by mechanically inserting or removing a control rod containing a non-fissionable neutron absorber, like cadmium or boron. In contrast, the bomb maker seeks to make the increase in number of free neutrons as fast as possible.

As you can see, the physics of commercial power plants is much the same as that of an atomic bomb. There is a difference in the ^{235}U/^{238}U ratio in the fuels employed. But guaranteeing that no bombs are being made in a nation running its own nuclear power plants is a difficult task. This task is assigned to an international monitoring agency. Nuclear proliferation is probably the most serious problem threatening the survival of a not very peaceable 6-billion person world society.

Fusion Power

The alternate way of harnessing nuclear energy is fusion. Nuclear fusion is the process that powers the sun. The enormous amount of hot hydrogen gas in the center of the sun supports a very low rate of nuclear reaction, in which normal hydrogen H is slowly being converted into helium over the course of a few billion years. The gradual release of nuclear fusion energy is sufficient to keep the center of the sun very hot. The energy gradually leaks out of the sun in the form of infrared, visible, and ultraviolet light. The visible light energizes the biosystem of Earth, of which we are a part.

The fusion process in the sun is called "plasma fusion". The global community has committed billions of $ to develop plasma fusion as an alternative form of nuclear energy, with the goal of generating electricity with less radioactive waste than produced by fission, while tapping an essentially endless supply of heavy hydrogen fuel. Unfortunately, plasma instability problems associated with containing the required super hot plasma have delayed the development process. There is no guarantee of success. Some would say that the likelihood of commercial success in the 21st century is small. Although the radioactivity problem is small compared to that of uranium fission, it is not negligible. Radioactive equipment is costly to repair. The amount of future effort in this area is uncertain.

In addition to plasma fusion, fusion has been made to occur at laboratory equipment temperature. Laboratory temperature fusion is called "cold fusion". There are two forms of cold nuclear fusion energy that have been demonstrated in the laboratory. The first discovered form was observed in 1956, in a reaction called "muon-catalyzed fusion". Muons are radioactive unstable particles that were first identified in cosmic rays, and subsequently found as secondary decay products in nuclear physics accelerator experiments. There are 3 types of muons: positive, negative, and neutral. The negative muon is very much like a heavy electron. Its mass is ~200 times that of an electron. It is an unstable "meson". The negative muon decays into an electron and a muonic antineutrino in about 2 microseconds (2.1×10^{-6} s). If you mix negative muons and hydrogen gas, you end up with very small hydrogen ionic molecules like H_2^+ in which the separation between paired hydrogen nuclei is about 200 times smaller than in a normal H_2 molecule. In terms of volume ratio, which determines density, the factor is 8 million. The element hydrogen H has 3 isotopes, ^1H, ^2H, and ^3H. These are often designated H, D, and T, where D stands for deuterium and T stands for tritium. H and D are stable isotopes, whereas T is a man-made radioactive isotope. Nuclear physicists generally use "d" for the deuterium nucleus, which is called a deuteron. Muon-catalyzed fusion works best with the DT^+ muonic molecule, but also is observed with the D_2^+ muonic molecule. The reaction process always creates copious neutrons, energetic particles, and sometimes gamma-rays. The process was explained quantitatively by J. D. Jackson in 1957. Many studies have been carried out to see whether there could be some way of efficiently producing enough negative muons to make muon-catalyzed fusion a practical energy source. The process is not a good candidate for future energy production. The energy required to replace the decaying muons turns out to be greater than the electrical energy that could be produced.

The clean energy cold fusion discussed in this book is the second form of cold fusion. Unlike muon-catalyzed fusion, it does not depend on high density. It is a remarkably beneficent form of nuclear energy. It was discovered by two chemists, Martin Fleischmann and Stanley Pons (F-P), about 20 years ago. Because high densities are not involved, and because of a special "quantum" geometry that must be imposed, there is no emission of energetic particles or gamma rays allowed. The primary nuclear product is helium, which is a harmless gas. The response of the consensus science community was disbelief. Fusion heat production without radiation seemed too good to be true. Cold fusion violated the consensus view that chemistry can never affect nuclear physics. Fusion without neutrons and energetic particles violated every aspect of known fusion physics. Initial skepticism was increased by quick attempts to reproduce the F-P experiments. These first verification experiments showed little evidence of fusion heat. Even F-P had difficulty in reproducing their first results for a half year. Nevertheless, a few scientists accepted the initial published laboratory evidence. They questioned the majority view, respected the F-P data, and stuck to the rule that lab and observations are the boss. Eventually, F-P and a number of others obtained new evidence that some sort of nuclear process was being made to occur by chemical means. Today's evidence is conclusive.

During cold fusion's first decade, supporting evidence for heat production accumulated, but poor reproducibility of the F-P process persisted. Only the research team of Yoshiaki Arata and YueChang Zhang (A-Z), using nanometer size palladium powder, seemed to get consistent results If the F-P discovery was correct, there was some sort of instability or unknown factor involved. An inconsistent process is not the sort of thing one needs for generating home heat and electricity. It is not surprising that research support in this area has been lacking.

We now know a lot more about the F-P process than we did in the early 1990s. Conditions leading to heat production have been identified. Studies have shown a quantitative match between helium production and nuclear heat produced. Two types of instability that have plagued earlier work have been identified. A-Z methods involving a new type of fine metal powder have recently led to easier reproducibility. Empirical factors that control F-P heat production in bulk metal have been identified.

Cold fusion depends on a physical configuration that can only be understood in terms of quantum mechanics. However, one does not need quantum mechanics to understand the engineering and operation of the new experiments that have shown that workable cold fusion heaters can be built. But, one does need some quantum mechanics to understand why the cold fusion process works.