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# Analysis of the Application of Atoms in Nuclear Fission and Fusion

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**Abstract:**
This paper delves deeply into the application of atoms in nuclear fission and nuclear fusion. Nuclear fission and nuclear fusion, respectively originated from the exploration and utilization of the energy mysteries of atomic nuclei. Nuclear fission is often used in military applications and civilian nuclear power plants, while nuclear fusion began with the theoretical exploration of the energy sources of stars. Due to the high difficulty of controllable and drastic changes, it is still in the process of exploration and development. First, the basic principles of nuclear fission and fusion are expounded. Then, the applications of nuclear fission in energy, military, medicine and other fields are introduced in detail, as well as the potential applications and challenges of nuclear fusion in the energy field. By comparing the characteristics of the two in terms of energy utilization, safety, waste treatment, etc., the importance and application prospects of atoms in these two reactions are demonstrated, providing references for related fields and decision-making.

**Keywords:** Atoms, Nuclear fission, Nuclear fusion, Applications

## 1. Introduction

Since the early 20th century, based on Rutherford's atomic nucleus model and Einstein's mass-energy equation, the theory that "atoms contain tremendous energy" has begun to gain wide recognition. Nuclear fission and nuclear fusion, as two ways to obtain nuclear energy, have profoundly changed the course of human social development since their discovery. Among them, nuclear fission has been widely applied in fields such as energy and the military. Nuclear fusion, with its potential advantages such as cleanliness, high efficiency and abundant raw materials, has become an important research direction for future energy development. It is of great significance in many aspects, including addressing the current global energy shortage, promoting scientific and technological progress and ensuring international security.

This paper, through the method of literature review, investigates the basic principles of nuclear fission and fusion, and their applications. This paper provides a comprehensive foundation of nuclear fission and fusion, offering valuable insights and references for future research and practical applications in the field of nuclear science.

## 2. Basic Principles of Nuclear Fission and Nuclear Fusion

Nuclear fission refers to the process in which heavy nuclei (such as uranium-235, plutonium-239, etc.) split into two or more atomic nuclei after being bombarded by neutrons. Taking uranium-235 as an example, when a uranium-235 atomic nucleus is bombarded by a neutron, it becomes unstable and splits into two lighter atomic nuclei, simultaneously releasing 2 to 3 neutrons and a large amount of energy. The neutrons released by this reaction can react with other uranium-235 atomic nuclei, thereby triggering a chain reaction and continuously releasing energy.

Nuclear fusion refers to the process in which two light nuclei (such as deuterium and tritium, isotopes of hydrogen) overcome the repulsive force between atomic nuclei and merge into a heavier nucleus under extremely high temperatures (about 100 million degrees Celsius) and extremely high pressures. During this process, there is a mass loss, and according to the mass-energy equation, it can be deduced that a large amount of energy is released. Take the fusion of deuterium and tritium as an example. Nuclear fusion reactions require extremely high temperatures and pressures to enable light nuclei to approach each other and undergo fusion reactions [1,2].

## 3. Applications of Nuclear Fission

### 3.1 Energy Generation

Nuclear fission power generation is currently the main way to utilize nuclear energy. Nuclear power plants use nuclear reactors to control the rate of the nuclear fission chain reaction and convert the thermal energy generated by fission into electrical energy. In a nuclear reactor, nuclear fuel (such as uranium-235) continuously undergoes fission reactions under controlled conditions, releasing heat energy that raises the temperature of the coolant (usually water), generating high-temperature and high-pressure steam. The steam drives the turbine to rotate, which in turn powers the generator to produce electricity.

Compared with traditional fossil energy power generation, nuclear fission power generation has the advantage of high energy density. The energy released by the complete fission of 1 kilogram of uranium-235 is equivalent to that released by the complete combustion of 2,000 tons of coal. This enables nuclear power plants to provide a large amount of electricity while reducing the transportation and storage costs of fuel. At present, many countries around the world have nuclear power plants, such as the United States, China, France and so on. However, nuclear fission power generation faces some problems, such as the difficulty in handling nuclear waste.

Fast reactor technology, as an important application of nuclear fission technology, brings new opportunities for the sustainable development of nuclear energy. The common type of nuclear reactor is the pressurized water reactor, which requires neutrons to be slowly converted into thermal neutrons to react with uranium-235. In contrast, fast reactors directly utilize high-energy fast neutrons to trigger nuclear fission. The core area of the fast reactor is loaded with plutonium-239 as fission nuclear fuel, surrounded by uranium-238. When fast neutrons fly out of the core area and strike uranium-238, uranium-238 absorbs the neutrons and undergoes several decays to transform into plutonium-239, achieving fuel proliferation. In large fast reactors, for every 10 plutonium atoms consumed on average, 12 to 14 new plutonium atoms can be produced. Academician Xu Mi of the Chinese Academy of Engineering pointed out that the utilization rate of uranium resources by pressurized water reactors is only about 1%, while fast reactors can increase it to 60% - 70% [3]. Fast reactors can not only increase fuel production but also handle the spent fuel generated by ordinary nuclear power plants. By placing long-lived actinide nuclides in the fast reactor for reaction, the radioactive decay period can be shortened to two or three hundred years, significantly reducing the long-term toxicity risk of nuclear waste.

### 3.2 Military Weapons

The atomic bomb is a typical application of nuclear fission in the military field. The atomic bomb utilizes the nuclear fission chain reaction to release tremendous energy in an instant, generating intense photothermal radiation, shock waves and nuclear radiation, and possesses powerful killing and destructive power. During World War II, the United States dropped atomic bombs on Hiroshima and Nagasaki in Japan on August 6 and 9, 1945, respectively. This was the first time in human history that nuclear weapons were used in actual combat, which had a significant impact on the course of the war. In addition to direct military strikes, nuclear weapons also play a significant deterrent role in international relations, influencing the military strategies and foreign policies of various countries.

The new generation of nuclear weapons, characterized by

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adjusting and controlling the energy of nuclear explosions, is constantly evolving, such as the neutron bomb, which is a special type of hydrogen bomb that uses the large number of high-energy neutrons produced during light nuclear fusion for killing and destruction. It belongs to the third generation of nuclear weapons. The main nuclear charge of a neutron bomb is a mixture of deuterium and tritium. The atomic bomb used for detonation is smaller, with only a few hundred tons of TNT equivalent. Moreover, its shell is made of beryllium and beryllium alloy, allowing high-energy neutrons to freely escape and reducing the range of radioactive contamination. The equivalent of a neutron bomb is generally 1,000 tons of TNT. Its explosion can be released in all directions in the form of a fast neutron stream, with a particularly strong nuclear radiation effect. It can penetrate tanks, bunkers and brick walls to kill people, while causing little damage to weapons and buildings, and has low radioactive pollution. The military can quickly enter the target area for combat after an attack and can be used as a tactical nuclear weapon.

### 3.3 Medical Applications

In the field of medicine, radioactive isotopes produced by nuclear fission have extensive applications. For instance, gamma rays produced by cobalt-60 are used for tumor radiotherapy. Gamma rays can destroy the DNA of tumor cells, inhibit their growth and division, and thus achieve the purpose of treating tumors. In addition, radioactive isotopes can also be used in medical diagnosis. For instance, iodine-131 is used in the diagnosis and treatment of thyroid diseases. By detecting the distribution and metabolism of radioactive isotopes in the body, doctors can obtain functional information about internal organs and assist in the diagnosis of diseases.

Boron neutron capture therapy (BNCT) is an emerging application of nuclear fission in the medical field. Its essence is binary targeted therapy. The non-toxic boron drug penetrates into cancer cells like a “Trojan horse”, and thermal neutrons act as “igniters” to trigger nuclear fission. The alpha particles and lithium ions produced have a range of only one cell diameter, and almost all the energy is deposited within the cancer cells, causing minimal damage to the surrounding normal tissues. The BNCT equipment in Dongguan has complete independent intellectual property rights and shows great potential in treating difficult-to-treat diseases such as recurrent head and neck tumors, advanced nasopharyngeal carcinoma, and malignant glioma [4].

### 3.4 Other Applications

Nuclear fission also plays a role in fields such as industrial flaw detection, food preservation and agricultural breeding. In industrial flaw detection, radioactive isotopes are used to emit rays to detect internal defects in metal materials or components, ensuring product quality. In terms of food preservation, irradiating food with gamma rays can kill harmful microorganisms such as bacteria, viruses and parasites in food, thereby extending the shelf life of food. In agricultural breeding, radioactive rays are used to irradiate seeds, inducing gene mutations in seeds and cultivating new varieties with superior traits.

In the field of cultural relics research, nuclear technology, with its unique advantages of strong penetration and non-destructive analysis, can be used to determine the age and origin of artifacts. For instance, through the neutrons released by the operation of the reactor, the atoms in the ancient ceramic samples are captured by neutrons and become excited states. When the excited atomic nuclei return to a stable state, gamma rays are released. By this, the elemental composition and content of the samples can be inferred, thereby identifying the kiln sites of cultural relics. In the field of security inspection, the X-ray imaging security inspection equipment developed based on the interaction between ray particles and matter is widely used in customs container inspection, security checks at airports, stations and docks, as well as anti-terrorism detection, etc., to ensure national security and public security. The energy generated by nuclear fission can also be used for industrial steam supply. For instance, the steam energy supply project of Tianwan Nuclear Power Plant uses nuclear power steam as a heat source for industrial production, which can effectively reduce energy consumption and carbon emissions.

## 4. Applications of Nuclear Fusion

There are significant differences in the development and application of fusion and fission. Different from fisson, fusion cannot be stabilized right now. So, all kinds of developments are still in exploration.

### 4.1 Potential Applications in the energy sector

Nuclear fusion is regarded as one of the most promising clean energy solutions for the future. Compared with nuclear fission, the fuel for nuclear fusion (such as deuterium) is abundant and almost inexhaustible. Seawater contains a large amount of deuterium. It is estimated that the energy released by deuterium in each liter of seawater through nuclear fusion reactions is equivalent to the energy released by the combustion of 300 liters of gasoline [5]. Moreover, nuclear fusion reactions produce relatively less radioactive waste, and their radioactive half-life is short, making their treatment relatively less difficult. If controlled nuclear fusion can be achieved, it will bring revolutionary changes to the global energy supply and effectively alleviate the current energy crisis and environmental pollution problems.

At present, many countries and regions around the world are actively conducting research on controlled nuclear fusion, among which the most representative project is the International Thermonuclear Experimental Reactor (ITER) program. ITER aims to build an experimental reactor capable of conducting large-scale nuclear fusion reactions to verify the feasibility of nuclear fusion energy. In addition, some countries are also conducting their own nuclear fusion research projects. For instance, China's Eastern Super Ring (EAST) has achieved a series of significant results in exploring controllable nuclear fusion technology.

### 4.2 Challenges Faced

Although nuclear fusion has great potential, it still faces many challenges to achieve commercial application. First of all, the extremely high temperature and pressure conditions required for achieving nuclear fusion are difficult to reach and maintain. At present, controlled nuclear fusion is mainly attempted through two methods: magnetic confinement and inertial confinement. However, both the tokamak device (a typical representative of magnetic confinement) and the laser inertial confinement device require a large amount of energy to maintain the extreme conditions necessary for nuclear fusion reactions. Secondly, the control of nuclear fusion reactions and the stability of energy output are also issues that need to be urgently addressed. How to precisely control the rate and intensity of nuclear fusion reactions so that they can continuously and stably output energy is the key and difficult point of current research. In addition, the high construction and operation costs of nuclear fusion devices also restrict their large-scale development.

## 5. Comparison between Nuclear Fission and Nuclear Fusion

Fission and fusion share some commonalities. Their energy sources are the same which are both from the reaction of atomic nuclei, following Einstein's mass-energy equation. Also, the core medium for both fission and fusion reactions is the neutron. There are some differences in the application and development between fusion and fission.

In terms of energy utilization, nuclear fission has been widely applied commercially on a large scale, but the fuel is relatively scarce and there is a problem of nuclear waste disposal. Nuclear fusion fuels are abundant and have huge potential energy, but they have not yet been commercially applied. In terms of safety, nuclear fission poses risks of nuclear leakage and explosion, such as the Chernobyl nuclear accident and the Fukushima nuclear accident, which brought huge disasters to humanity. Nuclear fusion is relatively safe. It releases less energy during the reaction process and cannot sustain a chain reaction on its own. Even if an accident occurs, it will not cause serious consequences similar to nuclear fission. In terms of the generation and treatment of radioactive waste, nuclear fission produces a large amount of radioactive waste with a long half-life, which is difficult to handle and store. Nuclear fusion generates less radioactive waste with a short half-life and is relatively easy to handle.

## 6. Conclusion

The application of atoms in nuclear fission and nuclear fusion has had a profound impact on human society. Nuclear fission has been widely applied in fields such as energy generation, the military, and medicine, providing important energy and technical support for humanity. However, it also faces issues such as nuclear waste disposal and safety risks. Nuclear fusion, as an important direction for future energy development, has potential advantages such as abundant fuel resources, cleanliness and safety. Although it still faces many challenges in achieving commercial application, the active research and exploration by the international community have brought hope for its future development. With the continuous advancement of technology, it is believed that more breakthroughs will be made in the field of nuclear fission and nuclear fusion, better serving the development of human society.

This article has not delved deeply into the theories of nuclear fission and nuclear fusion, nor has it supplemented them with experimental proof. In the future, experiments and other methods will be used to further improve this article.

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