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Discussion on the development of nuclear energy and nuclear power plants

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Abstract. Nuclear energy is an extremely important source of energy. Nuclear energy always is considered a kind of clean energy, which has given it a lot of chances to develop. Nevertheless, the potential hazards associated with nuclear energy as well as concerns regarding resource depletion and environmental impact often result in strong opposition. Therefore, the future direction of nuclear power plants is particularly important. This paper aims to discuss the current state and prospects of nuclear energy development. While nuclear energy is experiencing rapid growth, it also faces various challenges simultaneously. These previous advancements serve as crucial foundations for future progress in nuclear energy. Therefore, this passage highlights the pivotal developments in the history of nuclear power plants, encompassing both fission and fusion reactions at their physical core. Additionally, it addresses the issues currently encountered by nuclear plants and proposes potential solutions to these concerns. Furthermore, it acknowledges that public perception plays a significant role in shaping the trajectory of nuclear energy development. Lastly, it introduces novel technologies and strategies that have the potential to enhance the future of nuclear energy. By analyzing emerging fusion-based nuclear energy approaches, we can discern valuable insights into the future direction of our existing nuclear technology landscape. Consequently, comprehending contemporary developments and challenges within the realm of nuclear energy enables us to better evaluate its role and impact within our future energy framework.

Keywords: Nuclear Plant, Nuclear Reactor, Nuclear Issue, Fusion Nuclear Energy, Tokamak.

1. Introduction

Traditional fossil energy brought humans to modern society. In 2001, 86% of worldwide energy was produced from fossil fuels, especially for those "fossil-fuel-rich countries" who are already on the road to carbon-intensive development. However, through constant mining, fossil fuels, which are non-renewable energy, could be used up. Besides, burning fossil fuels would create greenhouse gases like carbon dioxide, which would decrease Earth's radiation and cause climate change. Furthermore, impurities in fossil fuels could create contaminants such as sulfur dioxide and pollute the atmosphere.

In order to optimize the energy mix, more and more clean energy has been included and developed such as solar energy and wind energy. For example, in the European Union, one of the guidelines No.2002/91/EK goal was diversifying the energy produced. Solar energy allows residents to meet the energy needs of their own homes through renewable energy supplies, so it has become the most popular type of energy [1]. However, these energy sources are unable to meet the needs of society. For example, solar energy is largely dependent on the location and weather of the location. Moreover, solar panels have a high production cost and relatively low transition efficiency [2].

Nuclear energy is one of the hottest energy sources. In recent years, nuclear energy's consumption of hull energy has increased by 40%. Besides, it produces 12% of electricity in 2018 [3]. As an alternative to fossil fuels, nuclear energy could be considered clean energy, which means it produces little contamination and greenhouse gases. However, many people consider that nuclear plants might pose security risks since there have been many accidents that have happened.

In the following content, the problem of nuclear energy development is illustrated by examples, and the differences between nuclear power plants are demonstrated through several parallel examples. Finally, by analyzing the problems existing in nuclear power plants, possible solutions and innovation points are proposed. This research helps to summarize the achievements of nuclear energy today and indicate possible future research direction.

2. Nuclear energy with fission reaction

2.1. Discovery of nuclear energy and fission

Nuclear energy began with the discovery of Uranium in 1789, which was significant since Uranium is a crucial element that is widely used in nuclear fuel processing [4]. Then in 1898, Pierre Curie and his wife Marie Curis discovered two other radioactive elements, Polonium and Radium [5]. In 1938, Otto Hahn and his assistants first discovered the phenomena of nuclear fission by the nucleus of uranium-235 capturing a neutron and then breaking up into two lighter nuclei [6].

$$ {}^{235}_{92}U + n \rightarrow {}^{236}_{92}U^{*} \rightarrow {}^{93}_{37}\mathrm{Rb} + {}^{141}_{55}\mathrm{Cs} + 2n. \quad (1) $$

This process could basically be divided in two. Firstly, uranium-235 and a neutron form uranium-236 which could be seen as an excited state of uranium-235. Secondly, uranium-236 would go through a fission reaction that can take place in approximately 10^-8 seconds. After that, two different elements are created, in the reaction above which are rubidium-93 and cesium-141, and two new ne utrons. These neutrons might continue to react with other uranium nuclei.

2.2. Basic development of nuclear energy and nuclear energy plants

2.2.1. Development of nuclear power plant. In the early 1940s, three programs were initiated in America (Los Alamos, New Mexico; Richland, Washington; and Oak Ridge, Tennessee) to develop nuclear weapons. These programs greatly accelerated the advancement of nuclear energy but also led to their use as weapons. On July 7th, 1945, the first nuclear weapon was detonated. Following the explosions of two atomic bombs in Japan, President Eisenhower signed the Atomic Energy Act in 1954, marking the beginning of the commercial development of nuclear energy [7].

From the 1960s, fission weapons were developed rapidly. The United States, the Soviet Union, and other countries conducted more nuclear tests, including China and India which carried out their first nuclear test. Cold war is the main reason for the above events, especially the arms race between the United States and the Soviet Union. However, the signing of the NPT in 1970 successfully stopped the preventing the proliferation of nuclear weapons [7]. After that in the 1970s, since people were worried about the N-war, large demonstrations and protests were held around the world. However, in this time period, the technology of nuclear power plants has also developed greatly.

Calder Hall Nuclear Power Station was one of the earliest boiling water reactors for commercial use and its commercial operation began in 1956. Besides, in 1960, the first commercial pressurized water reactor, Yankee Rowe nuclear power station, was started and since then pressurized water reactors become the most common reactors [8].

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2.2.2. Pressurized water reactors and boiling water reactors. Pressurized water reactor (PWR, a kind of light water reactor) technology was commercialized, which was once been used on submarines and acted much safer than previous types of reactors. It uses ordinary water as a coolant and a moderator and a pressurizer would keep water from vaporizing after the heated by the reactor in the first loop according to Figure 1. Then the heated water would boil water in the second loop, which is the loop shown in the middle of Figure 1, and make it vaporize to push the turbine and generate electricity [9]. Steam generating tube which is in the second loop was first made of stainless steel which is based on submarines, but this material could easily stress corrosion cracking in chloride solution, which had the risk of disclosure. Therefore, H.R. Copson from International Nickel Company developed Alloy 600 which could both tolerate a high chlorine environment and have good physical characteristics [10]. Although heat would be wasted while transferring between the first and second loops it could sustain a higher density of fuel (uranium oxide) [9]. Pressurized water reactors use uranium dioxide as fuel. The uranium dioxide inside the reactor is present in cylindrical pellets, which serve to maintain stable chemical properties under reactor temperature and pressure conditions while remaining fixed in tubes made of Zircaloy and held in place by spring. These tubes are assembled into a 16×16 square. Between the tubes, there are spaces for control rods and neutron sources [11]. Finally, the average energy production efficiency of a pressurized water reactor would be 33%.

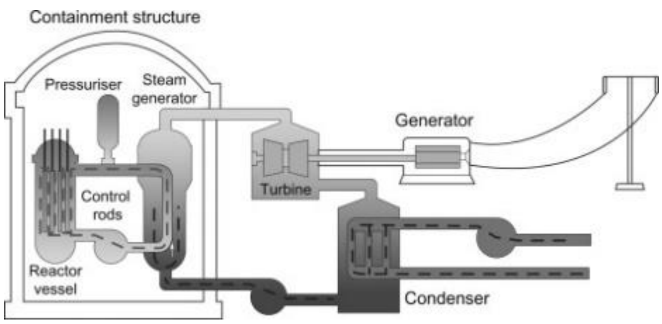

Figure 1. Processes of Pressurized Water Reactor [11].

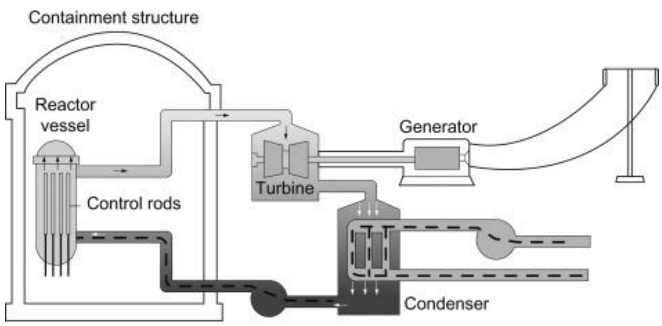

Figure 2. Processes of Boiling Water Reactor.

Similarly boiling water reactor also uses light water as both coolant and moderator. In the core of the reactor, water would not boil only till raised to 285 °C, since the pressure is high in the reactor. Then the steam would enter the turbine and generate electricity, like Figure 2 that is shown above. After that, the steam is condensed by the condenser and turned back to the core. However, since water is exposed to radiation generated by the reactor water would appeal to radioactivity. A boiling water reactor is a simpler structure compared to a pressured water reactor since it does not have two cycles for exchanging heat [12].

3. The problems with nuclear energy

3.1. Safety problems

The impact of safety problems at nuclear power plants could be called the most destructive and long-lasting. Therefore, people have a high requirement for the safety performance of nuclear power plants. But even though the safety of nuclear power plants is enhanced a lot, nuclear power plants could cause safety problems in rare cases. For instance, the nuclear accident at Fukushima Daiichi Nuclear Power Plant on March 11, 2011, was one of the serious nuclear accidents. The tsunami caused by the earthquake damaged and shut down the power supply system of the power plant. Furthermore, design flaws caused standby energy cannot be used immediately. After that, the cooling system shut down for lake of power, and melted fuel rods melted through the reactor causing a nuclear accident. Safety problems of nuclear power plants could lead to diverse kinds of problems that strongly affect governments and people's opinions toward nuclear power plants. Even after 10 years, people are still worried that the Fukushima nuclear accident could happen again [13]. Moreover, people living at the Fukushima plant are often worried about the problem of excessive radiation [14]. Aside from these effects, further environmental problems are also significant. For instance, after the happened of Fukushima nuclear accident large amount of cesium, which is radioactive, was released into the sea areas as sediments. However, since winds and waves cause resuspension, food chains and the effect of river currents, would send cesium back off offshore [15].

3.2. Environmental problems

Even though nuclear power could be called clean power, it will still cause some environmental problems. First of all, environmental problems would occur if radioactive waste did not go through impropriate treatment. The radiation caused by these waists would affect human and natural creatures' health. For example, if the repositories of radioactive nuclear wastes are partly damaged, some radioactive nuclear wastes might be leaked and released into the groundwater system [16]. Therefore, nuclear waste containers are really hard to design and keep. For example, since the nuclear wastes could erode the containers largely, corrosion modelling is still essential. Moreover, current methods of temperature measurement, for example, infrared thermometers and spring-loaded thermometers, might have a certain amount of uncertainty [17]. Furthermore, large amounts of nuclear fuels, usually uranium are heavily requested, which might cause soil pollution, forest degradation or other environmental problems while mining. Besides, as the mining area expands, the areas of local natural habitat would decrease, which leads to a decrease in biodiversity.

4. Further developments in nuclear energy and nuclear plants

4.1. Developing fission nuclear power plants

Although recent nuclear plants do have some significant drawbacks recently, nuclear power remains the most promising energy technology. There are two basic ways to develop nuclear power: enhancing fission technology and creating commercially viable fusion technology.

Firstly, some nuclear plant accidents make people doubt the safety of nuclear energy but also make people aware that nuclear plants need more scientific management and more scientific structure. The nuclear energy industry strengthened risk management and control through design refinement, contingency reserve, waste management, and better personal training.

Moreover, the invention of information technology and artificial intelligence let nuclear power plants process data and control the system better, which largely reduces risks. For example, I & C systems began to be introduced in many nuclear power plants, which could control and protect the regular operation of the nuclear plants. Besides, this system could provide forecasts and post-analysis that could help engineers get useful information [18].

Secondly, there are more and more diverse types of fission nuclear power plants that are developed by scientists and new generation reactor technologies are invented continually. Fast neutron reactors,

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High-Temperature Gas-Cooled Reactors (HTGR), Molten salt reactors (MSR), and Small modular reactors (SMRs). These technologies have several advantages compared to older reactors. For instance, a High-Temperature Gas-Cooled Reactor uses liquid nitrogen as the coolant, which highly increases fuel efficiency and security. Besides, one of the other important new reactors is the small modular reactor. This kind of nuclear reactor sharply decreases the size of the reactor, which turns out that Small modular reactors would be able to be used in more diverse places such as in cities. Moreover, the usage is increasing while the sizes are decreasing, since it can be used either alone or as an integrated system.

4.2. innovating fusion nuclear power plants

Fusion nuclear power plants bass on fusion reactions which occur at high temperatures and pressures. Then the nuclear fuel in the high temperature and pressure would become plasma form and collide with each other. While two atoms are close enough, they would able to overcome the Coulomb repulsion that is created by the Coulomb barrier. After that, these two lighter atoms would fuse together and generate a heavier atom. The energy produced by this reaction comes from the differences between two light atoms and the new heavier atom as a form of high-speed neutron and electron.

Compared to fission nuclear power plants, fusion nuclear power plants have a lot of potential benefits. The nuclear reaction that provides energy for fusion nuclear power plants is the isotopes of hydrogen, deuterium, and tritium, which are more available than the fuel that is used in fission nuclear power plants. The reason is that deuterium is widely found in the oceans and tritium are able to produce in large quantity. Besides, since fusion reaction could generate more energy by using even less weight of nuclear fuel, fission could generate a much larger amount of energy by using only a little deuterium and tritium.

The reason why we are not having fusion nuclear plants nowadays is our technologies are not enough to support its commercialization. However, researchers still solved some of the problems in fusion nuclear plants. For instance, Tokamak is a newly developed equipment to confine high-temperature plasma by creating huge magnetic fields. There are two main magnetic fields that are created, one of the fields could control the axial and radial movement of plasma. One of the challenges of such a system is how to fully control the system, since it requires strong closed-loop control by using a magnetic actuator coil, and it needs to become more and more complex. In order to improve the control ability, some researchers design a structure that can help the control system to learn and train architecture. Therefore, the Tokamaks might have enhanced ability and better control over uncertain operating conditions [19]. Finally, there is still a long way for fusion nuclear power plants to go through.

5. Conclusion

Through the examples of different reactors, the development of nuclear energy is explained and the problems faced by nuclear energy are analyzed. Finally, the possible solutions such as developing fission nuclear energy are given. Even with the risk to occur accidents, nuclear energy is still the energy type that have the most room to develop, which means in future nuclear energy would be one of the most important energy sources. Furthermore, the future of nuclear power is clear since by solving safety problem and develop fusion nuclear plants, we could get lots of clean energy, which would be the goal of energy researcher. However, I did not dully consider the factors for the development of nuclear energy and I should refer to more relevant cases. Therefore, in the future people could improve the developmental pace of nuclear energy and try to involve with new technologies.

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