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Proton-Boron Fusion (Rostoker's vision)

Reduction of the risk of radioactivation of the reactor wall

TAE Technologies was founded in 1998 and has been challenging fusion power for many years. It is the oldest existing fusion startup. While fusion typically uses deuterium and tritium, TAE aims to achieve fusion using the unconventional combination of hydrogen (i.e. protons) and boron.

This experiment was conducted using the Large Helical Device (LHD) at the National Institute for Fusion Science (NIFS) in Japan. Boron powder was dropped into the hydrogen plasma confined by a magnetic field. Then, a hydrogen beam was injected from the sides at a speed exceeding 15 million km/h to collide with the boron, causing fusion between the two elements. The helium produced by this fusion reaction was detected using instruments developed by TAE.

In conventional fusion using deuterium and tritium, neutrons are generated as radiation during the fusion reaction. Neutrons carry a huge amount of thermal energy, but they are difficult to shield, and when they hit the reactor wall, they can activate the metal and transform it into a radioactive material that emits radiation. In the case of proton and boron fusion, only high-temperature helium atoms are produced as a result, so the risk of the reactor wall becoming radioactive is small. Although there are challenges in achieving the required reaction conditions, TAE continues to pursue the fusion of proton and boron, as it is carrying on the vision of its founder, the late Prof. Norman Rostoker.

Professor Rostoker was a plasma researcher at the University of California, Irvine (UCI) in California, and Prof. Toshiki Tajima was one of his students. In 1973, when Prof. Tajima first met Rostoker, he was told that "the theory of plasma has been established. Now, the application of it is important." One of those applications is nuclear fusion, and after 50 years, Prof.ro Tajima is trying to realize his teacher's teachings.

"End in mind" is the philosophy advocated by Prof. Rostoker, which means to consider the end goal from the beginning. So, what is the end goal of power generation using nuclear fusion? The end goal is to establish a device that can stably generate energy for a long period of time. In order to achieve this, TAE has concluded that the only way is to pursue nuclear fusion of proton and boron.

Toward higher safety and compactification - Amassing Y33.6B last year

Professor Tajima points out that "the impact of neutrons on stable operation is significant." The main challenges that hinder the development of conventional nuclear fusion are the radiation caused by neutrons and the performance degradation of superconducting magnet coils. Radiation makes maintenance difficult and can cause problems for stable operation. Moreover, if many neutrons hit the superconducting magnet coils, a phenomenon called "quench" occurs where the superconducting properties are lost due to heat. To prevent this, increasing the size of the neutron shielding wall would result in the entire device becoming larger, leading to increased costs.

On the other hand, with proton-boron fusion, there is no concern for radiation and it can lead to device compactness. However, the reaction plasma temperature required for proton-boron fusion is extremely high, requiring 30 times higher than that needed for deuterium-tritium fusion. As a result, methods such as tokamak, which uses strong magnetic fields to confine plasma as in the International Thermonuclear Experimental Reactor (ITER), or laser fusion cannot be used. Therefore, TAE has adopted the Field Reversed Configuration (FRC) to confine such high-temperature plasma.

FRC has the theoretical potential to create a high-energy plasma with high confinement performance. First, a plasma with low confinement efficiency is generated at both ends of a linear device. Then, they are accelerated towards the center and combined to create a plasma with high confinement efficiency. As the performance of the plasma improves, there is no need to confine it with a strong external magnetic field from the outside, and it can be confined by the magnetic field inherent in the plasma itself.

So far, it was difficult to confine FRC plasma for a long period of time, but this issue has been resolved by injecting high energy into the plasma from outside. Regarding these methods, Prof. Tajima compares plasma to a bicycle, stating as follows: "A bicycle is unstable and easy to fall off until you start pedaling and begin to move forward steadily. Similarly, as plasma's energy increases, it can be stably confined by the magnetic field it generates on its own."

The concrete process is as follows: First, external energy is injected into the FRC plasma using an accelerator. The plasma, having received the energy from the accelerator, stabilizes and increases its own magnetic confinement capabilities. In future experimental equipment and commercial reactors, the power of the accelerator will be increased to provide more energy to the plasma. At the same time, there are plans to introduce a superconducting magnet to prevent the high-energy plasma from spreading outward.

Materials development surviving high temperature: Necessary

The business structure is also steadily being established. In 2022, TAE conducted fundraising of 250 million USD from companies such as Google and Sumitomo Corporation. TAE is also leveraging Google's computing expertise to streamline its development process. The dream that Prof. Rostoker had is being carried on by TAE and is now beginning to blossom. Professor Tajima emphasizes that this is the result of advancing the knowledge of plasma and devices that Prof. Rostoker has been researching for over 20 years.

In nuclear fusion, progress has been made in plasma research, but energy extraction and device safety are required for power generation. In particular, FRC uses higher-temperature plasma than other fusion reactors, so it is essential to develop materials that can withstand it.

Professor Tajima also said, "While we are experts in plasma, we need to collaborate with peripheral equipment. We expect Japanese companies to contribute in this regard." It was believed that the realization of fusion was distant, and the government had been leading the research. However, the rapid increase of fusion startups around 2010 has brought about a change in this situation.

With enormous private funding flowing in, fusion research and development have accelerated, and ambitious fusion startups are determined to demonstrate their power generation capabilities between the 2020s and 2030s. TAE is also one of those companies. Professor Tajima says, "I'm not saying that we can achieve fusion power generation in two or three years. However, it's not a 30-year story." He has a clear vision of the "exit" of fusion.