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Abstract

The fusion triple product (Fusion triple product) is an important criterion for self-sustaining nuclear fusion reactions, which utilizes three physical quantities in a fusion reactor—the fuel number density n , the plasma confinement time τ_m , and the fuel temperature T —to determine whether the fusion reactor can satisfy the energy balance condition for achieving self-sustaining nuclear fusion. This study investigates a fusion reaction system using ${}^6\text{Li-D}$ as nuclear fuel, and considers the influence of relativistic effects on bremsstrahlung and the impact of energy recovery efficiency on the energy gain factor Q , calculating the fusion triple product for the ${}^6\text{Li-D}$ fusion reaction system under the condition of neglecting cyclotron radiation ($n_m \tau_m T = 4.9 \times 10^{23}$ per cubic meter kilo electronvolt second). The results demonstrate that ${}^6\text{Li-D}$ can serve as a nuclear fusion fuel to achieve net energy gain, but its ignition condition for achieving self-sustaining nuclear fusion is more challenging compared to that of D-T fusion.

Full Text

Calculation of the Fusion Triple Product for ${}^6\text{Li-D}$ Thermonuclear Reactions

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Abstract

The fusion triple product is a crucial criterion for self-sustaining nuclear fusion reactions. It utilizes three physical quantities—the number density of fuel nuclei in a fusion reactor (n), plasma confinement time (τ_E), and fuel temperature (T)

—to determine whether a fusion reactor can satisfy the energy balance conditions required for achieving self-sustained nuclear fusion. This study investigates a fusion reaction system using ${}^6\text{Li}$ -D as nuclear fuel, considers the influence of relativistic effects on bremsstrahlung radiation and the impact of energy recovery efficiency on the energy gain factor Q , and calculates the fusion triple product for the ${}^6\text{Li}$ -D fusion reaction system under the condition of neglecting cyclotron radiation ($n_i T \tau_E = 4.9 \times 10^{23} \text{ m}^{-3} \cdot \text{keV} \cdot \text{s}$). The results demonstrate that ${}^6\text{Li}$ -D can serve as a nuclear fusion fuel to achieve positive energy gain, but the ignition conditions required for its self-sustaining fusion are more challenging compared to those for D-T fusion.

Keywords: Lawson criterion; Fusion reactions; Bremsstrahlung radiation; Fusion energy gain factor

Introduction

With societal progress and industrial development, humanity's demand for energy is increasing day by day. Currently, fossil fuels account for the largest proportion of global energy consumption. However, fossil fuel reserves on Earth are limited, and their use causes environmental problems such as climate change and air pollution, making them unsuitable as a long-term energy resource. Although significant progress has been made in recent years in utilizing renewable energy sources like solar and wind power, the energy they provide represents a relatively low proportion of the total, and their availability is constrained by weather and geographical conditions, allowing them to serve only as a partial supplement to energy needs. To fundamentally resolve the human energy crisis, nuclear energy—with its high energy density—has gradually become a focus of attention [1-2].

Nuclear energy is the energy released through nuclear reactions or decay processes, which primarily include heavy nuclear fission, light nuclear fusion, and radioactive decay. The total energy released in a nuclear reaction or decay is related to the mass difference of the atomic nuclei involved before and after the process. Generally, medium-mass atomic nuclei have larger average binding energies. When heavy nuclei undergo fission or light nuclei undergo fusion to produce medium-mass nuclei, a certain amount of mass is lost. This lost mass is converted into energy and released during the nuclear process. Calculations show that the energy released from the complete fission of 1 kg of uranium fuel is equivalent to that produced by burning 20,000 tons of petroleum, while the energy generated from the fusion of 1 kg of deuterium-tritium fuel is comparable to that stored in 80,000 tons of petroleum. These calculations demonstrate that the energy density of nuclear power is millions of times greater than that of fossil fuels, representing an extremely vast energy resource.

The application of nuclear fission energy achieved success as early as the 1950s, but this does not mean that humanity's energy problem has been completely solved [1-2]. Currently, nuclear fission power plants worldwide predominantly

use ^{235}U as fuel, yet ^{235}U reserves on Earth are limited. Estimates indicate that even considering breeder reactors, the currently proven reserves of ^{235}U and ^{232}Th would only sustain human energy consumption for a few hundred years. Furthermore, the long-lived high-level radioactive waste produced by fission power plants remains highly active for considerable periods, raising concerns about nuclear waste disposal. Worries about nuclear waste accumulation and the damage from nuclear accidents may trigger political debates over nuclear energy applications, offsetting the advantages offered by fission energy.

In 1920, British scientist Arthur Eddington first proposed the concept of nuclear fusion reactions when considering the energy source of stars [3]. Since then, scientists from around the world have been dedicated to achieving controlled nuclear fusion. Fusion energy offers numerous advantages as an energy source: (1) Fusion fuel is extremely abundant. Current fusion fuels under consideration include deuterium, tritium, helium, lithium, and boron—all of which, except tritium, exist in large quantities in nature and are readily obtainable. (2) Fusion reactions are inherently safe. Once plasma confinement is established under fusion conditions, any accident will disrupt the confinement and cause the plasma to cool rapidly, leading to quick shutdown of the fusion reactor. Additionally, the plasma energy storage in a fusion reactor is relatively small, requiring continuous fuel input. If fuel injection stops, the reactor will cease operation promptly. (3) Fusion energy is clean. Fusion reaction products are generally non-radioactive or have short half-lives, posing no environmental hazards. (4) Fusion fuel has even greater energy density. The deuterium contained in 1 liter of water on Earth can produce fusion energy equivalent to that released by burning 300 liters of gasoline [1]. This means fusion reactors do not need to store as much fuel as fission reactors. As the renowned scientist Stephen Hawking stated [4]: “I would like nuclear fusion to become a practical power source by the end of the century, providing an inexhaustible supply of energy for humanity without causing environmental pollution or global warming.”

Until now, the majority of fusion research has focused on achieving controlled nuclear fusion using the deuterium-tritium reaction $\text{T}(\text{d}, \text{n})^4\text{He}$ [5]. This reaction was chosen because it possesses a high cross-section at relatively low energies, meaning it has a high energy production rate at lower temperatures, making it easier to achieve ignition conditions. However, the $\text{T}(\text{d}, \text{n})^4\text{He}$ reaction is not without flaws: it produces 14 MeV neutrons that not only carry away approximately 80% of the reaction energy but also cause neutron activation damage to reactor components and may react with certain elements in structural materials to produce long-lived high-level radioactive waste. Moreover, tritium is a radioactive nuclide with a half-life of about 12 years, extremely low natural abundance, and a very high cost. Although lithium materials can be used near the fusion core to absorb neutrons and produce tritium via the $^6\text{Li}(\text{n}, \text{t})^4\text{He}$ reaction, this leads to large quantities of residual tritium in the core vicinity and recycling systems, thereby compromising nuclear safety.

The concept of advanced fuels was proposed many years ago [6]. The goal of ad-

vanced fuels is to find a naturally abundant fuel alternative to deuterium-tritium that not only has a high reaction cross-section at low energies but also minimizes neutron production during the reaction. In early research, scientists typically searched for potential fusion reactions in astrophysical environments. However, the cross-sections of these thermonuclear reactions are generally small, making it difficult to obtain accurate data [7]. During stellar evolution, deuterium and lithium ignite before hydrogen due to their larger reaction rates [8-9]. Inspired by this, researchers naturally focused on nuclear reactions using hydrogen, deuterium, lithium, and boron as fuels, such as D-³He, D-D, and p-¹¹B fuels. With advances in experimental technology and deeper understanding of fusion theory, many thermonuclear reactions have been reconsidered for achieving controlled nuclear fusion [10-12].

This work focuses on ⁶Li-D fuel. The possible thermonuclear reactions include ⁶Li(d, p)⁷Li, ⁶Li(d, n)⁷Be, ⁶Li(d, α)⁴He, ⁶Li(d, nα)³He, and ⁶Li(d, pα)⁴T. Among these, only the ⁶Li(d, n)⁷Be and ⁶Li(d, nα)³H reactions produce neutrons. Under the same temperature and density conditions, their neutron yield is approximately two orders of magnitude lower than that of D-T reactions. This low neutron flux represents a significant advantage of ⁶Li-D as a fusion fuel. This study surveys the research progress on these reactions and calculates the energy balance conditions for the ⁶Li-D reaction series under magnetic confinement using relatively accurate cross-section data, providing the triple product for ⁶Li-D fusion reactors.

1 Ideal Ignition Temperature

The core concept in building a controlled nuclear fusion reactor is to create a self-sustaining steady-state fusion system without external energy input, which requires the system to at least balance the energy produced by fusion with the energy lost through radiation. For a plasma volume V , the power generated by fusion reactions is:

$$P_{Fi} = n_{Li}n_D\langle\sigma v\rangle_i\varepsilon_{Fi}V$$

where the subscript i denotes the i -th reaction channel of the ⁶Li-D fuel, and summation indicates that all possible reaction channels are considered. n represents the number density of fuel nuclei, ε_F is the energy released per reaction, and $\langle\sigma v\rangle$ is the convolution of reaction cross-section and velocity—the velocity-distribution-weighted cross-section, also known as the astrophysical reaction rate [13]. The energy for nuclear reactions in a plasma environment is provided by the thermal motion of ions, whose velocities follow a Maxwell-Boltzmann distribution with an average energy of $1.5kT$, where k is the Boltzmann constant and T is the plasma temperature. Consequently, the astrophysical reaction rate is a temperature-dependent physical quantity. To study the origin of elements in the universe, nuclear astrophysicists have obtained extensive astrophysical reaction rate data. Figure 1 [Figure 1: see original paper] presents

the astrophysical reaction rate data required for subsequent calculations. The astrophysical reaction rate curves for ${}^3\text{He}(\text{d}, \text{p}){}^4\text{He}$ and $\text{D}(\text{t}, \text{n}){}^4\text{He}$ are taken from the international nuclear astrophysics REACLIB database [14]; the curves for the three reactions ${}^6\text{Li}(\text{d}, \text{p}\alpha)\text{T}$, ${}^6\text{Li}(\text{d}, \text{n}\alpha){}^3\text{He}$, and ${}^6\text{Li}(\text{d}, \text{n}){}^7\text{Be}$ were fitted based on data from McNally et al. [15]; the curves for ${}^6\text{Li}(\text{d}, \text{p}){}^7\text{Li}$ and ${}^6\text{Li}(\text{d}, \alpha){}^4\text{He}$ adopt the parametric equations recently provided by Fang et al. [16]. The ${}^6\text{Li}(\text{d}, \text{p}){}^7\text{Li}$ and ${}^6\text{Li}(\text{d}, \text{n}){}^7\text{Be}$ astrophysical reaction rates used in this work are approximately one order of magnitude lower than those in the REACLIB database at the same temperature. When the temperature is fixed, the value of $\langle\sigma v\rangle$ remains constant, and the power generated by fusion reactions depends only on the reactant number densities. Based on charge conservation, the relationship between electron number density and ion number density in the plasma is $n_e = 3n_{\text{Li}} + n_{\text{D}}$. Substituting this into equation (1) reveals that the fusion power reaches its maximum when $n_e = 2n_{\text{D}} = 6n_{\text{Li}}$. To simplify calculations, the number densities of D and ${}^6\text{Li}$ will hereafter be expressed in terms of the electron number density n_e according to this proportional relationship.

In high-temperature plasmas, fusion reactions release energy while also experiencing several energy loss processes, including bremsstrahlung, impurity radiation, recombination radiation, and cyclotron radiation. Among these, impurity radiation and recombination radiation are relatively small and can be neglected. Bremsstrahlung is electromagnetic radiation produced by electron-ion interactions. For ${}^6\text{Li}$ -D fuel, the bremsstrahlung power density can be expressed as [17]:

$$S_B = C_B n_e^2 T_e^{1/2} Z_{\text{eff}}$$

where $C_B = 5.34 \times 10^{-37} \text{ W} \cdot \text{m}^3 \cdot \text{keV}^{-1/2}$ is known as the bremsstrahlung constant [12]. For ${}^6\text{Li}$ -D fuel, $Z_{\text{eff}} = (Z_{\text{D}}^2 n_{\text{D}} + Z_{\text{Li}}^2 n_{\text{Li}})/n_e = 2$. For convenience, we use the product of the Boltzmann constant and temperature, kT , to represent temperature in units of keV. In high-temperature environments, relativistic effects can significantly enhance bremsstrahlung power and must therefore be considered. Here, we adopt the fitting formula given by Svensson [18], which shows good agreement with the calculations of Heitler et al. [19] over a wide range of temperatures and effective charges [20]:

$$\gamma(Z_{\text{eff}}) = Z_{\text{eff}}(1 + 1.78t^{1.34}) + 2.12t(1 + 1.1t + t^2 - 1.25t^{2.5})$$

where $t = T_e/(m_e c^2)$ is a dimensionless parameter. Based on this, the bremsstrahlung power density formula (2) is corrected to:

$$S_B = C_B n_e^2 T_e^{1/2} \gamma(Z_{\text{eff}})$$

Cyclotron radiation is emitted by charged particles under the influence of the Lorentz force in a magnetic field. The power density of cyclotron radiation can

be expressed as [21]:

$$S_{cyc} = A_{cyc} n_e B^2 T_e \phi$$

where B is the magnetic field strength, ϕ is the absorption correction factor [22-23], and $A_{cyc} = 6.3 \times 10^{-20} \text{ J} \cdot \text{eV}^{-1} \cdot \text{T}^{-2} \cdot \text{s}^{-1}$. The curves of cyclotron radiation power density versus temperature for different magnetic field strengths are shown in Figure 2 [Figure 2: see original paper]. For comparison, we also plot the bremsstrahlung power density versus temperature in Figure 2. It can be observed that near the temperature of interest (200 keV), when the magnetic field is less than 2 T, the cyclotron radiation power density is far smaller than the bremsstrahlung power density and can be neglected. In cases of stronger magnetic fields, the cyclotron radiation power density would exceed the bremsstrahlung power density and must be taken into account. This work considers only the case where cyclotron radiation is negligible.

To simplify calculations, this work assumes that ion and electron temperatures are identical. The relativistically corrected bremsstrahlung power for 6Li-D fuel is shown in Figure 3 [Figure 3: see original paper]. It can be seen that near the temperature of interest (200 keV), the radiation power considering relativistic effects is 2.1 times the original value. This indicates that the influence of relativistic effects cannot be ignored, and all calculations in this paper use the bremsstrahlung power density corrected for relativistic effects.

When the bremsstrahlung power of the plasma exceeds the fusion reaction power, the plasma temperature decreases, reducing the fusion reaction rate and thereby breaking the dynamic equilibrium of the plasma and terminating the fusion process. Therefore, for fusion reactions to continue, the power generated by fusion fuel reactions must be greater than or equal to the power lost through bremsstrahlung radiation, i.e., $P_F \geq P_B = S_B V$:

$$\sum_i n_{Li} n_D \langle \sigma v \rangle_i \varepsilon_{Fi} V \geq C_B n_e^2 T^{1/2} \gamma(2) V$$

Dividing both sides of the equation by volume V yields the relationship between the nuclear reaction power density ($S_C = P_F/V$) and the bremsstrahlung power density S_B . Their variation with temperature T is shown in Figure 4 [Figure 4: see original paper]. It can be seen that to achieve plasma energy balance, the condition $S_C \geq S_B$ must be satisfied, which requires $T \geq 180 \text{ keV}$. This temperature, which maintains plasma energy balance, is called the ignition temperature. It is evident that the ideal ignition temperature for 6Li-D fuel is 180 keV, approximately 41 times higher than that for D-T fusion (4.3 keV). Based solely on ignition temperature, achieving self-sustaining fusion with 6Li-D is considerably more difficult than with D-T fusion.

2 Lawson Criterion and Triple Product for 6Li-D Fusion

In the mid-20th century, British scientist John Lawson conducted in-depth research on this fusion process [24]: to comprehensively account for plasma energy gain and loss, he defined the energy gain factor Q as the ratio of energy released by thermonuclear fusion (P_{out}) to the total energy that must be absorbed to form and maintain plasma in dynamic equilibrium (P_{in}). To achieve self-sustaining fusion, the energy gain factor Q of a fusion device should be no less than 1, i.e., $Q \geq 1$. This requirement can be used to derive the temperature and density conditions for self-sustaining fusion, and the resulting condition is known as the Lawson criterion. The Lawson criterion remains an important guiding principle for fusion research to this day and has been further developed and refined in subsequent fusion studies [17,25-27]. Currently, researchers commonly use the fusion triple product (the product of plasma temperature, density, and confinement time) to evaluate how close a fusion research reactor is to achieving self-sustaining fusion. This work also employs the fusion triple product to estimate the conditions required for self-sustaining reactions in 6Li-D nuclear devices.

First, following the approach of Wurzel et al. [17], we consider a pulsed scenario: plasma is instantaneously heated by an external heat source to temperature T and maintained at this temperature for duration τ . Thereafter, bremsstrahlung radiation and all fusion reaction products escape and participate in the formation of the next pulse. In this scenario, the energy required for the plasma to reach equilibrium temperature equals the sum of the thermal energy needed to heat all matter, $\frac{3}{2}(n_e + n_i)TV$, and the energy that must be absorbed during the pulse duration τ to maintain temperature and density equilibrium, τP_a . Here, the plasma absorption power P_a in equilibrium approximately equals the bremsstrahlung energy loss power P_B . The energy gain factor Q of the system can then be expressed as:

$$Q = \frac{\tau P_{out}}{\tau P_a + \frac{3}{2}(n_e + n_i)TV}$$

To better approximate actual experimental conditions, we additionally consider heat conduction losses and the self-heating effect of charged fusion products in the formula, using the confinement time τ_E to characterize the timescale for energy loss through heat conduction from the plasma [17]. Within the τ_E timescale, heat conduction has not yet removed the energy, and the power balance equation for the plasma can be expressed as:

$$P_a + P_C = P_B + \frac{(n_e + n_i)TV}{\tau_E}$$

where $P_C = \sum_i f_{ci} P_{Fi}$ represents the energy carried by charged particles produced in fusion reactions, and f_{ci} is the fraction of energy carried by charged

particles in different exit channels of the ${}^6\text{Li}$ -D nuclear reactions. Since the energy carried by neutral particles such as neutrons and neutrinos is difficult to recover and reuse, it is not considered in the calculations. For the reactions considered in this work, the f_c values for ${}^6\text{Li}(d, p){}^7\text{Li}$, ${}^6\text{Li}(d, \alpha){}^4\text{He}$, and ${}^6\text{Li}(d, p\alpha)\text{T}$ reactions are 1. The f_c values for ${}^6\text{Li}(d, n\alpha){}^3\text{He}$ and ${}^6\text{Li}(d, n){}^7\text{Be}$ reactions are 0.14 and 0.63, respectively.

Substituting the P_a calculated from equation (9) into equation (8) yields the expression for the energy gain factor. In this expression, $\tau_{\text{eff}} = \tau\tau_E/(\tau + \tau_E)$ represents the effective confinement time of the plasma by the device. When the conduction time τ_E is much smaller than the pulse time τ , τ_{eff} can be approximated as τ_E . Differentiating the equation reveals that the maximum energy gain factor is obtained when the number density ratio of ${}^6\text{Li}$ to D is close to 3, confirming that the assumed ratio of ${}^6\text{Li}$ to D in the preceding text is reasonable.

Substituting the expressions for P_F , P_B , and P_C into the power balance equation and isolating the parameter $n_e\tau_E$ on the left side yields the Lawson criterion expression for a ${}^6\text{Li}$ -D fuel reactor at the corresponding energy gain factor Q [28]:

$$n_e\tau_E = \frac{\sum_i \varepsilon_{Fi}(Q^{-1} + f_{ci})\langle\sigma v\rangle_i}{12C_B\gamma(2)T^{1/2}}$$

Considering that temperature T is also an important condition for the reactor to achieve self-sustaining reactions, the triple product of ion number density n_i , temperature T , and confinement time τ_E is now widely adopted as a new criterion for determining whether self-sustaining fusion can be achieved, replacing the double product of electron number density n_e and confinement time τ_E [17]. Multiplying both sides of the equation by temperature T and changing the electron number density n_e on the left side to ion number density n_i yields the Lawson criterion formula for the fusion triple product [29]:

$$n_i T \tau_E = \frac{20T^2 \sum_i \varepsilon_{Fi}(Q^{-1} + f_{ci})\langle\sigma v\rangle_i}{12C_B\gamma(2)T^{1/2}}$$

When a fusion device satisfies the required temperature, density, and confinement time conditions for $n_i T \tau_E$, its energy gain factor Q is greater than or equal to 1, and the device can be considered to have the potential to achieve self-sustaining fusion.

Based on the above formulas, curves of the fusion triple product versus temperature can be plotted to visually assess the difficulty of device implementation. In Figure 5 [Figure 5: see original paper], we present the relationship between the fusion triple product $n_i T \tau_E$ and temperature T for ${}^6\text{Li}$ -D, D-T, and ${}^3\text{He}$ -D fuels at an energy gain factor of $Q = 1$. The fusion triple product curves

for ${}^3\text{He}$ -D and D-T fuels obtained in this calculation are basically consistent with the results of Nevins [5], Wurzel [17], and Alper [28], demonstrating that our calculations are reasonable and reliable. The curves in Figure 5 [Figure 5: see original paper] show that the triple product of density, temperature, and confinement time $n_i T \tau_E$ must reach at least $4.9 \times 10^{23} \text{ m}^{-3} \cdot \text{keV} \cdot \text{s}$ to achieve self-sustaining fusion with 6Li-D fuel and produce an energy gain with $Q \geq 1$. This value is about one order of magnitude lower than the calculation by McNally et al. in 1981 [12], possibly because their calculation overestimated the effect of impurities on the triple product. The minimum value of $n_i T \tau_E$ required for self-sustaining fusion with 6Li-D fuel is approximately 20 times that for ${}^3\text{He}$ -D fusion ($n_i T \tau_E = 2.2 \times 10^{22} \text{ m}^{-3} \cdot \text{keV} \cdot \text{s}$) and 1000 times that for D-T fusion ($n_i T \tau_E = 4.8 \times 10^{20} \text{ m}^{-3} \cdot \text{keV} \cdot \text{s}$). From the perspective of temperature required for self-sustaining fusion, the temperature needed for 6Li-D fuel to achieve self-sustaining fusion under the condition of minimum $n_i T \tau_E$ ($T = 216 \text{ keV}$) is about 15 times that for D-T fuel ($T = 14 \text{ keV}$) and 4 times that for ${}^3\text{He}$ -D fuel ($T = 57 \text{ keV}$). This means that developing a fusion reactor fueled by 6Li-D remains highly challenging at present and will require significant effort.

Conclusion

Nuclear fusion reactions induced by 6Li and D can occur in relatively low-temperature astrophysical environments, making 6Li-D fuel a candidate for future fusion reactors. This paper uses the latest international reaction rate data, considers the influence of relativistic effects and energy recovery efficiency on self-sustaining fusion conditions, and calculates the $n_i T \tau_E$ triple-product Lawson criterion for achieving self-sustaining fusion based on 6Li-D nuclear fuel. The calculation results indicate that, under the condition that cyclotron radiation can be neglected, obtaining an energy gain greater than or equal to 1 through 6Li-D plasma nuclear reactions is theoretically possible, requiring a fusion triple product $n_i T \tau_E$ of $4.9 \times 10^{23} \text{ m}^{-3} \cdot \text{keV} \cdot \text{s}$. Although this triple product is about one order of magnitude lower than previous calculations ($n_i T \tau_E = 1.4 \times 10^{24} \text{ m}^{-3} \cdot \text{keV} \cdot \text{s}$) [12], it remains three orders of magnitude higher than the fusion triple product of $1 \times 10^{20} \text{ m}^{-3} \cdot \text{keV} \cdot \text{s}$ for the deuterium-tritium fusion experimental reactor planned for ITER [22-23,30]. In reality, to neglect the influence of cyclotron radiation, the plasma in a magnetic confinement device needs to have a large β value [31].

Assuming an energy confinement time of 50 s and a temperature of 200 keV, the electron number density required for 6Li-D fuel fusion ignition is $5 \times 10^{19} \text{ m}^{-3}$. If the magnetic field strength is limited to below 2 T, the plasma β value would need to be greater than 1. However, the plasma β value in current state-of-the-art tokamak devices is only a few percent [32], meaning that existing tokamaks cannot satisfy the plasma confinement conditions required for 6Li-D fuel fusion ignition. Currently, international research is being conducted on magneto-inertial fusion (MIF) with plasma β values greater than 1 [33]. Research in this area is still almost blank in China and requires increased investment to promote

related studies. Additionally, designing innovative plasma confinement devices to increase the relative velocity between reactants and thereby enhance fusion power [34-35] could reduce the fusion triple product.

${}^6\text{Li}$ and D are abundant in nature, making the nuclear fuel relatively inexpensive and readily obtainable. Moreover, the neutron flux produced during ${}^6\text{Li}$ -D fuel reactions is low, causing less damage to the environment and instrumentation. Therefore, ${}^6\text{Li}$ -D fuel can serve as an alternative option for achieving controlled nuclear fusion in the future. Although numerous difficulties currently exist in realizing self-sustaining ${}^6\text{Li}$ -D fusion, with advances in fusion research, we believe that more knowledge can be accumulated to further advance the study of ${}^6\text{Li}$ -D reactors.

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Note: Figure translations are in progress. See original paper for figures.

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