Machine Learning Optimization of Room-Temperature Target for Laser Inertial Fusion Energy

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The recent successful demonstration of inertial confinement fusion (ICF) ignition represents a pivotal milestone toward realizing fusion energy as a sustainable power source. However, significant challenges remain in target fabrication and storage for practical implementation. While DT targets currently offer optimal reaction cross-sections for ignition demonstration experiments, their cryogenic storage requirements present substantial logistical constraints for reactor-scale applications. These frozen targets impose stringent environmental controls during transportation and introduce technical complexities in target injection processes. The double-cone ignition (DCI) scheme [1-2] demonstrates enhanced tolerance to hydrodynamic instabilities through its unique target configuration devoid of central hot gas layers. The repeatability of the DCI experiment also requires non-cryogenic targets. Therefore, the design of room-temperature targets is necessary.

The commonly used solid target, the CD series, has a high Z element, which greatly reduces the fusion energy gain value. Therefore, we will use a compound series comprising low-Z elements (Z<5) combined with hydrogen isotopes [3], combined with the optimization assistance of machine learning, to design room-temperature solid targets with considerable gain. We have firstly implemented a multi-fuel module within the MULTI radiation hydrodynamics code to enable coupled simulations of multiple nuclear reaction pathways. We developed a modified $LiBD_2T_2$ fusion simulation code incorporating tritium breeding effects through neutron-lithium interactions. During the fusion process, Li has the opportunity to combine with neutrons and becomes T, significantly increasing the total fusion energy output.

In recent years, the application of artificial intelligence in fusion has also become increasingly widespread [3]. Our approach leverages genetic algorithm (GA) to optimize both target geometry and laser pulse shaping parameters. The GA implementation mimics biological evolutionary processes through selection, crossover, and mutation operators, enabling efficient exploration of high-dimensional parameter spaces. In the future, we will collaborate with the target fabrication team and the experimental team to further verify the real performance of the room-temperature targets designed through simulation optimization. At the same time, the experimental data collected will be used through transfer learning methods to assist in our next round of target design [4].

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