Inertial Fusion Energy Fuel Targets

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Introduction and Objectives

Inertial Fusion Energy (IFE) stands at the forefront of innovative solutions for meeting the world's growing energy demands. Inertial Fusion Energy is the ignition of a fusion reaction using lasers to heat and ignite deuterium and tritium fuel pellets [1]. From the fusion reaction energy is created. Industry looks to harness this created energy creating a reliable and clean energy source for the world. Some key issues faced in bringing fusion energy to industry include efficient and reliable lasers, high gain low-cost fuel targets, and long life sustainable and replaceable reactor materials. In this research project we focus on addressing the issue of manufacturing low-cost fuel targets. Targets are an essential part of an Inertial Fusion Energy Reactor, targets contain the fuel consisting of a mix of hydrogen isotopes, typically deuterium and tritium. For a successful ignition of the fuel target in the fusion reaction, high levels of fabrication precision is required (Targets need to be manufactured approximately accurate to a scale of ±0.02 mm) [1]. Along with the manufacturing limits of targets there are also economic limits, for the operation of a profitable fusion reaction we require large quantities of targets (approximately 500,00 targets per day for every reactor) to be produced at a cheap costs (estimated to be around $0.25 per target) [1].

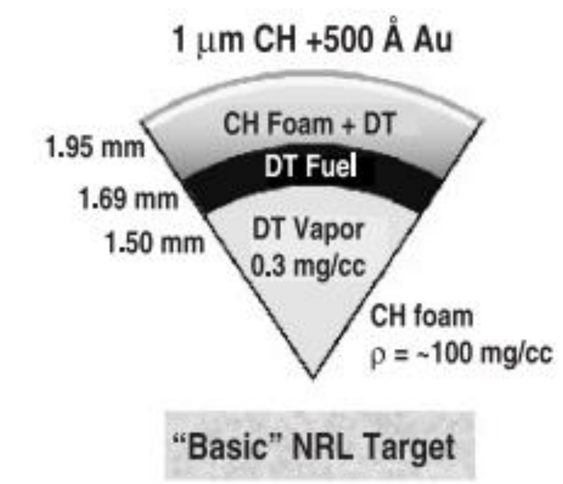

Figure 1. Example target structure [1]

Current target structures consist of a Deuterium and Tritium (DT) Fuel core, capsulated commonly by a polystyrene or glass shell (in this project we elect to focus on polystyrene shells as they are the most common microsphere used in the application of IFE [3]). The manufacturing process of these targets starts with the polystyrene capsules. Using a process of microencapsulation shells are created from a liquid layer of polystyrene that gets mixed with solvents and sent into a water bath through a triple concentric nozzle creating the spherical shell. The shell is then removed through the bath and hardened by diffusion as the water diffuses from the inner shell. The polystyrene capsules are then filled with DT gas at cryogenic temperatures by process of diffusion. Precise control of pressure is needed while filling to ensure the polystyrene capsule remains perfectly spherical [1].

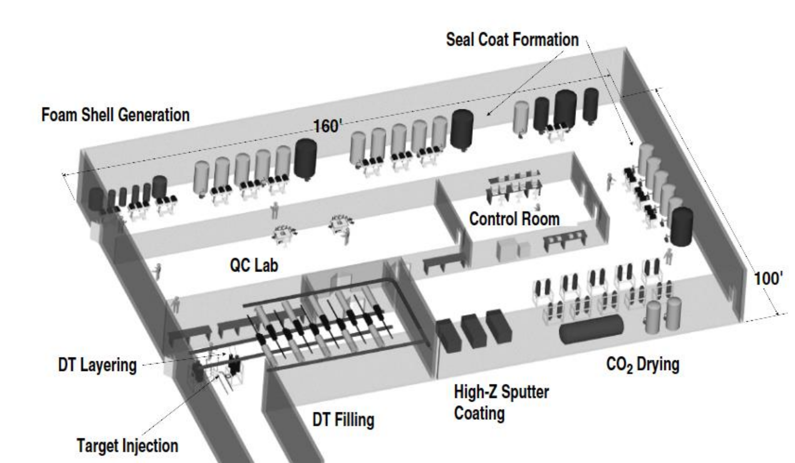

Figure 2. Mass target production facility layout [1]

In this research project these issues will be addressed by focusing on the quality control of IFE targets and how one can implement a quality control system into the manufacturing process. The proposed methodology to be tested uses light scattering methods implemented within a flow cytometer, which is a preexisting device that is used to detect and measure characteristics of a particle. With modification we can use this to determine the quality of the target. The main objective of this research project is to preform preliminary testing on this proposed quality control method to conduct a proof-of-concept experiment to establish if it is possible to determine with accuracy which targets are imperfect.

Results

Fluorescence Spectrum Testing:
In this research project I conducted an experiment to determine the fluorescent spectrum of polystyrene plastic samples, this spectrum is a critical component in determining the quality of a fuel target. As polystyrene is the proposed main component of the target shell, the spectrum can be used to contrast with the manufactured fuel cells to check the quality and presence of the fuel in the target. By contrasting the spectrum of an ideal fuel target, discrepancies in quality can be detected by identifying factors such as if there is fuel in the target and if the fuel has been contaminated with undesired substances. The resulting measured fluorescent spectrum of the polystyrene sample from the experiment can be seen in Figure 3. Determining that the polystyrene sample has an emission wavelength of ~328nm. Which can be used as a benchmark for contrasting to targets in the manufacturing process.

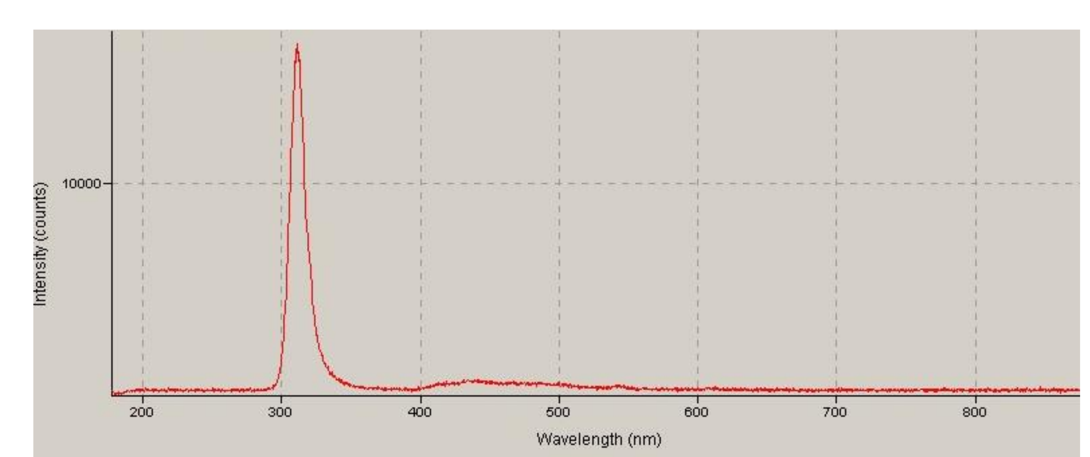

Figure 3. Polystyrene fluorescence spectrum

Target Light Scattering:
Continuing the work done for the fluorescence spectrum testing a laser light scattering experiment was conducted to determine the surface roughness of a fuel target. Using a light scattering setup including a red laser, spherical polystyrene samples, and a CCD camera I was able to record the scattered light from a spherical polystyrene particle seen in Figure 4. From these light patterns the roughness of the polystyrene spheres can be determined, allowing for the identification of imperfect fuel targets. Using the light patterns identification of roughness can be done through the analysis of patterns which can be converted into a simulation an example of this can be seen in Figure 5 where the light scattering patterns were analyzed using software to create a simulated particle [2].

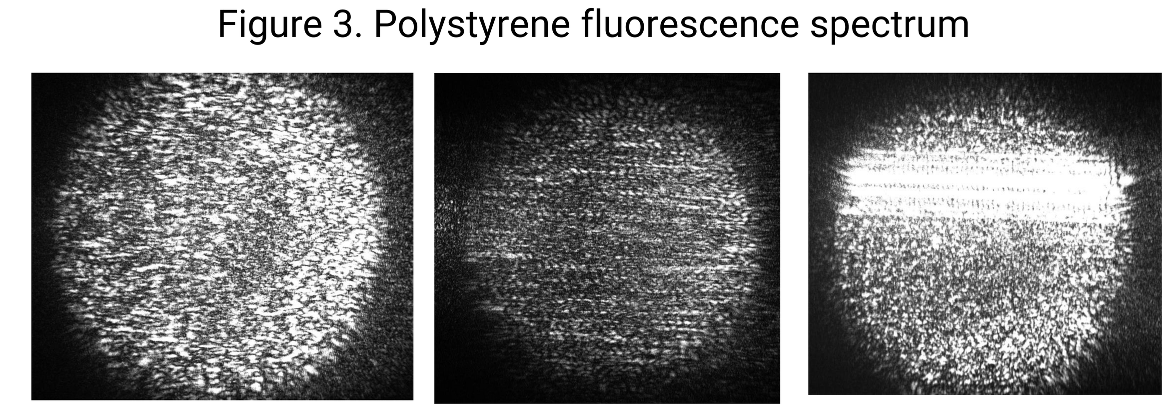

Figure 4. Captured polystyrene bead scattered light patterns

Implementation of quality control testing:
Using the two tested methods of quality control through experiment we can implement these testing processes into the manufacturing process of a target. The proposed method for this is implementing the quality control testing into a flow cytometer which already uses light scattering and fluorescence absorption spectrums to determine the properties of particles. With modification we can take this existing device and design components to specialize flow cytometers for the testing of fuel targets. This quality control testing device would be added at the end of the target manufacturing process to ensure quality before targets are injected into the reactor allowing for a more cost-efficient operation of an Inertial Fusion Reactor.

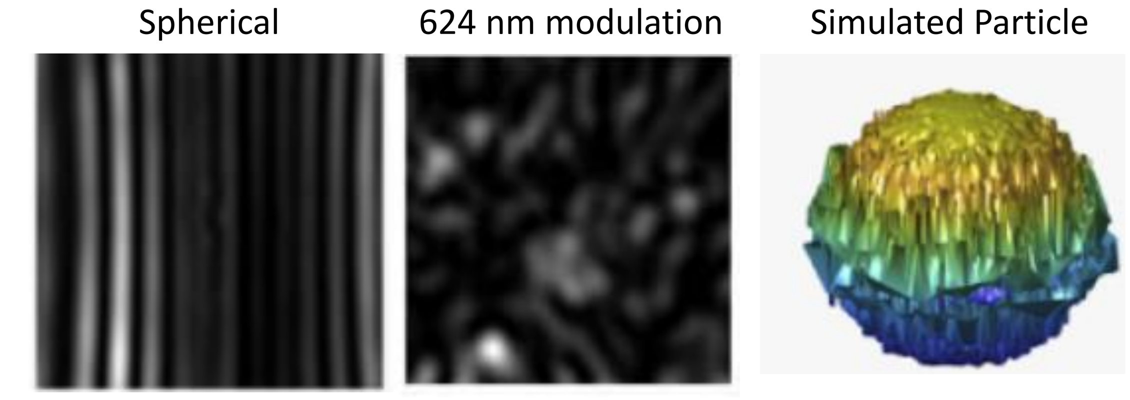

Figure 5. Scattered light patterns and simulated particle [2]

Future Considerations

Future Continuations:
Further research on the advancement of target efficiency continues naturally from this DRA project such as:

Spectrum and Light Scattering Analysis of Targets with Fuel:
Work done in this research project can be further continued by doing an in-depth analysis of functional targets with DT fuel injected inside to provide accurate measurements to be able to further differentiate high quality targets from low quality targets. This research will be essential in the actual implementation of a target quality control system.

Quality Identification Using Machine Learning:
In this research project the focus was on how we can measure the quality of a target and a key component of this process will include the identification of this quality from the measure light scattering patterns and fluorescence spectra. The solution to this issue is the use of machine learning to identify the structure and components of a target based off the light scattering patterns and emission spectra. Extensive testing and work will have to be done to create a machine learning model that can identify these targets with accuracy and at high speeds to ensure quality throughout the manufacturing process.

References

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[3] Righini, G.C. Glassy Microspheres for Energy Applications. Micromachines 2018, 9, 379. https://doi.org/10.3390/mi9080379