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NEUTRON AND ALPHA PARTICLE YIELD MODELING OF PLASMA JET-DRIVEN MAGNETO-INERTIAL FUSION

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This paper explores the neutron and alpha particle yield of a uniform argon plasma liner imploding on a target of deuterium-tritium using smoothed particle hydrodynamics. A baseline case is first examined based on a study conducted by Knapp and Kirkpatrick in order to benchmark the code's capability in accurately simulating the alpha particle and neutron yield generated by deuterium-tritium fusion reactions.

I. INTRODUCTION

In plasma jet-driven magneto-inertial fusion (PJMIF), a series of plasma jets are fired from plasma guns to form a cylindrical or spherical liner, which then implodes on a magnetized fusion fuel target and causes fusion reactions to occur [1]. A major advantaged that this has over other fusion concepts is that the plasma drivers may be located far enough away from the resulting fusion plasma to avoid being damaged by fusion products.

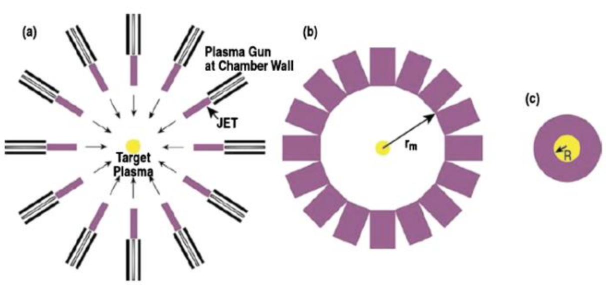

Figure 1. Plasma-jet-driven magneto-inertial-fusion.

This paper presents simulations of a PFMIF problem investigated by Knapp and Kirkpatrick consisting of a uniform plasma liner and fusion fuel target and afterburner. The primary objective of this was to benchmark the code's capability in simulating nuclear fusion reactions so that the code may be used in future studies.

II. SIMULATIONS

Simulations are performed with the Smoothed Particle Fluid with Maxwell equation solver (SPFMax), with uses smoothed particle hydrodynamics (SPH). In SPH, a fluid is divided into a set of particles and uses a summation interpolant function to calculate the properties and gradients for each of these particles. A kernel function is then used to calculate the properties for each of these particles by adding up the properties of the particles that lie within the kernel. The properties assigned to a specific particle are determined based on the particle volume and proximity of other nearby particles [2] [3].

The baseline case is taken from a study conducted by Knapp and Kirkpatrick. This study consisted of a uniform xenon shell surrounding a target and afterburner of deuterium-tritium.

Knapp and Kirkpatrick found that the fusion gain increases as the liner implosion velocity increases up until about 100 km/s. With higher implosion velocities, the fusion energy yield is eventually unable to keep up with a higher initial kinetic energy, leading to smaller fusion gain. Gains greater than 30 were observed, with the highest gain achieved with full electron heat conduction. electron heat conduction. Knapp and Kirkpatrick also found that gains were about the same for cases that had no electron heat conduction and full electron heat conduction that was suppressed by a B-theta magnetic field [4].

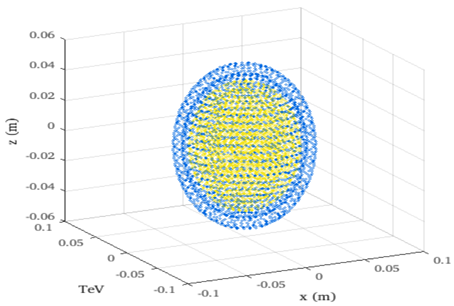

Figure 2. Spherical xenon liner surrounding deuterium-tritium target and afterburner.

The thickness, density, initial temperature, and implosion velocity of the liner, target, and afterburner for the Knapp/Kirkpatrick case are presented in **Table 1**.

Table 1. Baseline case initial conditions [4].

Liner thickness (cm)	1.16
Liner temperature (eV)	1.379
Liner density (kg/m^3)	35.75
Liner implosion velocity (km/s)	58.83
Target radius (cm)	4.06
Target temperature (eV)	80
Target density (kg/m^3)	0.0178
Target implosion velocity (km/s)	6
Afterburner thickness (cm)	0.14
Afterburner density (kg/m^3)	0.776
Afterburner temperature (eV)	0.5

The Knapp/Kirkpatrick case is simulated using SPFMax, but neglects the afterburner and electromagnetism. This was done in order to verify the code's accuracy in simulating fusion reactions, and including electromagnetism and the afterburner would complicate the code's development. The authors fully intend to eventually include the afterburner and electromagnetism, but leave this for future work.

III. RESULTS

The simulation time is one microsecond, which is more than sufficient time for the plasma liner to compress the target and initiate fusion reactions.

The ion temperature is one of the most important properties to examine in order to verify that the deuterium-tritium target becomes hot enough for fusion to occur. Profiles for the ion temperature throughout the target and the liner at various times in the simulation are provided in Figure 3 and Figure 4.

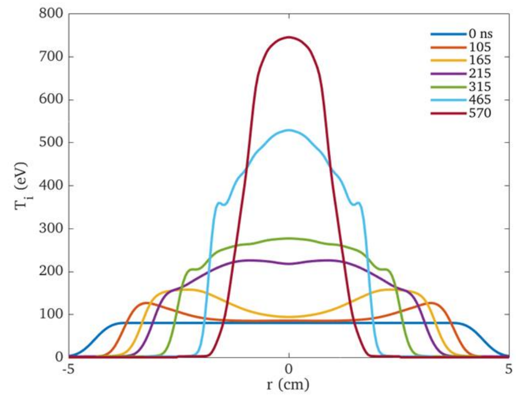

Figure 3. Ion temperature profiles up to 570 ns.

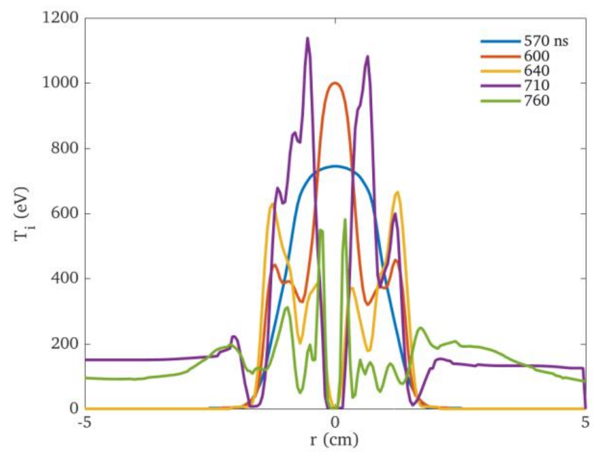

Figure 4. Ion temperature profiles up to 760 ns.

At the start of the simulation, the temperature profile is seen to be very uniform, with a steep drop in the temperature profile seen at the edges, corresponding to the uniform cold liner surrounding the hotter DT target. This can clearly be seen in a planar slice of the liner and target taken at the start of the simulation, shown in Figure 5.

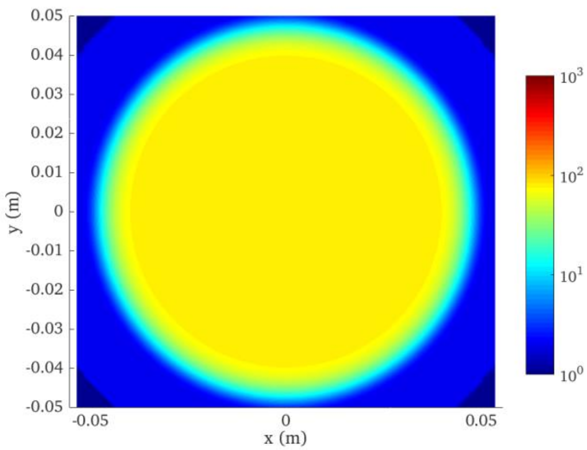

Figure 5. Planar slice of initial ion temperature.

As the liner and target compress, the liner can initially be seen to grow hotter as heat is transferred to it from the target. But as compression continues, the target begins to heat, with the temperature peaking above 1 keV at 710 ns and then dropping quickly as the target and liner plasma begin to disperse. The temperature profile at 710 ns can also be seen to no longer be uniform. This is due to non-uniformities appearing in both the liner and target plasma as peak compression occurs, and is further seen in the planar slice in Figure 6

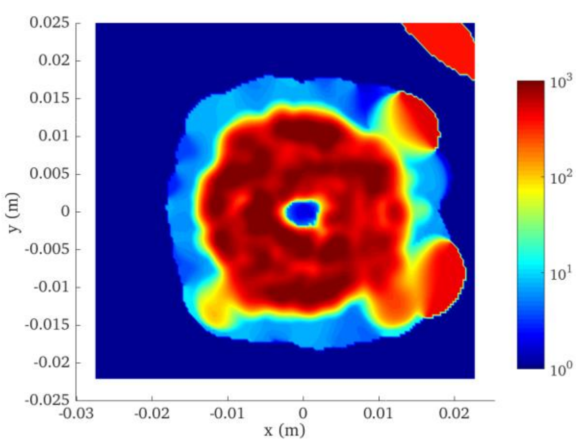

Figure 6. Planar slice of ion temperature at 710 ns.

Fusion reactions were observed to occur during the target compression, with the peak value occurring at around 710 ns. Cumulative values for the neutrons and alpha particles are provided in Figure 7 and Figure 8, respectively

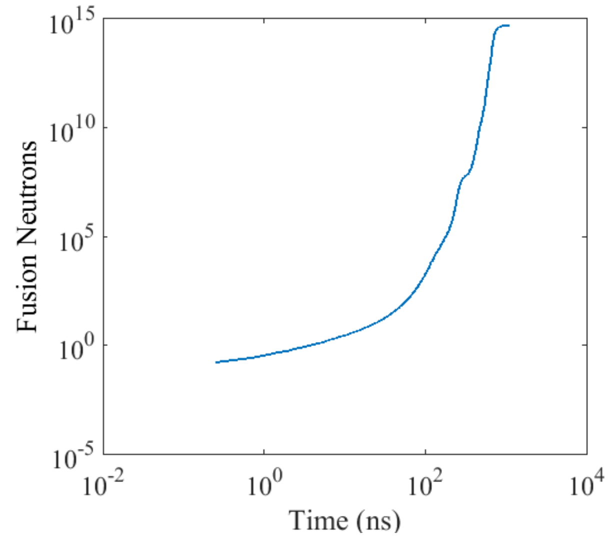

Figure 7. Cumulative fusion neutron yield.

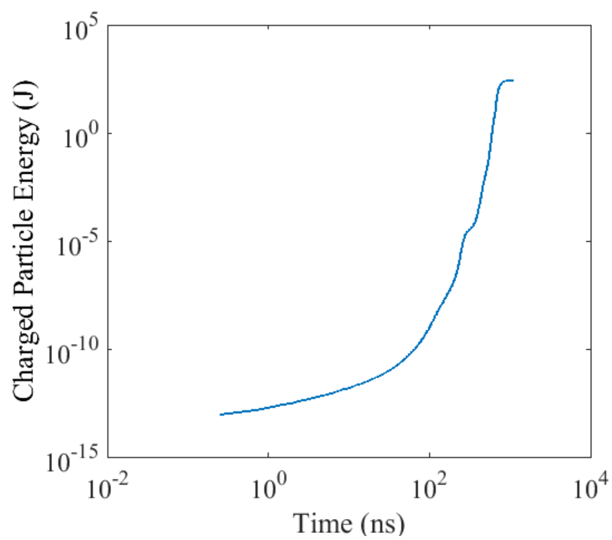

Figure 8. Cumulative alpha particle energy yield.

In both figures, a sharp increase in the generation of both neutrons and alpha particles is seen as the target is compressed and DT fusion reactions occur. The yield peaks at around 710 ns, followed by a plateau due to the sudden drop in fusion reactions as the plasma begins to disperse.

IV. CONCLUSIONS AND FUTURE WORK

The SPFMax code was used to simulate a uniform plasma liner compressing a target of deuterium-tritium target with conditions used in a study conducted by Knapp and Kirkpatrick. The principle objective of this study was to demonstrate the code's ability in simulating nuclear fusion, which was accomplished. Peak fusion reactions in the target were seen to occur at the same time that the ion temperature peaked, with non-uniformities observed to develop in both the liner and the target as compression occurs.

Future studies will incorporate both electromagnetism and an afterburner of deuterium-tritium surrounding the target. Both of these are necessary in order for breakeven fusion to be made possible.

ACKNOWLEDGMENTS

Your acknowledgments should be entered here.

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