On a Z-pinch device that reaches a maximum of 60MA of current it would have overcome that of radiation losses and diffusive losses of heat. On the current Z would reach ignition and the heating from alphas and compression would magnetic field also helps the hot inner fuel heat the colder denser surrounding temperature gradient at the liner fuel interface by making the electron preheating comes from a pressure, compressing the gas to form a very hot, dense plasma compression by a strong extrapolate an instability farther than it might otherwise go, or the reverse. instabilities as these are similar to the wire array problem, while in 2D the codes properly (successfully used to simulate wire array implosions for the creation of x-rays MagLIF Gorgon is a 3D magneto-hydrodynamics (MHD) code that has been fusion design. Figure 1: Schematic of z-pinch

Figure 2: Temperature, Z magnetic field, and Density profiles with respect to radius for 240 kilovolt, left density is fuel and right density is the liner, 25g/m² simulation at around stagnation (when liner stops imploding from pressure from fuel)

Figure 3: Yield dependence on Resolution on a 240kV case with 25kg/m² fuel density and 29.5kJ preheat energy (y = 0.000599x²+6.1635x+2431 and R²=99889 fit to guide the eye)

Figure 4: Fusion Cross-section as a function of Pressure. This is the averaged reactivity for a given temperature.

Figure 4(right): Yield in kilojoules as a function of Current

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References


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Introduction

Gorgon is a 3D magneto-hydrodynamics (MHD) code that has been successfully used to simulate wire array implosions for the creation of x-rays and model instability growth in imploding Beryllium liners and would be ideally suited to simulate and test the idea of Magnetized Liner Inertial Fusion (MagLIF). MagLIF may suffer considerable loss in fusion yields because of the magneto-Rayleigh-Taylor instabilities, and a 3D code is needed to simulate these properly. Gorgon, as a 3D code would be very good at simulating the instabilities as these are similar to the wire array problem, while in 2D the codes extrapolate an instability farther than it might otherwise go, or the reverse. Before moving on to 3D simulations however, it is important to test the fundamental physics in the simpler and less computationally expensive 1D simulations.

MagLIF is a concept where an inertially confined, preheated Deuterium-Tritium gas that is magnetized in the z direction undergoes fusion from compression by a strong azimuthal magnetic field which creates tremendous pressure, compressing the gas to form a very hot, dense plasma (Fig. 1). The preheating comes from a kilojoule range laser to get the gas to a higher initial temperature before compression, and the magnetic field in the z direction helps keep that heat in the fuel by reducing thermal diffusion across the steep temperature gradient at the liner fuel interface by making the electron gyroradius smaller so it moves more in a circle instead of escaping in a line (Fig 2). The z magnetic field also helps the hot inner fuel heat the colder denser surrounding fuel as the heat moves more slowly. This plasma would be hot and dense enough for significant fusion to take place and above 5keV and a ρR of 2-4kg/m² [4] it would reach ignition and the heating from alphas and compression would overcome that of radiation losses and diffusive losses of heat. On the current Z-machine with a max current of 27MA the radial magnetic field is 5000T and the pressure it exerts is 1000bars which would compress the gas at high speeds reaching a ratio of up to 20 of initial fuel radius over final fuel radius in 100ns. On a Z-pinch device that reaches a maximum of 60MA of current it would have approximately 120,000T, 57Gbars, and the yield might exceed 100’s of MJ’s.

The simulated yield had a strong dependence on the resolution or number of cells in the problem (Fig. 3). This was especially evident on higher density and higher current runs. The high resolution needed would be very difficult to run on a 3D simulation which this code is designed for.

An important part of fusion calculations is the fusion cross-section which is how close the two particles have to come to one another to fuse. It is highly dependent and originally the code was written for lower current implosions, and at temperatures above 25keV the code was set to have a 0% cross-section because the fit that was being used was not accurate above that temperature [1]. I wrote the code for adopting

\[ \text{Yield (kJ)} = M_0 + M_1 \times x + \ldots + M_8 \times x \]

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Results

Atzeni’s fit to the fusion cross-section (Fig. 4) which is accurate to higher temperatures then the approximation that was previously being used.

The way that the energy from the alpha particles that were born in the fusion process was redeposited in the fuel was also changed, so that only a fraction of the energy was deposited in the fuel instead of all of it in one spot. M.M. Basko et al. showed that for uniform cylinders only a small fraction of the alpha particle’s energy is deposited in the fuel unless the radius of the cylinder is large compared to the alpha particle’s gyroradius or when the radius is large compared to the alpha mean free path\[ \text{where temperature is in keV, density is in g/cc} \]

\[ \text{kg/m}^2, \text{and L is the Coulomb logarithm. This is proportional to temperature to the 3/2 over the density so large amounts of energy escapes except in cold dense regions like .5 to .1 mm radius in Figure 2 where over 90% of the energy of an alpha particle going through would be dropped.} \]

Conclusion:

The yield was optimized as a function of the current was then compared against the references⁴ to see if the fundamental physics of the Gorgon code had improved.

The yield was still very low compared to the references except when the resolution was very high, which is impractical to run as a 3D simulation.

Constant Density Optimized Yield vs. Current

\[ Y = M_0 + M_1 \times x + \ldots + M_8 \times x \]

\[ Y = M_0 + M_1 \times x + \ldots + M_8 \times x \]