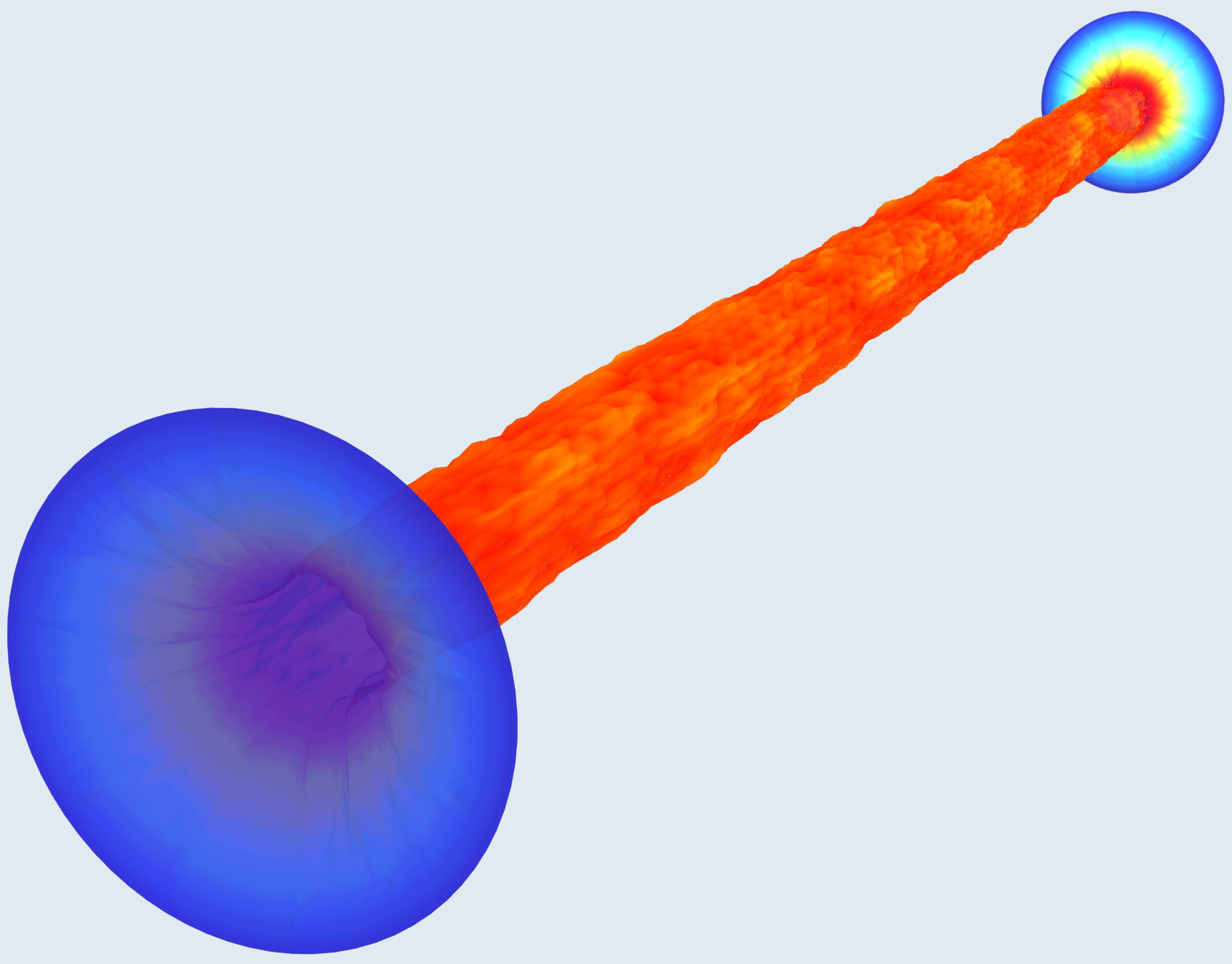

Supernova on Your Table Desk - Inertial Nuclear Fusion by Z-Pinch with a Hollow-Fiber Exploding Wire

The Z-pinch (or zeta pinch) is a type of plasma confinement system used in fusion power research. It relies on an electric current discharge within the plasma to generate a magnetic field that compresses the plasma, creating conditions conducive to nuclear fusion.

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1. Renewable Energy Interest Group (NGO in founding phase)

Introduction

In this approach we tried to simulate a multiphysics model that consists of a thin single hollow-fiber copper exploding wire, filled with nuclear fusion fuel material like Deuterium and Tritium (^2D and ^3T). Unlike the Sandia Lab's Z-machine that uses hundreds of parallel wires forming a 20cm long cylinder with some cm diameter. The main idea was to force and tweak that system to reach the Lawson criterion in a simple and easy way, that means the system should produce net energy. The trick was not to use hundreds of wires shaping a cylinder shell, but use a single hollow-fiber metal wire instead. The inner diameter surface of the hollow-fiber metal wire will form an implosion that compresses the nuclear fuel infill. One of the main advantages is, that the primary formed metal plasma has the generic density of the metal itself (copper : 8960 kg/m³). The following implosion shockwave can easily compress the nuclear fuel while adiabatic compression raises the temperature up to billions of K (~1.8e9 K) and about hundred Trillion Pa pressure, just without Z-inch compression respected (~9.0e13 Pa).

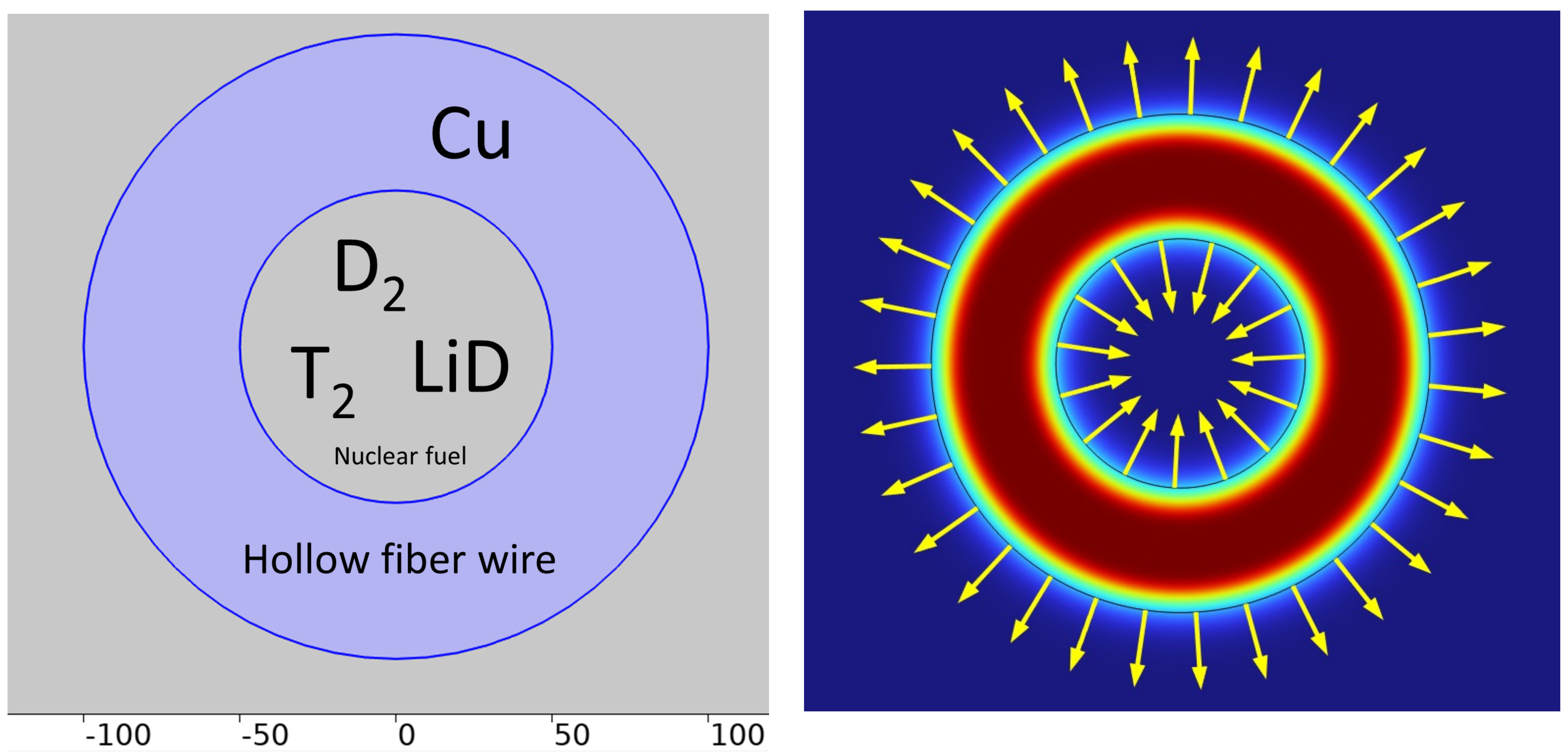

Figure 1. Left : Cross section of the d=200µm copper hollow fiber with nuclear fuel infill. Right : Electric discharge shockwaves forming an implosion compression of the nuclear fuel infill.

Methodology

The simulation approach in this work uses a sequence of one-way coupled classical multiphysics calculations with some very crude simplifications and assumptions. The simulation steps are as follows:

1) Estimation of the rise time of the exploding wire discharge breakdown. Assumptions : the breakdown time can be estimated by a given electric charge (capacitor C) Q and U {U(t) = L di(t)/dt}. The inductivity of the circuit is estimated by COMSOL Multiphysics®, while the electric conductivity is based on a 100% ionized plasma.

2) Joule heating of the wire by electric discharge with W = 10kJ {W = 1/2 C U²} . Assumptions : the system behaves adiabatic while the discharge time can be run in less than t << 1.0 ns , so no radiation can travel at the speed of light at most L<< 0.3m distance. The solid and liquid and gas phase state of matter can be neglected in favor of the plasma state, because heat capacity and temperature range is significantly lower than that of the plasma state. The metal plasma model can be simplified as a 1-atomic ideal gas with the heat capacity of {c_v = 3/2 R} or {E_kin = 3/2 k_b T}.

3) Adiabatic compression of the plasma by forming a shockwave using compressible Euler equations. Assumptions : as in the step above the metal plasma is treated like a 1-atomic ideal gas with the start condition density of solid copper and the temperature calculated in step 2.

4) Z-Pinch by current discharge in the metal plasma. Assumptions : the Z-pinch deformation of the plasma is calculated by the structural mechanics module as a pseudo-elastic body. The Young's modulus E can be expressed by the plasma compressibility {E = p} for ideal gases.

Results

The simulation results are promising. As mentioned before in the introduction section, the pressure rises up to ~9.0e13 Pa , and the temperature up to ~1.8e9 K at the specific maxima times. Density goes up to ~1.1e4 J/kg, slightly more than density of copper. Velocity reaches ~4.0e5 m/s. Interestingly, the maxima do not occur at exactly the same time. Just the maximum of the compression shockwave velocity and the temperature maximum are quite synchronized at ~1.2e-10 s at the shockwave focus in the center of the wire's cross section. One of the most surprising findings is a sharply defined center of the pressure maximum , that keeps its value stable for a relatively very long time. The magnetic z-pinch itself (see header image) was simulated out of scope due to solver instabilities. A realistic solution was probably not achieved. The Lawson criterion "triple product" is fulfilled regarding to temperature and density, but the confinement time is very short for a theoretically self-sustaining fusion reaction.

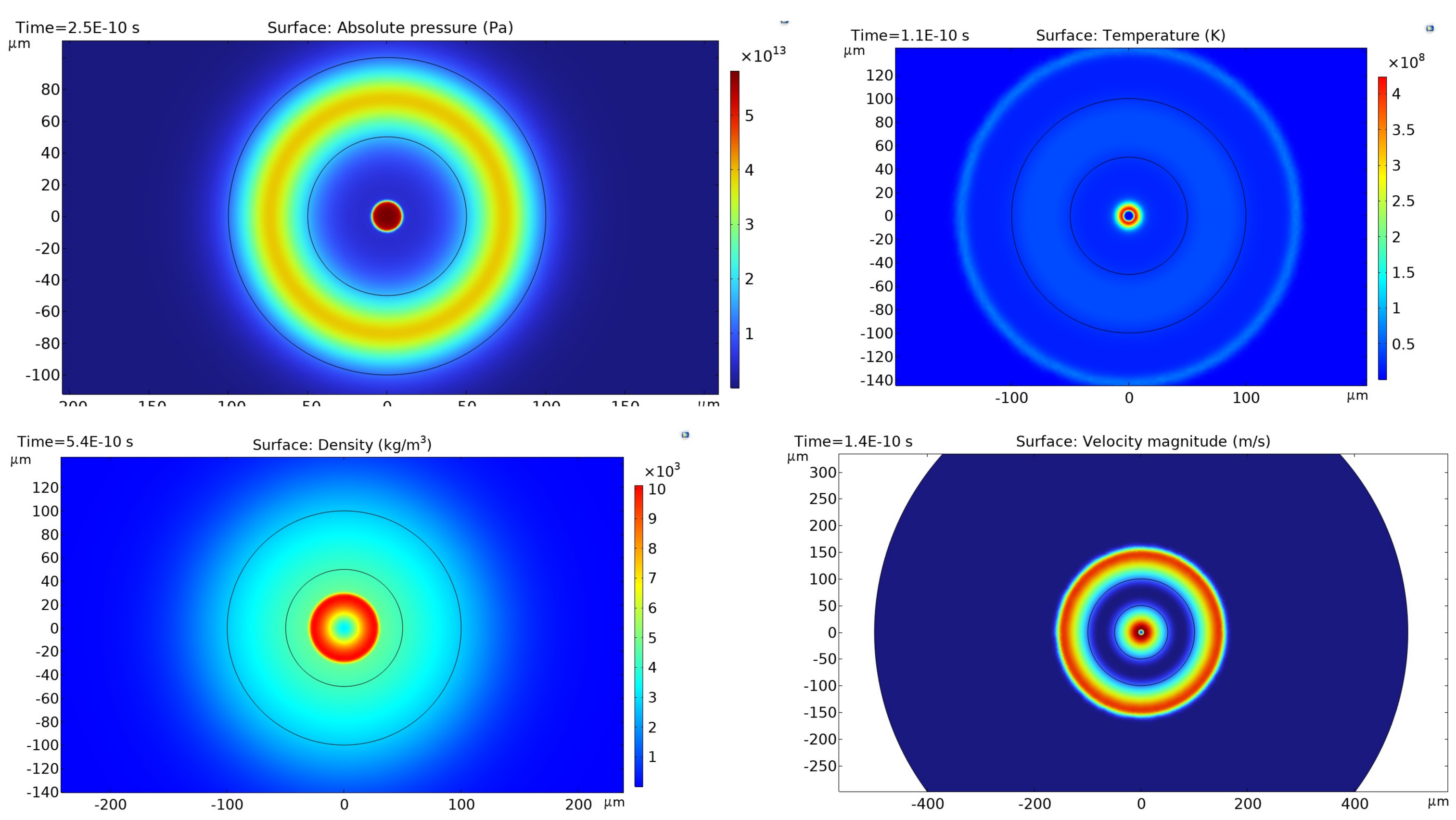

Figure 2. Pressure, Temperature, Density and Velocity of the Exploding Wire's implosion and collapse compression by focused shockwave near to the specific maxima times.

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