2D Simulation of Experimental Fusion Plasma

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What is fusion energy?

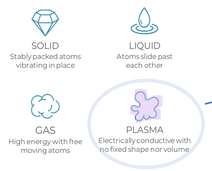
- Fusion is how the sun and other stars generate their energy
- Einstein's $E = mc^2$ … describes the relation of mass and energy
- Fusion is when two particles collide and form one particle with slightly less mass than the original two
- The difference in mass is related to the energy released by this process
- The sun releases light and heat from fusing protons into helium ions

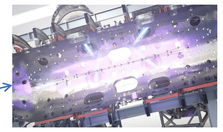
Why is fusion an attractive source of clean energy?

- Safe (no runaway chain reactions like in nuclear fission)
- Carbon-free energy source that can scale with demand

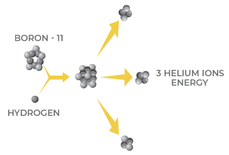
How to create fusion?

- To fuse, need to overcome repulsion between similarly charged particles
- Need high energy (> 10 million degrees Kelvin). At this energy, materials exist as plasmas





FRC plasma inside the C-2W confinement vessel with neutral-beam injection for plasma heating



p-^{11}B fusion reaction

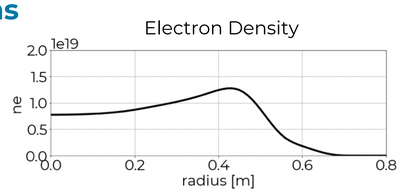
Why us?

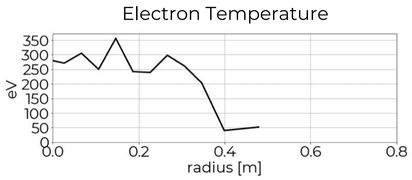
- FRC (Field-Reversed Configuration) is the most effective container for holding the plasma
- Goal is to use advanced fuels, e.g. Boron-11 and protons, for an aneutronic fusion
- Simple linear geometry for the machine. More compact than the doughnut-shaped tokamaks like ITER

Research Highlights

- TAE Technologies' fusion device, C-2W, produces and sustains high-temperature FRC plasmas
- Total energy accumulated in plasma is a key metric of machine performance
- Evaluating total energy from sparse measurements of magnetic field at the wall is very difficult due to FRC magnetic container
- Newly developed SEquOIIA code overcomes these difficulties by using combination of hydrodynamic and kinetic methods to calculate magnetic configuration and match it to magnetic probe measurements
- Produces more reliable estimates of total energy

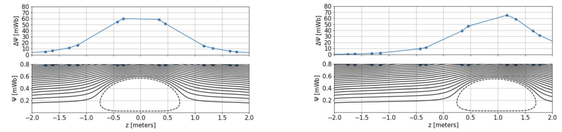
Diagrams





Diagnostics for density and temperature have lines of sight at the midplane cross section

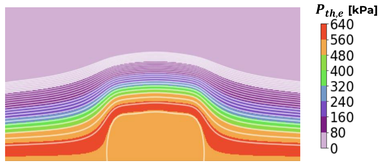
Flux at wall (blue) is related to the position and size of the plasma



Need 3D kinetic simulations of energetic particles to produce a 2D description of the plasma that is consistent with measurements at the wall

Plasma and fast ions as well as currents of external coils fully define total magnetic field and used to match probe data at vessel wall

Electron Density x Temperature follow field lines



Thermal plasma follows total magnetic field

Methods

The TAE team developed the Synthetic Equilibrium from Observational Inputs Interpretive Algorithm (SEquOIIA) code. Uses plasma physics equations to reconstruct internal plasma properties not otherwise available from direct experimental measurements. Reconstruction minimizes difference in experimentally measured quantities and simulated quantities.

Features

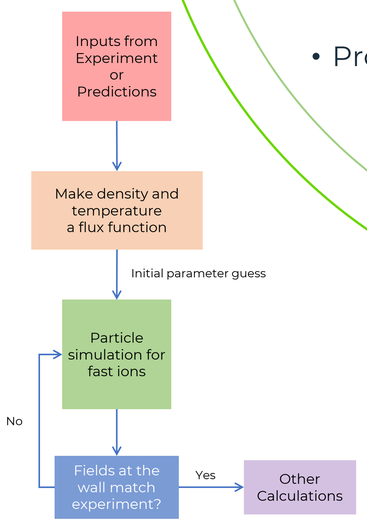
- Thermal plasma and suprathermal (fast) ions substantially contribute to plasma pressure.
- Fully kinetic description of fast ions with Monte Carlo simulation

Inputs:

- Density
- Temperature
- Neutral Beam Injection (source of fast ions)
- External (vacuum) magnetic field

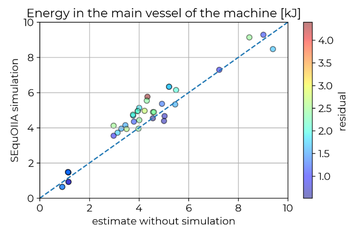
Results optimized to fit magnetic probe data

- Identify magnetic configuration that fits magnetic probe data
- Vary the accumulation of fast ions by modifying the sink mechanisms

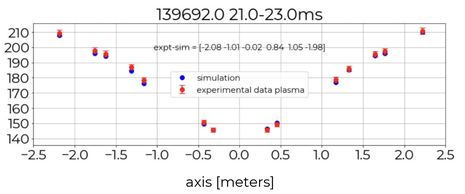


Results and Conclusion

- It calculated total plasma energy with higher accuracy than previously was available.
- Preliminary results show that accumulated plasma energy is higher than currently available estimates and in the best shots > 9 kJ.
- The SEquOIIA code is still under development. More work needed to implement as a routine method of evaluation of total plasma energy in FRC configurations.



Compare two methods of calculating plasma energy
X-axis: Energy calculated from magnetic data at the wall using 1D pressure balance
Y-axis: Energy calculated from fast ion particle energy and 2D thermal profiles



Example of matching simulated fields at magnetic probe locations (blue) to experimental values (red)

Bibliography

1. H. Gota *et al.*, Nucl. Fusion 61, 106039 (2021)