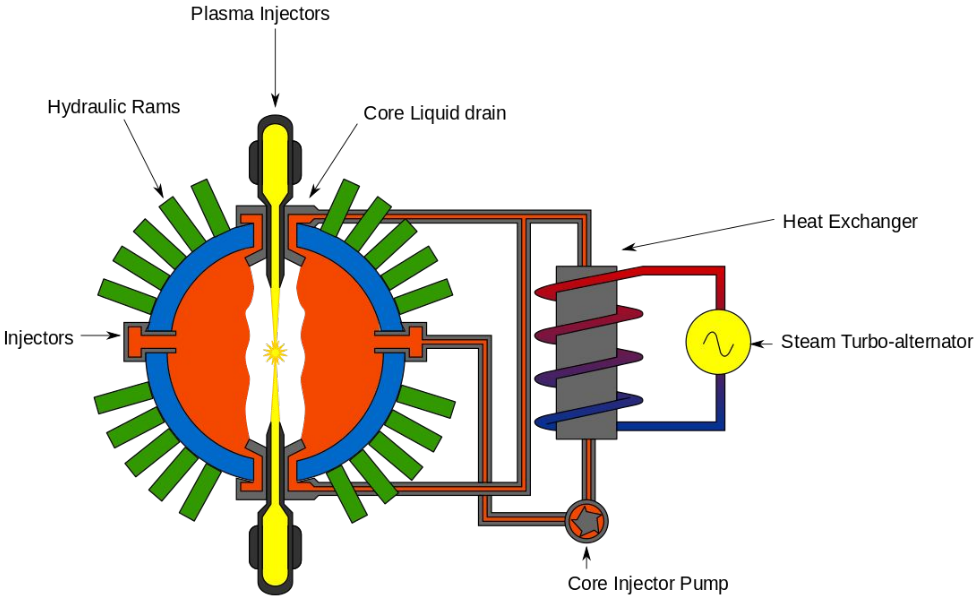
General Fusion

Max Mendoza, Daniel Zhan

Introduction

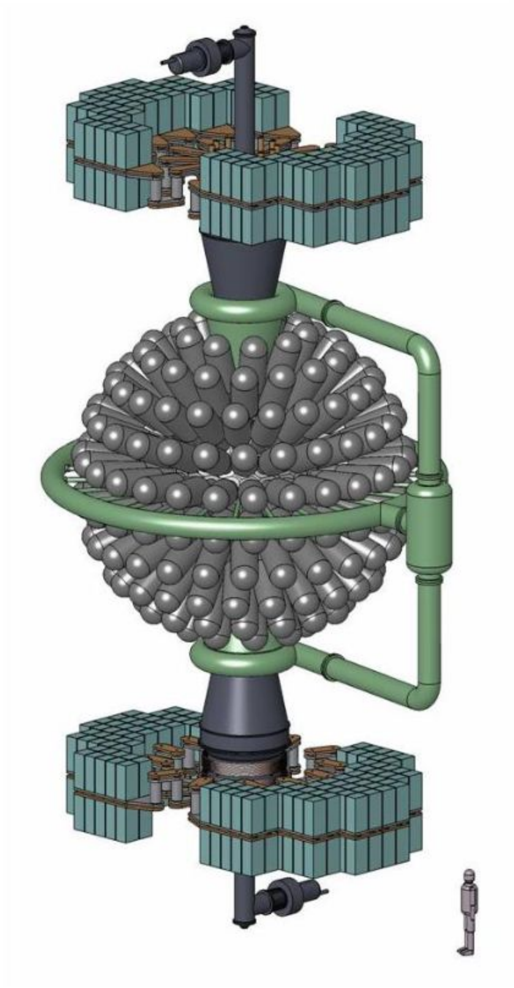
Technology:

- ➔ Magnetized Target Fusion
- ➔ Standard DT plasma fuel
- ➔ Spheromak Plasma Shape
- ➔ Compression achieved using pistons
- ➔ Energy extracted via liquid metal wall
- ➔ Lithium in liquid wall breeds tritium



Other:

- ➔ Purpose: Achieve commercial fusion energy quickly using relatively simple methods
- ➔ Canada-based, founded in 2002, aim to complete 70% scale size of reactor by 2025



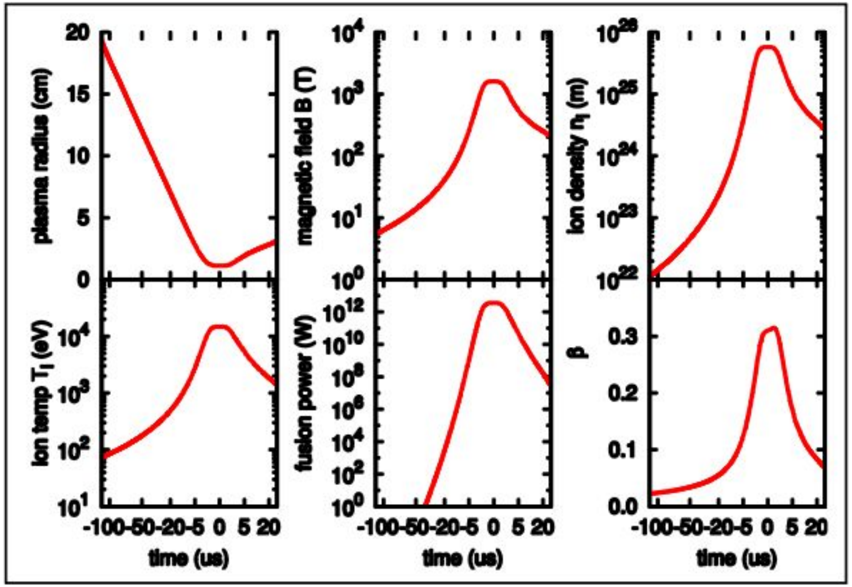
General Fusion Acoustic MTF Reactor Concept

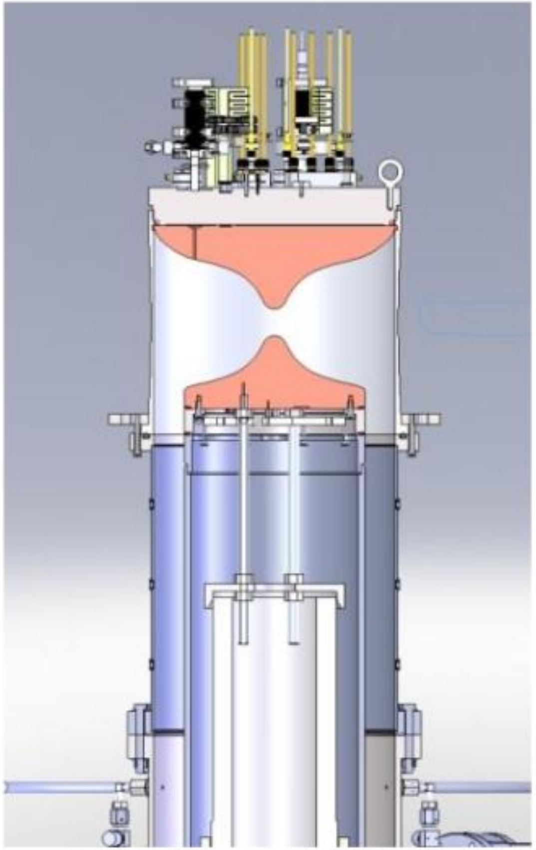
Plasma Injectors/Gas Piston Compression

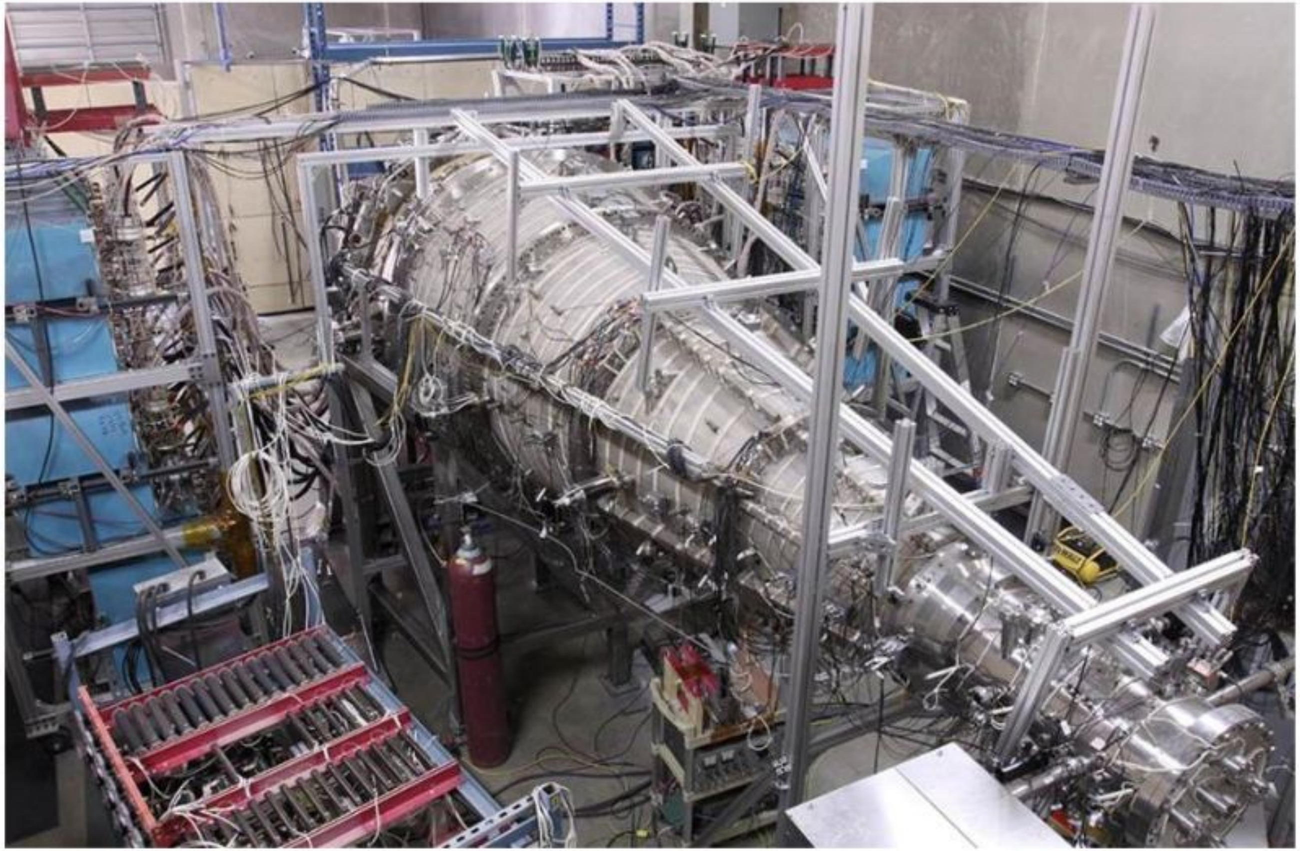
Max Mendoza

Plasma Injectors

- Self-contained compact toroids merge
  - Pair of CTs injected into evacuated volume in center
- PI-1 and PI-2
  - Magnetized Marshall gun
  - Spheromak configuration
- Single or multiple CTs
  - Multiple - near zero final momentum
- Separate experiments with MRT device
  - Test compression effects on magnetized plasma (Beta)
- Future Development
  - High efficiency PIs
  - Operate at high power
  - Non-conical injector design

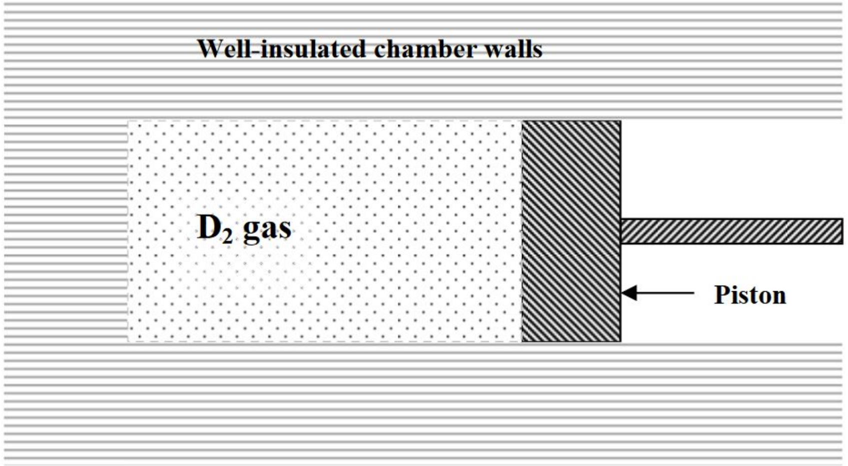






Ideal Gas Piston Compression

- Fusion reactions proportional to N^2
  - Make fuel more dense, same Power at a lower Temp
- Theoretical set-up
  - Rapid, adiabatic compression of D gas by piston
  - Reduce degrees of freedom of plasma particles
- $T=T_0\beta^{2/f}$
  - β is compression ratio, f is degrees of freedom (ideal gas)
- Results: look at $\delta E/W$
  - Ideal gas = 14 at lowest f and highest β
  - Van der Waals = 4100 at same f and β



Piston Compression in General Fusion

- Prototype: 14 pistons mounted on steel sphere
- Sphere design
  - Interior filled with pumped molten Pb
  - Inner radius of 0.5 m
- Piston design
  - 100 kg hammer piston (steel)
    - Accelerated by compressed air to around 50 m/s
  - Floating anvil piston (steel)
    - Contact with liquid Pb
    - Acoustic match between steel and Pb
      - $Z=\varrho c$
      - Closer match, more energy transfer
- Converging waves hit Pb-vacuum interior
  - ~entirely reflected - acoustic impedance mismatc
    - Rapid acceleration inward

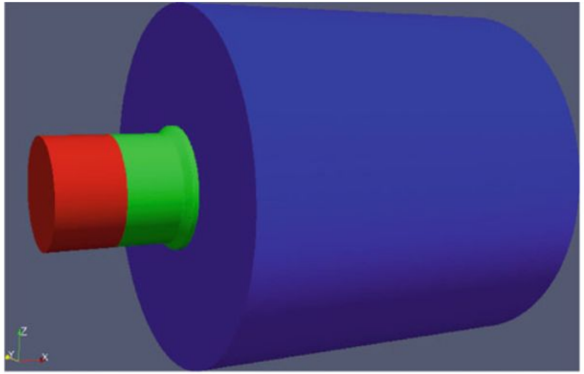


Fig. 2 Three-body system (hammer (*red*), anvil (*green*), and lead tank (*blue*)) simulated with Y code to obtain temporal and spatial structure of the pressure wave transferred by the anvil piston into molten lead

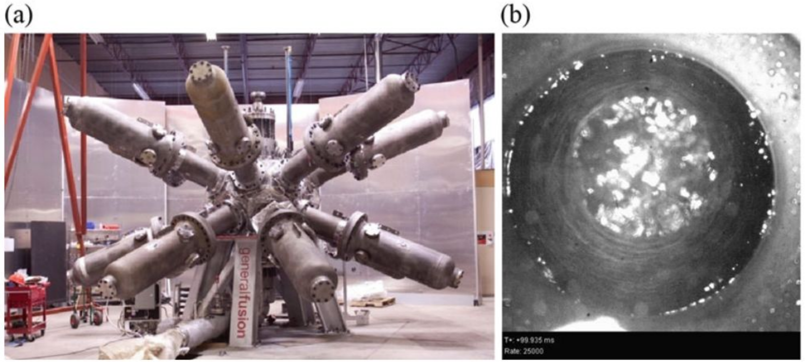


Fig. 1 (**a**) Current prototype of the compression system in General Fusion Inc. and (**b**) liquid lead vortex inside the compression system (view from the *top*)

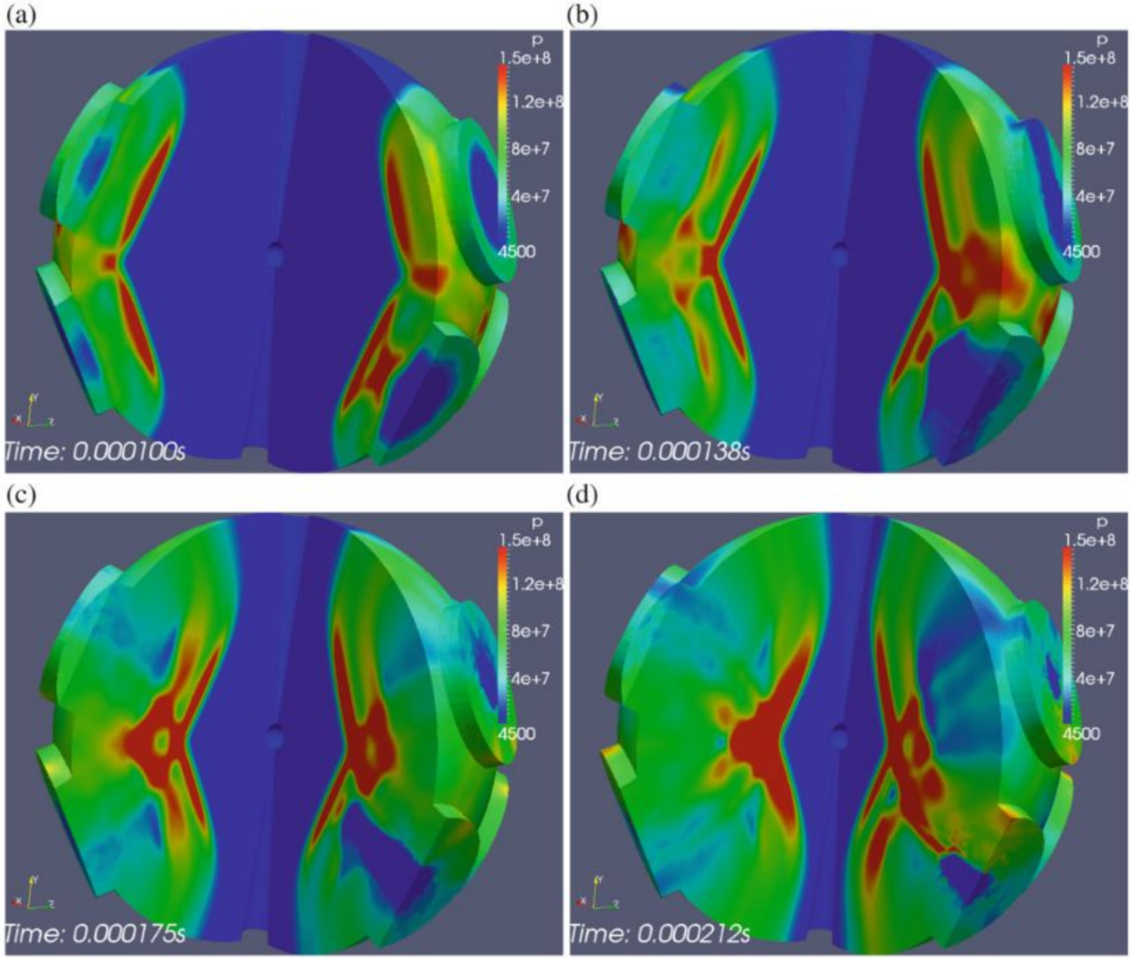


Fig. 7 Structure of the pressure wave produced by the fourteen pistons inside current compression system prototype as it propagates through the molten lead obtained with open FOAM (**a**) $t = 100\mu s$; (**b**) $t = 138\mu s$; (**c**) $t = 175\mu s$; (**d**) $t = 212\mu s$

Can It Work?

- Pros
  - Cheap (less than $0.2/J)
  - Working gas reused
  - Precise (modern servo controllers)

- Cons
  - Hydrodynamic instabilities
    - Non-uniform p wave
  - Cavitation
    - Pitting in liquid metal
  - Reliance on acoustic impedance

- Summary
  - Ideally, use compression to limit degrees of freedom and compress gas
    - Can achieve same fusion energy at lower temperatures
  - General Fusion Prototype (14 pistons)
    - Proves concept of piston driven compression of vacuum chamber
  - Actual plan:
    - 100s of pneumatic pistons (100 MJ acoustic pulse)
    - 1 GPa to 10 Gpa amplification in pressure at liquid-plasma

References

[1] K. Bol *et al.*, “Experiments on the Adiabatic Toroidal Compressor,” MATT--1092, IAEA-CN--33/A4-2, 4203067, Dec. 1974. doi: 10.2172/4203067.

[2] P. O’Shea *et al.*, “Magnetized Target Fusion At General Fusion: An Overview,” p. 1.

[3] A. Froese, D. Brennan, M. Reynolds, and M. Laberge, “MHD Stability of a Magnetized Target During Non-Self-Similar Compression,” p. 1.

[4] M. Laberge *et al.*, “Acoustically driven Magnetized Target Fusion,” in *2013 IEEE 25th Symposium on Fusion Engineering (SOFE)*, San Francisco, CA, USA, Jun. 2013, pp. 1–7. doi: 10.1109/SOFE.2013.6635495.

[5] D. W. Kraft, “NUCLEAR FUSION BY MECHANICAL ADIABATIC COMPRESSION OF A DENSE PLASMA,” p. 8.

[6] V. Suponitsky, D. Plant, E. J. Avital, and A. Munjiza, “Propagation of Pressure Waves in Compression System Prototype for Magnetized Target Fusion Reactor in General Fusion Inc.,” in *30th International Symposium on Shock Waves 2*, Cham, 2017, pp. 955–960. doi: 10.1007/978-3-319-44866-4_30.

Liquid Metal Wall & Instability

Daniel Zhan

General Design Requirements for Plasma-Facing Component

A Fusion Reactor Blanket needs to:

1. Sustain a clean and pure plasma
2. Recover energy from fusion reaction
3. Shield outside structures and people
4. Breed tritium for use as fuel

Favorable Solution in ICF Configuration:

➔ Liquid Metal Wall

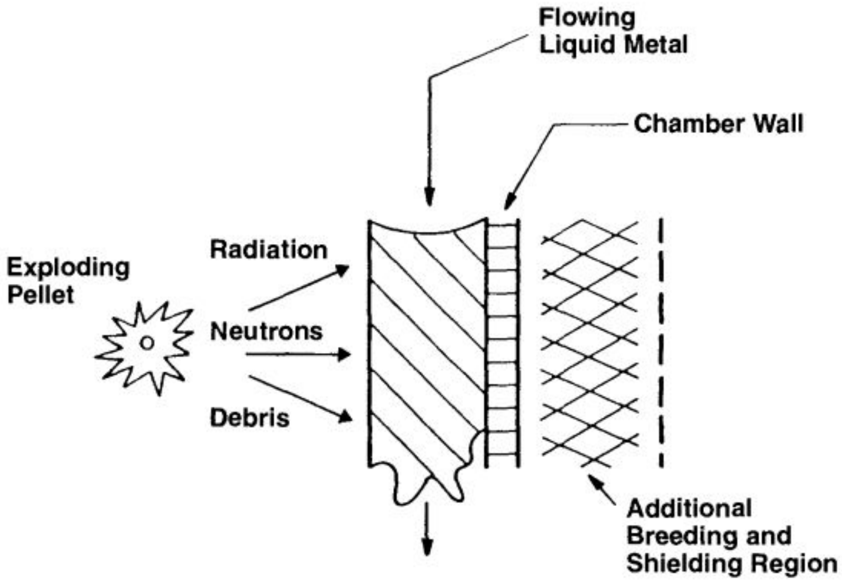
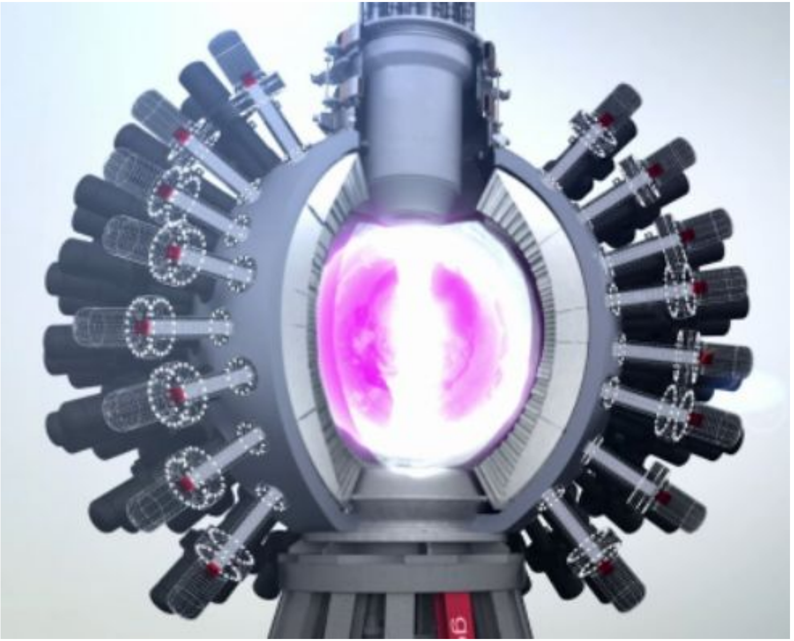


Fig. 13.2: Components of a blanket for an inertial confinement fusion reactor.

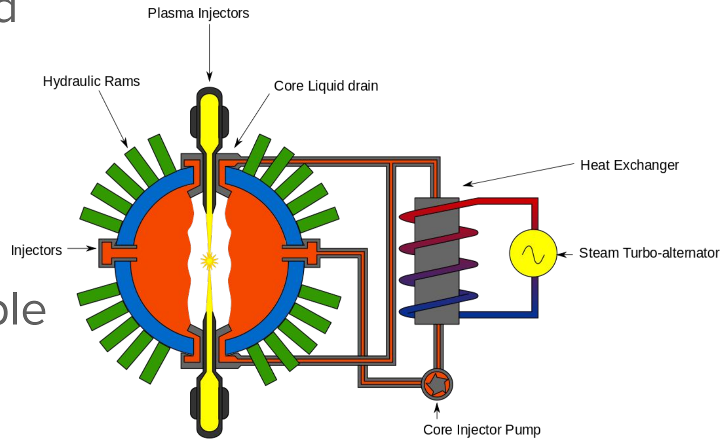
General Fusion’s Plasma-Facing Configuration

- ➔ Liquid Metal Wall made of Pb and Li
- ➔ Liquid fills about 20% of sphere volume
- ➔ Spinning spheromak centrifugally pushes liquid to sides, forming a “wall”
- ➔ Cylindrical gap in liquid metal provides space for fusion plasma
- ➔ Pistons compressing liquid metal cause compression in fuel as well
- ➔ Liquid metal pumped into sides and exit the poles, passing through heat exchangers



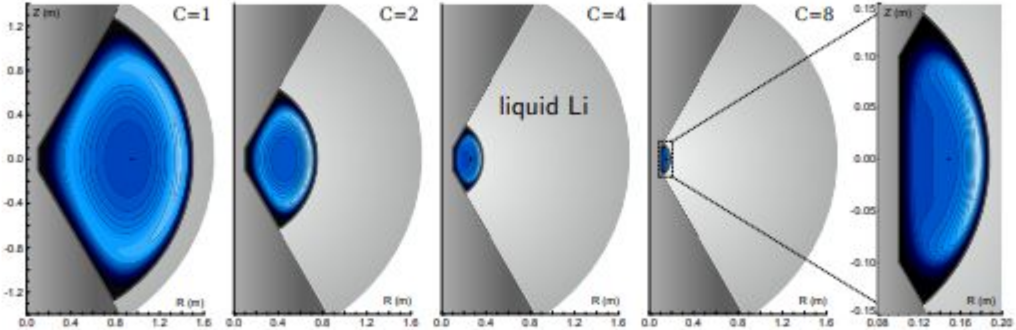
How this Liquid Metal Wall Achieves Design Reqs.

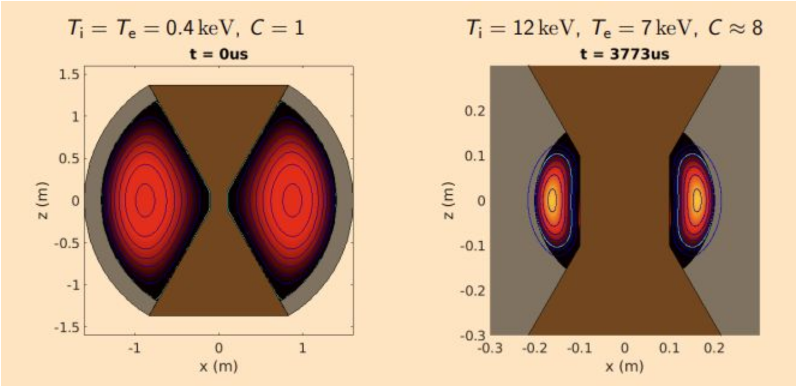
- [Keeping Plasma Pure] Liquid metal prevents fuel components from sputtering parts of the wall and cycles out waste
- [Energy Recovery] Heat from the fusion reaction raises liquid metal temperature; exiting liquid powers steam turbines
- [Shielding] Liquid metal shields reactor and people from incoming high energy particles
- [Tritium Breeding] Incident neutrons on lithium in liquid wall produces tritium, which is chemically extracted



Some Diagrams

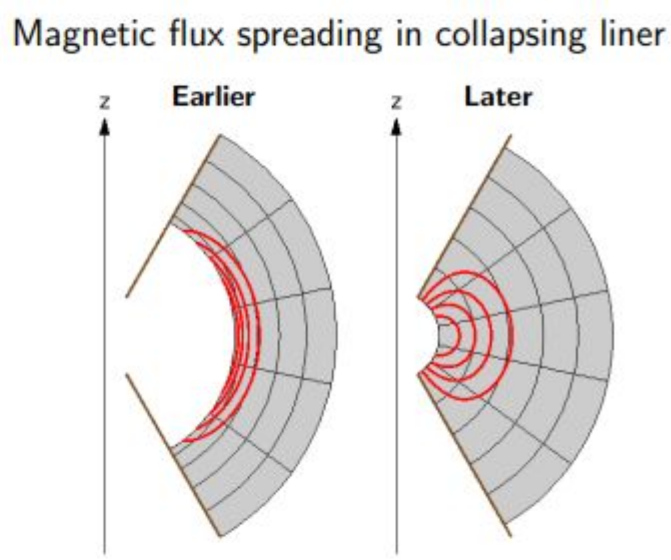
Compression of Liquid Metal Wall,
which compresses plasma



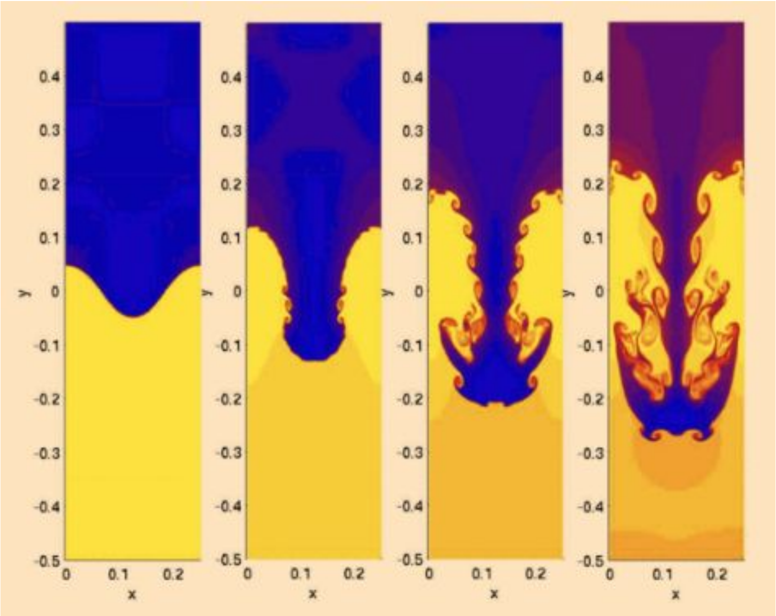


Potential Sources of Instability

Liquid Metal Wall conducts electricity and a magnetic field is present due to plasma current, leading to MHD effects, esp. during wall compression



Rayleigh-Taylor (RT) Instabilities occur when two fluids of different densities push on each other.



References

[1] A. Froese *et al.*, “Effects on Stable MHD Region of a Magnetized Target Plasma Compression,” p. 27.

[2] “SLIC_LiWallInteraction_APS_v5_StephenHoward_pdf.pdf.” https://generalfusion.com/wp-content/uploads/2020/12/SLIC_LiWallInteraction_APS_v5_StephenHoward_pdf.pdf (accessed Apr. 26, 2022).

[3] R. Munipalli *et al.*, “Modeling Highly Unsteady Current-driven Liquid Metal Free-Surface MHD Flows,” p. 1.

[4] M. Reynolds, “Consequences of Flux Diffusion in a Liner Compression Fusion System,” p. 12.