Lawson Machine 26: An Update on General Fusion's Magnetized Target Fusion Demonstration

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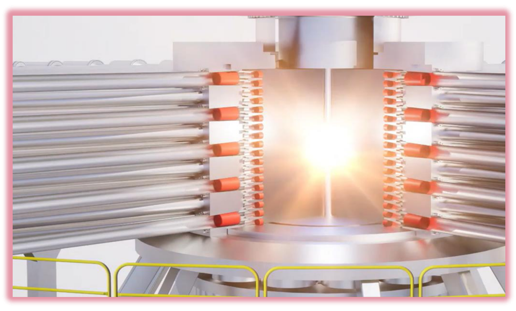
General Fusion's Magnetized Target Fusion

General Fusion is developing Magnetized Target Fusion (MTF) as a practical means of producing deuterium-tritium fusion power. In General Fusion's technology, a spherical tokamak plasma target is formed by coaxial helicity injection (CHI) into a rotating liquid lithium flux conserver (liner) and mechanically compressed to fusion conditions [1]. The rotation of the liquid liner generates a cylindrical cavity into which the plasma is formed and stabilizes fluid instabilities during compression.

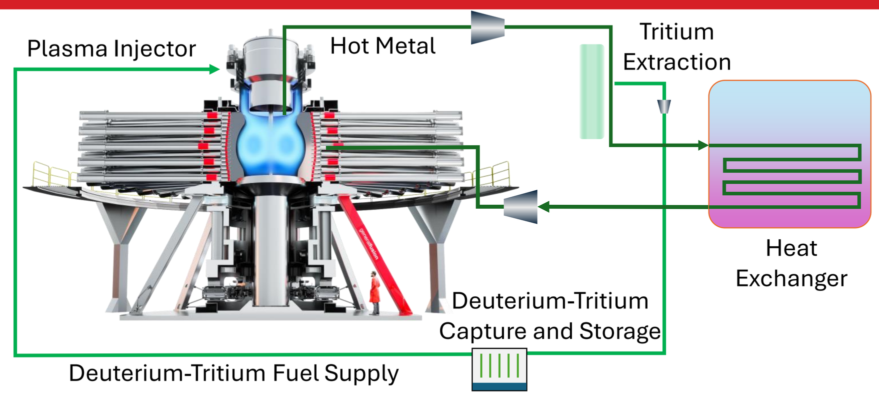
The mechanical compression is driven by high pressure gas and requires no superconducting magnets or high-power lasers. The short compression timescale (~40 ms) and compressive heating remove the need for any auxiliary heating, fueling, or external current drive after formation.

Overcoming Barriers to Commercial Fusion



Durable Fusion Machine

Liquid metal wall compression technology absorbs neutrons and protects machine from fusion damage



Sufficient Fuel Production

Liquid metal wall surrounding fusion plasma produces tritium fuel with a sustainable breeding ratio [2]

Simple Energy Extraction & Conversion

Liquid metal wall surrounding fusion absorbs neutrons and heat for simple conversion to electricity via steam turbine

Economical Fusion Power

Mechanical compression with liquid metal avoids the need for expensive magnets or targets, high-power lasers and exotic/unavailable materials

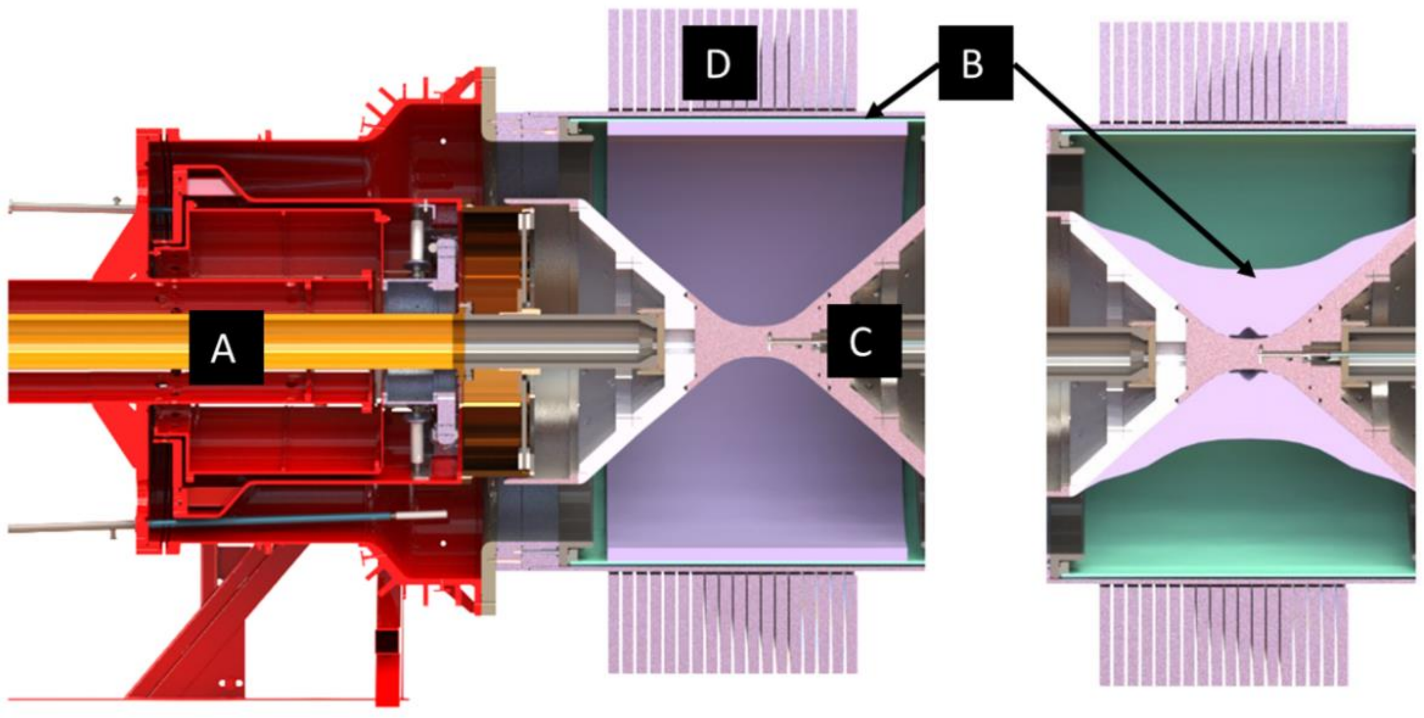
Lawson Machine 26

Lawson Machine 26 (LM26) is an MTF demonstration that is integrating General Fusion's operational Plasma Injector 3 (PI3) with a solid lithium compression system. PI3 has achieved energy confinement times (τ_E) of 10 ms [3], sufficient for compression. Results from LM26 will validate General Fusion's ability to compress magnetized plasmas in a repeatable manner and achieve fusion conditions.

Program Milestones

1. Form plasmas using PI3 with sufficient thermal confinement time for compression ✅ [3]
2. ~1 keV compressed plasma temperature in early 2025
3. ~10 keV compressed plasma temperatures in late 2025
4. Lawson Criterion, $nT\tau_E > 10^{21}$ keV-s/m³ in 2026

Schematic



A. PI3 Marshall gun
B. Lithium liner before and after compression
C. Central conducting cones
D. Drive coils

Key Facts

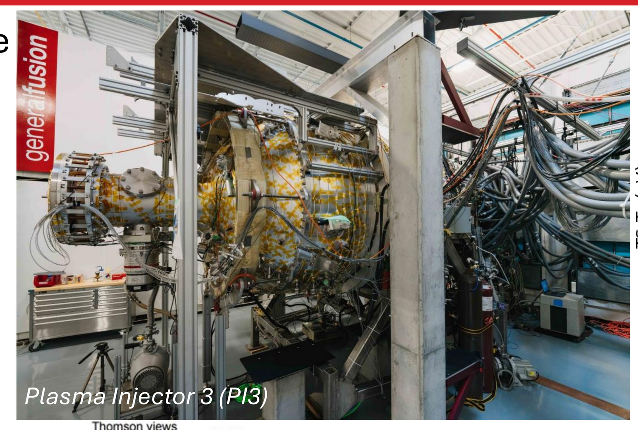
- ~50% scale of commercial fusion machine
- Solid lithium liner driven by electromagnetic force
- Designed to reach over 100 million degrees (10 keV) – fusion conditions
- Dozens of plasma-only pulses and one compression pulse per week
- Will run on deuterium fuel

Plasma Injector 3

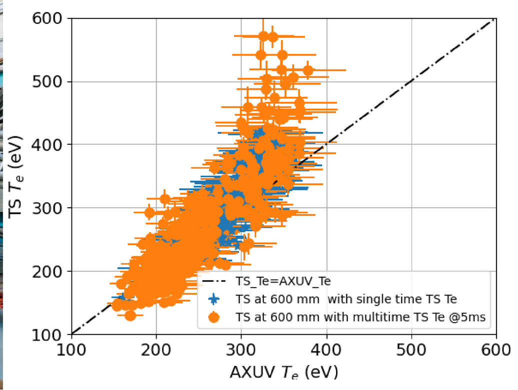
PI3 has been operational for seven years and is used to characterize and improve the performance of plasma targets for LM26

- **Sufficient thermal confinement time to meet 10 keV target**
- Spherical tokamak formed with coaxial helicity injection (CHI) forms plasma into 1 m radius flux conserver (1.7 MJ form bank)
- CHI provides separation of the plasma formation system from the collapse of the liner, satisfying a unique requirement of MTF
- Drive current through shaft to create toroidal flux to maintain q > 1 (max 5 MJ shaft bank)
- Evaporatively coating inside wall with lithium improves τ_E

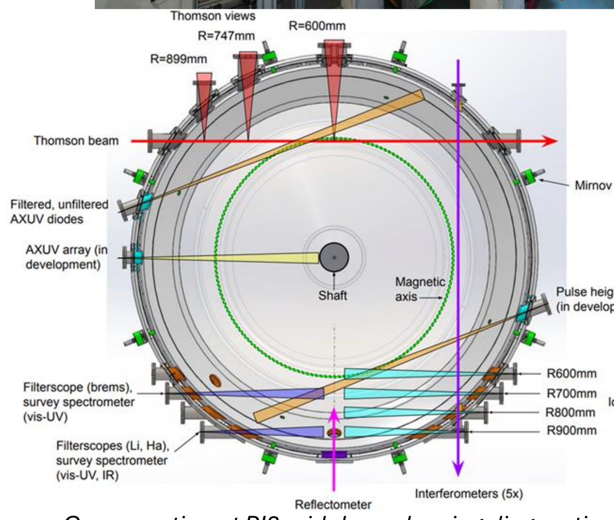
Parameter		Value range
Major radius	R	0.6 – 0.7 m
Minor radius	a	0.3 – 0.4 m
Poloidal flux	Ψ_{CT}	0.12 – 0.25 Wb
Plasma current	I_p	0.3 – 0.6 MA
Shaft current	I_s	1.0 – 1.2 MA
Plasma density	n_e	$1\times10^{19} - 4\times10^{19}$ m^{-3}
Temperature	$T_e \sim T_i$	100 – 300 eV
Thermal confinement time	τ_E	5 – 15 ms [3]



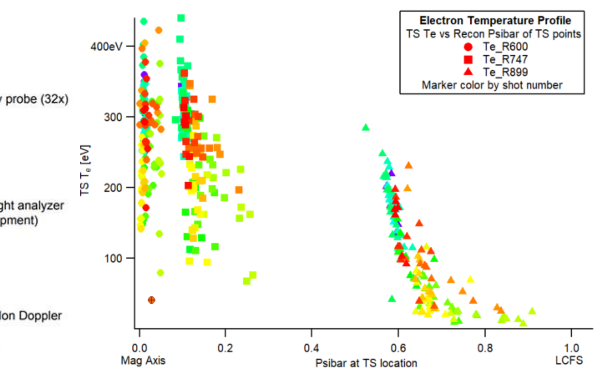
Plasma Injector 3 (PI3)



T_e from Thomson Scattering compared to T_e AXUV



Cross section at PI3 midplane showing diagnostics



T_e profile from 3-point TS vs normalized Ψ at TS location

Ring Compressor

The Ring Compressor was commissioned in spring 2023 and quickly achieved sufficiently symmetric compressions of solid rings. The project scope included:

- 10 lithium rings compressed; **desired symmetry achieved on 5th experiment**
- Electromagnetic compression testing of 50 cm diameter, 2.5 cm thick solid lithium rings in ~1 ms

Diagnostics

- Fast camera optics w/ triggered lighting, triggering, voltage, current

Ring Compressor

Frame from high-speed video showing symmetrical collapse

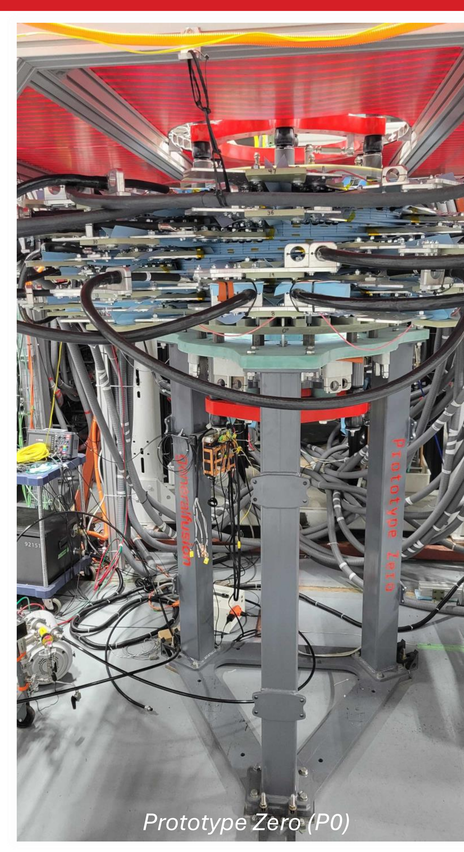
Prototype Zero

Prototype Zero (P0) is a 1:4 linear scale compression testbed for LM26. It uses electromagnetic force to compress a cylindrical solid lithium liner symmetrically inwards and validate the 3D compression technology for LM26. Ongoing simulation work has achieved close agreement with experimental results [4].

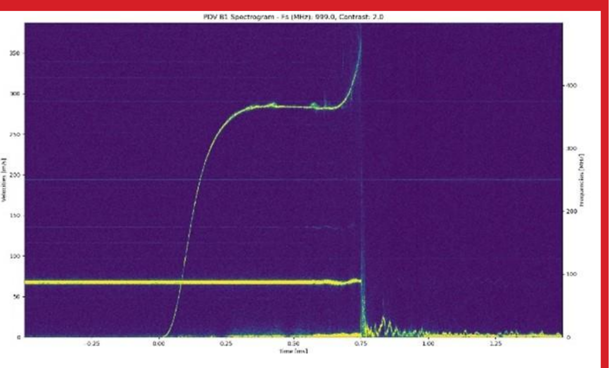
- **Successfully showed toroidal flux trapping, key aspect of MTF**
- 96 capacitors: 104 µF, 16 kV, up to 80 kA
- 1.25 MJ total energy
- First shot Oct-2023, two months after LM26 program announced
- 40 shots to date, cadence increased to one per week in 2024

Diagnostics

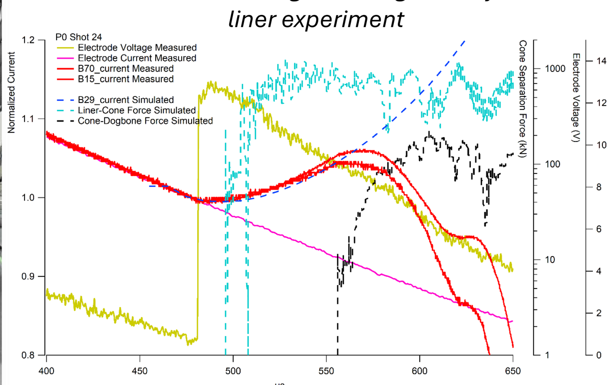
- LED illumination
- 9 fiber-optic camera views
- Magnetic probes (for measuring magnetic field)
- PDV (Photon Doppler Velocimetry, for measuring liner velocity)
- Piezo pins (for ejecta detection)
- Keyence sensors & accelerometers (measuring machine motion during a shot – for engineering design validation)



Prototype Zero (P0)



PDV trace measuring incoming velocity of P0 liner experiment



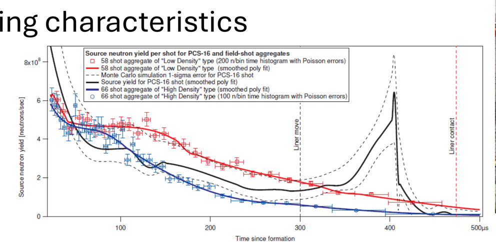
Magnetic probes showing flux trapping, closely matching simulation for 100 µs

Plasma Compression Science

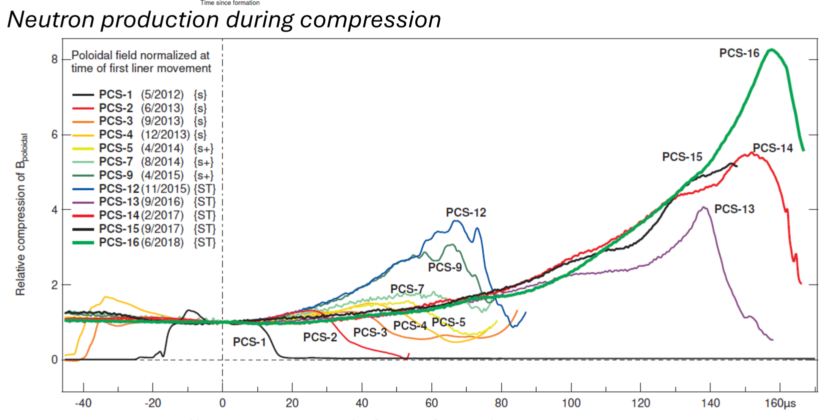
Plasma Compression Science (PCS) were a sequence of MTF devices built by General Fusion that compressed magnetically confined deuterium plasmas inside imploding aluminum liners. 17 such experiments were conducted, with the five most recent compressing a spherical tokamak plasma configuration. PCS-16 was the most successful experiment with the following characteristics

- **Neutron yield from D-D fusion increased significantly during compression**
- Plasma remained axisymmetric with $\delta B_{pol}/B_{pol} < 20\%$ to a high radial compression factor (compression ratio (CR) > 8)
- Significant poloidal flux conservation (77% up to CR = 1.7)
- Total compression time of 167 µs
- Poloidal plasma magnetic energy increased 19%, while toroidal increased 76%, thermal energy was in the range of 350 ± 25 J
- Compressive plasma behavior was monitored with multiple diagnostics [5]

Field location



Neutron production during compression



Successively increased magnetic compression over PCS experiment series

Cylindrical Water Compressor

Shaping the inner surface of a rotating, imploding liquid metal liner as it compresses a magnetized plasma target is an important aspect General Fusion's MTF concept. The Cylindrical Water Compressor is a sub-scale experiment that was constructed at General Fusion and operated with water as its working fluid. Here are some key takeaways from a recent publication: [6]

- **Very good agreement between numerical and experimental liner trajectories was obtained for a wide range of implosion parameters**.
- Experimental pressure and rotational speed were used as inputs to numerical simulations.
- Data analysis confirmed an initially cylindrical inner liner surface can be shaped, and the shaped surface remains symmetrical to radial compression ratios of at least **7:1**
- Experiments demonstrated suppression of Rayleigh-Taylor instability for shaped implosions by using liner rotation
- These results increase confidence in simplified numerical modelling as a predictive tool for designing MTF machines.

Cylindrical Water Compressor

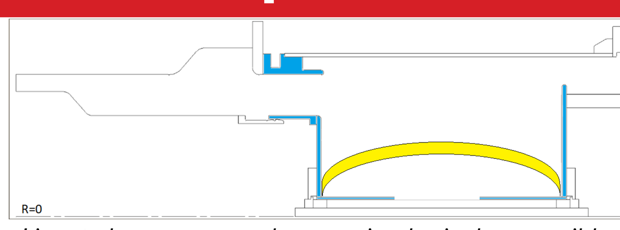
1 keV Compression

First full-scale compression planned for early 2025

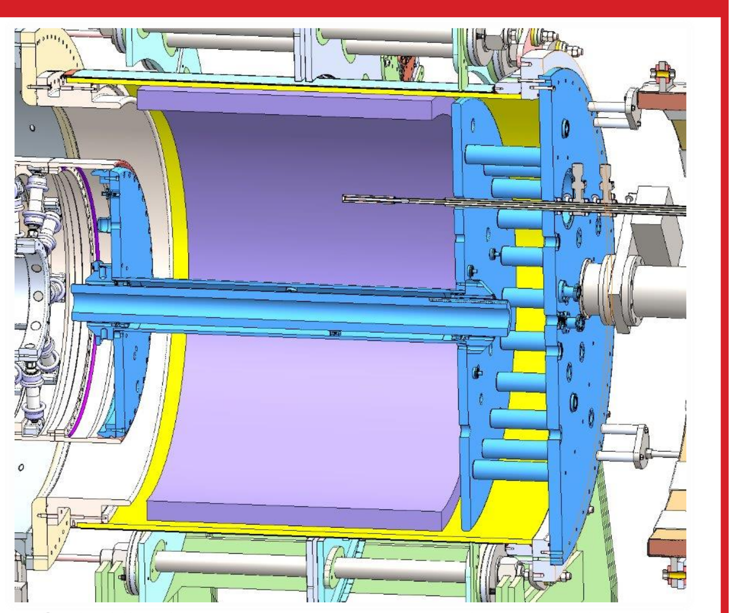
- 3:1 maximum compression ratio over 3 ms
- Show plasma compression stability and heating
- Targeting 1 keV ion temperature
- 18 MJ compression bank
- Fully upgradeable for deeper, higher ratio compression
- Full scale lithium liner will use learning and process development from P0
- Shaft current will be increased to maintain toroidal flux, based on learning from PCS

Diagnostics

- Plasma: magnetic probes, AXUV, Ion Doppler spectroscopy, passive spectroscopy, interferometer, neutron scintillators, activation foils
- Liner: Photon Doppler Velocimetry (PDV), structured light reconstruction, plasma imaging, narrow angle imaging + illumination



Liner to be compressed as quasi-spherical as possible



CAD of first full-scale plasma compression stage of LM26

References

[1] Laberge, Michel. "Magnetized target fusion with a spherical tokamak." *Journal of Fusion Energy* 38.1 (2019): 199-203.
[2] Eade, Tim, et al. "General Fusion TBR Analysis." *Report by UK Atomic Energy Authority* (2024) posted to General Fusion Research Library
[3] Tancetti, Andrea, et al. "Thermal energy confinement of Spherical Tokamak Plasmas in PI3" submitted to *Nuclear Fusion* in August 2024
[4] Sirmas, Nick et al. "Electromagnetic Lithium Ring Compression for Magnetized Target Fusion Application: Trajectories" submitted to *ASME PVP 2024 Pressure Vessels & Piping Conference*
[5] Howard, Stephen at el. "Measurement of spherical tokamak plasma compression in the PCS-16 magnetized target fusion experiment" submitted to *Nuclear Fusion* in May 2024
[6] Mangione, Nicholas S., et al. "Shape manipulation of a rotating liquid liner imploded by arrays of pneumatic pistons: Experimental and numerical study." Fusion Engineering and Design 198 (2024): 114087.