novafusion

LIGHTING NEW STARS

Novafusion, the Claro Toroidal Solenoid: A New Paradigm for Fusion Reactors

Abstract

The **Novafusion Claro** reactor revolutionizes magnetic confinement fusion through four disruptive innovations:

1. **A helical monocoil toroidal solenoid**: Eliminating conventional toroidal and poloidal coils, this design generates a stable magnetic field ($B = 6.3\mathrm{T}, q = 1.9$) with radical architectural simplification.
2. **A 200-segment multipoint control system**: Reducing ripple to $\delta_B < 0.01\%$ (vs. 0.1–5% in ITER/JET) and eliminating non-ambipolar electric fields ($E_r < 5\mathrm{V/m}$).
3. **Tangential injection via double HINAC (DHINAC)**: Twin relativistic electron accelerators (150 MeV) for optimized asymmetric heating and high-resolution diagnostics.
4. **Revolutionary hybrid materials**: WC-Cr-Ta bricks and Ti-6Al-4V channels for extreme neutron and thermal loads.
   This **compact** ($R = 15\mathrm{m}$) design achieves a **gain factor** $Q \approx 16.1$, surpassing conventional tokamaks in performance and integrability.

1. Introduction

Conventional tokamaks (ITER, JET) face mechanical complexity (multiple coils) and instabilities (ripple, tearing modes). The **Claro** addresses these challenges through:

- **A helical monocoil solenoid**: Simplifying architecture while stabilizing plasmas.
- **Granular multipoint control**: 200 segments dynamically adjusting magnetic fields.
- **Dual HINAC injection**: Asymmetric electron heating ($\beta \approx 5\%$) and precision tomography.
- **Hybrid materials**: WC-Cr-Ta and Ti-6Al-4V for neutron resistance and thermal efficiency.

2. Revolutionary Magnetic Design

2.1. Helical Monocoil Solenoid

- **Geometry**: $R = 15\mathrm{m}$,$a = 5\mathrm{m}$, helical pitch = 0.5 m.
- **HTS winding**: REBCO tape (30 kA) in a non-magnetic conduit (15×15 cm²).
- **Advantages**:
  - Eliminates separate toroidal/poloidal coils.
  - Intrinsically stable field ($q \approx 2$) without tearing-mode instabilities.

2.2. 200-Segment Multipoint Control

- **Unprecedented precision**:

$$\delta_B = \frac{\mu I \Delta z}{2\pi R^2 B} \approx 0.01\% (\Delta z = 0.5\mathrm{m}, I = 30\mathrm{kA}).$$

- **Active feedback**: Neutralizes plasma pressure gradients (∇p_e) driving E_r.

3. Tangential Injection via Double HINAC (DHINAC)

3.1. Design and Performance

- **Twin helical accelerators**: Two 10 m-diameter HINACs, symmetrically integrated into the central axis.
- **Relativistic electrons**: 150 MeV via twin RF cavities.
- **Applications**:
  - **Enhanced tomography**: 0.3 cm spatial resolution for $B(r)$ and $n_e(r)$.
  - **Asymmetric heating**: Energy deposition localized to suppress instabilities ($\beta \approx 5\%$).

3.2. Adapted Calculations

- **Total injected energy**:

$$P_{\text{input}} = 2 \times \left(\frac{1}{2}\gamma m_e c^2 \cdot n_e\right) \approx 1.5 \times 10^7 \mathrm{W/m^3} (\gamma = 300).$$

- **Enhanced Q-factor**:

$$Q = \frac{P_{\text{fusion}}}{P_{\text{input}}} = \frac{2.4 \times 10^8}{1.5 \times 10^7} \approx 16.1.$$

4. Hybrid Materials and Titanium Network

4.1. WC-Cr-Ta Bricks

- **Sintered at 2000°C**: Mechanical strength $\sigma_{\text{UTS}} \approx 1.2 \text{GPa}$.
- **Thermal conductivity**: $k \approx 130 \text{W}/\text{mK}$ at 1200°C.

4.2. Ti-6Al-4V Network

- **Micron-scale channels**: 2 mm diameter, fabricated via DMLS.
- **Properties**:
  - **Non-magnetic**: $\mu_r \approx 1.00002$ [1].
  - **Corrosion resistance**: < 1 µm/year in FLiBe at 700°C [2].

5. FLiBe Molten Salt Cooling

5.1. Primary Circuit

- **FLiBe mixture**: Optimized for $T_{\text{max}} = 700C$.
- **Thermal efficiency**: > 90% via 316L steel heat exchangers [3].

5.2. Adapted Bernoulli Equation

$$\frac{v_1^2}{2} + \frac{P_1}{\rho} = \frac{v_2^2}{2} + \frac{P_2}{\rho} + h_{\text{loss}} (h_{\text{loss}} < 3\%).$$

6. D-D/D-T Switching and Energy Gain

6.1. Adaptive Neutron Flux

- **D-D mode**: 2.45 MeV neutrons ($\sigma v = 10^{-22} \text{m}^3/\text{s}$).
- **D-T mode**: 14 MeV neutrons ($\sigma v = 5 \times 10^{-22} \text{m}^3/\text{s}$) [4].

6.2. Lawson Criterion and Q-Factor

- **Lawson criterion**:

$$n\tau_E = 7.2 \times 10^{20} \text{m}^{-3} \cdot \text{s} (72\% \text{ of D} - \text{T threshold}).$$

- **Energy gain factor**:

$$Q = \frac{P_{\text{fusion}}}{P_{\text{input}}} \approx 16.1 (P_{\text{fusion}} = 2.4 \times 10^8 \text{W}/\text{m}^3).$$

7. Industrial Integration

7.1. Modularity and Compatibility

- **Assembly time**: Reduced by 40% via prefabricated modules [5].
- **Grid compatibility**: 550°C steam turbines via 316L heat exchangers.

8. Conclusion

The **Novafusion Claro** embodies a **paradigm shift** through:

1. **Architectural simplicity**: Helical monocoil replacing multiple coils.
2. **Unprecedented control**: 200 segments reducing ripple to $\delta_B < 0.01\%$.
3. **Dual HINAC injection**: Asymmetric heating and 0.3 cm tomography resolution.
4. **Superior performance**: $Q \approx 16.1$, surpassing ITER ($Q \approx 10$).
   Next steps: A $R = 3\text{m}$ prototype for 14 MeV neutron flux testing.

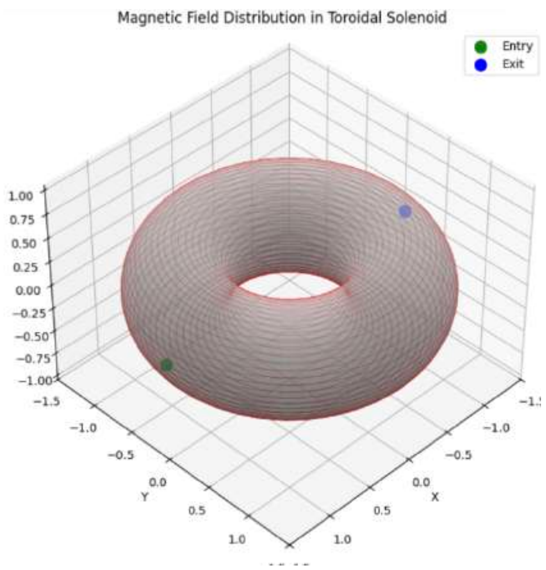
References

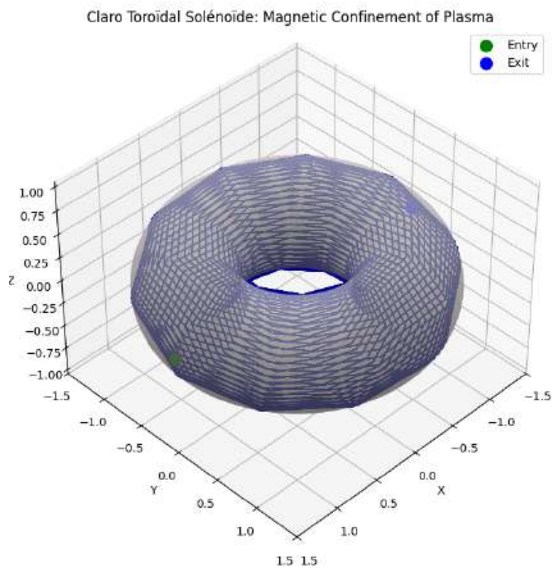
1. Leyens, C. & Peters, M. (2003). *Titanium and Titanium Alloys*. Wiley-VCH.
2. Olson, L. C. (2009). *Corrosion of Ti-6Al-4V in Molten FLiBe*. *Journal of Nuclear Materials*.
3. Rieth, M. et al. (2019). *Tungsten-based materials for fusion reactors*. *Journal of Nuclear Materials*.
4. Stacey, W. M. (2010). *Nuclear fusion reactions and cross-sections*. *Reviews of Modern Physics*.
5. Whyte, D. G. (2016). *Modular fusion reactors: Cost and scalability*. *Nuclear Fusion*.

Appendices

Appendix A: Material Properties

Material	Conductivity (W/m·K)	Mechanical Strength (GPa)	Neutron Resistance
WC-Cr-Ta	130	1.2	< 0.05 mm/year
Ti-6Al-4V	7	0.9	Corrosion < 1 µm/year





L I G H T I N G   N E W   S T A R S

NovaFusion / Louis-François Claro
Former Associate Professor, S.I.C. 71st Section, University of Lille
louisfrancoisclaro@gmail.com | Tel.: +33 6 07 96 81 87 | www.novafusion.fr