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Rationale for the Columbus Experiment*

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In principle, it is possible to scale up the geometrical parameters of Ignitor, which is the only experiment proposed and designed to reach ignition, but within a narrow range if the ability to maintain this goal is preserved with reasonable margins against the onset of macroscopic instabilities in plasmas with the high central pressures that are needed. Another important asset to be preserved is the strength of ohmic heating to the extent that the produced plasmas can attain ignition even in the case of failure of the auxiliary heating system, that is, by ohmic heating alone. We note that the only system demonstrated to be capable of heating high density plasmas is Ion Cyclotron Resonance Heating and that the reliability of this kind of system has been problematic. The Columbus experiment [1] is proposed as a parallel US project to the Ignitor program [2, 3] that is being carried out in Italy and is geometrically self similar to Ignitor the (linear) dimensions being increased by the factor 25/22.

The most important parameter to preserve is the value of the mean poloidal field defined as $\bar{\bar{B}}_p \equiv I_p/\left(5\sqrt{ab}\right)$, where I_p is the toroidal plasma current, in megampere, and a and b are the minor radii of the plasma cross section. We take $\bar{\bar{B}}_p \simeq 3.4\,\mathrm{T}$ as the target value that is close to that chosen for Ignitor. A list of the main design parameters is given in the following Table.

Parameter	Columbus	Ignitor
Major radius R_0	1.50 m	1.32 m
Minor radii $a \times b$	0.535 m × 0.98 m	0.47 m × 0.86 m
Aspect ratio A	2.8	2.8
Elongation κ	1.83	1.83
Triangularity δ	0.4	0.4
Vacuum Toroidal Field B_T at $R = R_0$	$\lesssim$ 12.6 T	$\lesssim$ 13T
Toroidal Current I_p	$\lesssim$ 12.2 MA	$\lesssim$ 11 MA
Poloidal Current I_θ	$\lesssim$ 10 MA	$\lesssim$ 9 MA
Paramagnetic Field Produced by I_θ	1.4 T	1.4 T
Mean Poloidal Field $\bar{\bar{B}}_p \equiv I_p/\left(5\sqrt{ab}\right)$	3.4 T	3.4 T
Confinement Strength $S_c \equiv \bar{\bar{B}}_p I_p$	$\lesssim$ 41.5 MN/m	$\lesssim$ 38 MN/m
Toroidal Current Density $<J_\Phi> \equiv I_p/(\pi ab)$	$\lesssim$ 7.4 MA/m^2	$\lesssim$ 9.3 MA/m^2
Maximum Poloidal Field B_{pM} $(R< R_0)$	$\lesssim$ 6.5 T	$\lesssim$ 6.5 T
Edge Magnetic Safety Factor q_Ψ	3.6 @ $I_p \simeq$ 12.2 MA	3.6 @ $I_p \simeq$ 11 MA
Magnetic Flux Swing	$\lesssim$ 37.5 Vs	$\lesssim$ 33 Vs
Plasma Volume V_0	14.5 m^3	10 m^3
Plasma Surface S_0	44 m^2	34 m^2

The plasma current $I_p \simeq 12.2\,\mathrm{MA}$ is close to that which the ITER-Feat concept would have for the same value of the safety factor $q_{95}(\psi) \simeq 3.6$ in spite of the large difference in the total magnetic energy associated with the two machines. The current densities in the toroidal magnet and the plasma for Columbus are about 85% lower than those for Ignitor. Therefore the machine characteristic times related to the ohmic heating of the magnet are longer by a factor of about 1.4, relative to Ignitor. As in the case of Ingitor and ITER-Feat, designed not to reach ignition but $Q = 10$ with a lower safety factor $q_{95}(\psi) \simeq 3$, the plasma current redistribution time and the duration of the plasma burning state are comparable.

*Sponsored in part by the U.S. Department of Energy

[1] B. Coppi and M. Salvetti, Massachusetts Institute of Technology, R.L.E., Report PTP-02/06 (December 2002)

[2] B. Coppi et al., Massachusetts Institute of Technology, R.L.E., Report PTP-02/05 (December 2002)

[3] B. Coppi, A. Airoldi, F. Bombarda, et al., *Nucl. Fusion* **41**, 1253 (2001)