Massachusetts Institute of Technology
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Ignitor 2008

50th Annual Meeting of the Division of Plasma Physics

of the American Physical Society

Dallas, TX , November 17-21, 2008

MIT (LNS) Report HEP 08/09

Cambridge, MA, November 2008

Physics of High Energy Plasmas

Thermonuclear Plasmas Plasma Astrophysics

Abstract Submitted
for the DPP08 Meeting of
The American Physical Society

Sorting Category: 5.6.1 (Experimental)

Ignitor and the High Density Approach to Fusion Reactors* F. BOMBARDA, ENEA, Italy, B. COPPI, M.I.T. — The optimal path to ignition that can be followed by experiments based on existing technologies and knowledge of plasma physics relies on the high plasma density regimes that are at the basis of the Ignitor design ($R_0 \cong 1.32$ m, $a \times b \cong 0.47 \times 0.83\text{m}^2$, $B_T \cong 13$ T, $I_p \cong 11$ MA). Their value has been rediscovered recently following experiments by the helical LHD facility that have systematically produced plasmas with $n_0 \leq 10^{21}\text{m}^{-3}$. Consequently, conceptual power producing reactors that would operate with plasma parameters close to those of Ignitor when reaching ignition have been envisioned. The main purpose of the Ignitor experiment is, in fact, that of establishing the reactor physics in regimes close to ignition, where the thermonuclear instability can set in with all its associated non linear effects. "Extended limiter" and double X-point configurations have been analyzed and relevant transport simulations show that similar burning plasma conditions can be attained with both. The machine core design has been essentially completed, but the recent development of a new intermediate temperature superconducting material (MgB_2) has led to its adoption for the largest poloidal field coils, producing a vertical field component of 4 T. The properties of this material make it possible to envision its future use for coils producing higher magnetic fields and open new options in the design of novel experimental devices.

*Sponsored in part by ENEA of Italy and by the U.S. D.O.E.

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Date submitted: July 17, 2008

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Abstract Submitted
for the DPP08 Meeting of
The American Physical Society

Sorting Category: 5.1.0 (Computational)

Analysis of Ignitor Discharges with Double X-point Magnetic Configurations[1] A. AIROLDI, G. CENACCHI, Italy, B. COPPI, M.I.T. — The Ignitor experiment[2] was proposed and designed to achieve ignited and sub-ignited conditions in well confined deuterium-tritium plasmas. Thanks to its unique features (high magnetic field up to 13 T, high plasma current up to 11 MA, and high plasma density up to $5 \times 10^{20}\mathrm{m}^{-3}$), Ignitor is the only device capable of exploring plasma regimes that are relevant to a net power producing D-T reactor and are not accessible to other existing or planned machines. Double X-point scenarios with magnetic field up to 13 T and plasma current up to 9 MA are analyzed. In these configurations, the access to a high confinement state is assumed when the available plasma heating power, supported by the injected auxiliary power, is larger than the L-H threshold value, according to recent suggested scalings[3]. The H-regime is modeled by a global reduction of the thermal transport coefficients used for the L-regime. Situations in the presence and in the absence of sawtooth oscillations have been investigated. Quasi-stationary conditions can be attained when a process producing re-distribution of pressure and current profiles is active.

[1]Sponsored in part by ENEA of Italy and by the U.S. D.O.E.
[2]B.Coppi, A.Airoldi, F.Bombarda, et al.,*Nucl. Fusion* **41**, 1253 (2001)
[3]D.C. McDonald, A.J. Meakins, et al., *PPCF* **48**, A439 (2006)

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Date submitted: July 17, 2008

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Sorting Category: 5.1.0 (Theoretical)

Effects of Radial Profiles in the H-Regime for Ignitor[1]

G. CENACCHI, A. AIROLDI, Italy, P. DETRAGIACHE, ENEA, Italy, B. COPPI, MIT — The radial profiles of the main plasma parameters in the central region of the plasma column and their connection to those at the edge have an important influence on the levels of fusion power that Ignitor can achieve by accessing the H-regime. It is well established by now that the fusion power can be strongly degraded ($\propto B_T^{3.5}$) by decreasing the magnetic field[2] and consequently the plasma current and the density limit. Ignitor does not have the last constraint but maintaining a reasonable magnetic safety factor is important. Therefore the maximum design field (13 T on axis) is considered. Then an analysis of the operating parameter space (in the H-regime) using a zero-dimensional model shows that a considerable ample space exists when $Q = 10$ is attained for a plasma pressure profile moderately peaked ($p_0/\langle p\rangle = 2.9$) and various scaling expressions for τ_E and P_{thr}. A considerably improved performance (with Q up to 100) can be achieved by a modest increase in the assumed density profile peaking, leading to an attractive regime of operation with moderate power flux to the wall (below about 20 MW) when a newly-proposed scaling expression[3] for P_{thr} is used.

[1]Sponsored in part by ENEA of Italy and by the U.S. D.O.E.
[2]R.V. Budny, et al., Report PPPL-4300 (March 2008)
[3]D.C. McDonald, et al., *Plasma Phys. Control. Fusion* **48**, A349 (2006)

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Sorting Category: 6.4.0 (Experimental)

Diagnostics Development for the Ignition Experiment Ignitor[1] G. PIZZICAROLI, F. BOMBARDA, ENEA, Italy, A. LICCIULLI, M. FERSINI, Universita' di Lecce, Italy, D. DISO, SALENTEC, Lecce, Italy, H. KROEGLER, Italy — The Ignitor experiment is designed to reach ignition conditions. The short, but intense neutron flux will pose challenging conditions for diagnostics, such as magnetic sensors or bolometers, in direct proximity, or in direct view, of the plasma. An R&D program is in progress to manufacture mineral insulated magnetic coils with a reduced sensitivity to radiation effects. A double layer, MgO insulated Ni coil has been produced and tested. The wire is wound on an alumina core and the coil is housed in an alumina box for high refractoriness and minimum vacuum degassing. A lanthanide glass ceramic has been used as sealant for the box. At the same time, alternative methods to provide critical plasma position information during the high performance discharges in Ignitor are being explored. For example, the radiation emitted at the plasma edge by Mo^{+14} can be monitored by means of a soft X-ray spectrometer equipped with a GEM detector, which allows high counting rates (> 1 MHz) and provides good energy resolution and flexibility of design. A 10×10 cm^2 multichannel prototype with its associated fast read-out system is being assembled. A layout of the complete spectrometer compatible with the Ignitor port design has been carried out, and the bolometer system design has been updated, taking into account the latest techological developments in this area.
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Sorting Category: 5.4.0 (Experimental)

Performance of the Ignitor Pellet Injector[1] A. FRATTOLILLO, S. MIGLIORI, S. PODDA, F. BOMBARDA, ENEA, Italy, L.R. BAYLOR, J.B.O. CAUGHMAN, S.K. COMBS, C. FOUST, D. FEHLING, J.M. MCJILL, S. MEITNER, ORNL, G. ROVETA, CRIOTEC Impianti, Italy — ENEA and ORNL have built a four barrel, two-stage pneumatic injector for the Ignitor experiment featuring two innovative concepts: (i) an optimal shaping of the propellant pressure pulse to improve pellet acceleration, and (ii) the use of fast closing ($<$ 10 ms) valves to drastically reduce the expansion volumes of the propellant gas removal system. The injector is designed to deliver pellets of different sizes with velocities up to 4 km/s, capable of penetrating near the center of the plasma column when injected from the low field side in Ignitor burning plasmas ($n_0 \cong 10^{21}\text{m}^{-3}$, $T_0 \cong 11$ keV). The ENEA sub-system, which includes the two-stage guns and pulse-shaping valves, the gas removal system, with associated controls and diagnostics, and the ORNL sub-system, consisting of the cryostat and pellet diagnostics, with related control and data acquisition system, have been assembled in Oak Ridge. Pellet speeds of 2 km/s have been achieved, despite the unfavorable configuration adopted in order to carry out some preliminary tests immediately after assemblying the system, a very promising result. A second experimental campaign is planned for the 2008 Fall, when all four diagnostic channels should be complete.

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Sorting Category: 6.1.3 (Simulation)

Vertical Control for Burning Plasmas in Ignitor[1] F. VILLONE, G. RUBINACCI, CREATE, Italy, F. BOMBARDA, G. RAMOGIDA, ENEA, Italy — The vertical position and shape controller for Ignitor has been designed on the basis of the CREATE_L linearized plasma response model[2], which assumes an axisymmetric system and describes the electromagnetic interaction of the plasma with the surrounding structures by a small number of global parameters (i.e., β_{pol}, l_i, I_p). In particular, the vertical stabilization system has been designed assuming that the vertical plasma centroid position can be estimated by a suitable linear combination of the available magnetic measurements. A possible partial failure of these magnetic diagnostics has already been taken into account, showing a good resilience to such events. However, in case of severe failures, it will be necessary to resort to a completely different (i.e. non-magnetic) measurement of the vertical position[3] . As an example, we apply this method to the simulated signal of a double, soft X-ray spectrometer looking at the top and bottom of the plasma edge. The spatial and spectral features of these segnals seem, in many cases, sufficient to discriminate beween actual movements of the plasma column and changes in the plasma paramters.

[1]Sponsored in part by ENEA of Italy and by the U.S. D.O.E.
[2]R. Albanese, F. Villone, *Nucl. Fusion* **38**, 723 (1998)
[3]F. Bombarda, et al., *35th EPS Plasma Phys. Conf.* P4.073 (2008)

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Sorting Category: 6.5.0 (Experimental)

Adoption of MgB_2 Superconducting Magnets for the Ignitor Machine and Relevant R&D[1] G. GRASSO, Columbus (Genova, Italy), B. COPPI, MIT, G. GIUNCHI, Edison (Milano, Italy) — The progress made in the fabrication of MgB_2 long cables, and related superconducting magnets of relatively large dimensions has led to the decision of adopting this material for the vertical magnetic field coils of the Ignitor machine. These will be the largest magnets (about 5 m in diameter) of the machine and will be cryocooled at the operating temperature of 15 K: a temperature compatible with the He-gas cryogenic cooling system of Ignitor of the actual machine design as well as with the projected superconducting current density of the MgB_2 material, at the magnetic field values ($\simeq 4 - 5$ T) in which these coils are designed to operate. The MgB_2 coils solution will avoid the adoption of a separate liquid-He cryogenic system that otherwise should be used for conventional superconducting NbTi wires. MgB_2 superconductors hold the promise of becoming suitable for high field magnets by appropriate doping of the material and of replacing gradually the normal conducting coils adopted, by necessity, in high field experiments. Therefore, an appropriate R&D program on the develpment of improved MgB_2 material and related superconducting cabling options has been undertaken, involving different institutions .

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Sorting Category: 5.3.0 (Theoretical)

ICRH Physics in the Ignitor Experiment[1] A. CARDINALI, ENEA, Italy, R.V. BUDNY, PPPL, B. COPPI, M.I.T. — The ICRH system adopted for Ignitor can operate with a large frequency band (80-120 MHz) that is consistent with toroidal magnetic fields in the interval 9-13 T. The broad range of delivered power (4-12 MW) is suitable to investigate different aspects of burning plasma dynamics. The ICRH physics relevant to the plasmas produced by Ignitor is reviewed. The calculated Power Deposition Profiles (PDP) when the ICRH is used to control the plasma relevant parameters in the igniting scenario has been used as an input for the transport code PTRANSP. In particular, PDP's calculated by means of the toroidal full wave code "TORIC" show that a small fraction of ^{3}He (1-2%) improve the wave absorption on ions at the plasma center, while a considerable fraction of the coupled power is damped on the electrons, in a broad range of plasma radii, considering the $n_{\|}$-spectrum radiated by the antenna. The evolution of the plasma parameter profiles simulated by PTRANSP using two different transport models are presented pointing out the role of the density profiles on fusion reaction rates. In particular, given the flexibility of the ICRH system, it is possible to control the plasma temperature, and consequently the thermonuclear instability that occurs at ignition, with modest amounts of ICRH power (≤ 8 MW).

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Sorting Category: 6.1.1 (Experimental)

The ICRH System for The Ignitor Experiment* M. SASSI, A. COLETTI, ENEA, Italy, R. MAGGIORA, Politecnico di Torino, Italy, B. COPPI, MIT — The ICRH system (80-120 MHz) is an important component of the Ignitor experiment as it provides the flexibility to reach ignition or nearly ignited regimes following different paths in parameter space and to shorten the time needed for this. The system is designed with a modular configuration and launches the power into the plasma through RF strap-antennas based on 4 straps per port. Each module consists of 4 high power generators whose power is split over two ports (8 straps). A 30 Ω vacuum transmission line transfers 0.4 MW of power per strap for a total power of 1.6 MW per port in order to keep the maximum electric field below 5 kV/cm in the vacuum region of the straps and trasmission line. The RF configuration of the modules allows a full phase controls (toroidal and poloidal) of the straps though a PLL phase control. Two modules, involving 4 ports, produce 6 MW at 115 MHz for the envisioned RF "accelerated ignition" scenario. A detailed design of the ICRH antenna has been carried out, including the Faraday shield, the current straps, the vacuum transmission lines and the vacuum feed-through. Its integration of the antenna with the plasma chamber is under way. The mechanical assembly of the relevant components is fully detailed and ready for a prototype manufacturing.
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Sorting Category: 6.5.0 (Experimental)

Global Machine Design and Double X-point Equilibrium Configurations for Ignitor* A. BIANCHI, B. PARODI, ANSALDO Ricerche, Italy, B. COPPI, M.I.T. — The detailed design of the Ignitor machine has been carried out by considering extended limiter plasma configurations that are up-down symmetric and whose outer magnetic surfaces follow closely the cavity of the toroidal magnet over most of the vertical cross section. This provision minimizes the out-of-plane forces produced by the plasma current and acting on the toroidal magnet. When, instead, the adopted plasma equilibrium configuration is of the double X-point type the out-of-plane forces increase, and a complete structural analysis to take this increase into account becomes appropriate. The reference maximum plasma current I_p, in order to maintain an acceptable magnetic safety factor, is reduced from 11 MA in the extended limiter to 9 MA in the double X-point configuration while the magnetic field on axis ($R_0 \cong 1.32$ m) is maintained at $B_T \cong 13$ T. The reduced scenario involving $I_p \cong 6$ MA and $B_T \cong 9$ T does not present a problem. Both 3D and 2D drawings of each individual machine component are produced using the Dassault Systems CATIA-V software. After their integration into a single 3D CATIA model of the Core (Load Assembly), the electro-fluidic and fluidic lines which supply electrical currents and helium cooling gas to the coils are included and mechanically connected to the main machine components.

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Sorting Category: 6.5.0 (Simulation)

Installation of the Ignitor Machine at the Caorso Site[1] S. MIGLIORI, F. BOMBARDA, S. PIERATTINI, ENEA, Italy, G. FAELLI, Ignitor-Piacenza, Italy, M. ZUCCHETTI, Politecnico di Torino, Italy, B. COPPI, M.I.T. — The actual cost of building a new experiment can be considerably contained if infrastructures are already available on its envisioned site. The facilities of the Caorso site (near Piacenza, Italy) that, at present, houses a spent nuclear power station, have been analyzed in view of their utilization for the operation of the Ignitor machine. The main feature of the site is its robust connection to the electrical national power grid that can take the disturbance caused by Ignitor discharges with the highest magnetic fields and plasma currents, avoiding the need for rotating flywheels generators. Other assets include a vast building that can be modified to house the machine core and the associated diagnostic systems. A layout of the Ignitor plant, including the tritium laboratory and other service areas, the distribution of the components of the electrical power supply system and of the He gas cooling sytem are presented. Relevant safety issues have been analyzed, based on the in depth activation analysis of the machine components carried out by means of the FISPAC code. Waste management and environment impact issues, including risk to the population assessments, have also been addressed.

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