OVERVIEW OF IGNITOR

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MASSACHUSETTS INSTITUTE OF TECHNOLOGY

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Table 1: Ignitor Reference Design Parameters

major radius	R_0	$1.32\,\mathrm{m}$
minor radius	$a \times b$	$0.47 \times 0.86\,\mathrm{m}$
aspect ratio	A	2.8
elongation	κ	1.83
triangularity	δ	0.4
toroidal field	B_T	$\lesssim 13\mathrm{T}$
toroidal current	I_p	$\lesssim 11-12$ MA
maximum poloidal field	$B_{p,max}$	$\lesssim$ 6.5 T
mean poloidal field	$\overline{\overline{B}}_p \equiv I_p / 5\sqrt{ab}$	$\lesssim 3.44-3.75$ T
poloidal current	I_θ	$\lesssim 9\,\mathrm{MA}$
edge safety factor ($I_p \simeq 11\,\mathrm{MA}$)	q_ψ	3.6
confinement strength	$S_c \equiv I_p \overline{\overline{B}}_p$	38 – 45 MA·T
plasma volume	V_0	$\simeq 10\ \mathrm{m}^3$
plasma surface	S_0	$\simeq 34\ \mathrm{m}^2$
ICRF heating ($\simeq 140$ MHz)	P_{RF}	18 – 24 MW

Table 2 Example of Plasma Parameters at Ignition

Plasma Current I_p	11 MA
Toroidal Field B_T	13 T
Central Electron Temperature T_{e0}	11.5 keV
Central Ion Temperature T_{i0}	10.5 keV
Central Electron Density n_{e0}	9.5×10^{20} m^{-3}
Central Plasma Pressure p_0	3.3 MPa
Alpha Density Parameter n_α*	1.2×10^{18} m^{-3}
Average Alpha Density $\langle n_\alpha \rangle$	1.1×10^{17} m^{-3}
Plasma Stored Energy W	11.9 MJ
Ohmic Power P_{OH}	11.2 MW
ICRF Power P_{ICRH}	0
Alpha Power $P_{\alpha H}$	19.2 MW
Bremsstrahlung Power P_{brems}	3.9 MW
Poloidal Beta β_p	0.2
Toroidal Beta β_T	1.2 %
Central $q(\psi)$ q_0	~ 1.1
Edge q_ψ	3.5
Bootstrap Current I_{bs}	0.86 MA
Energy Confinement Time τ_E	0.62 sec
Alpha Slowing Down Time $\tau_{\alpha,sd}$	0.05 sec
Average Effective Charge $\langle Z_{eff} \rangle$	1.2

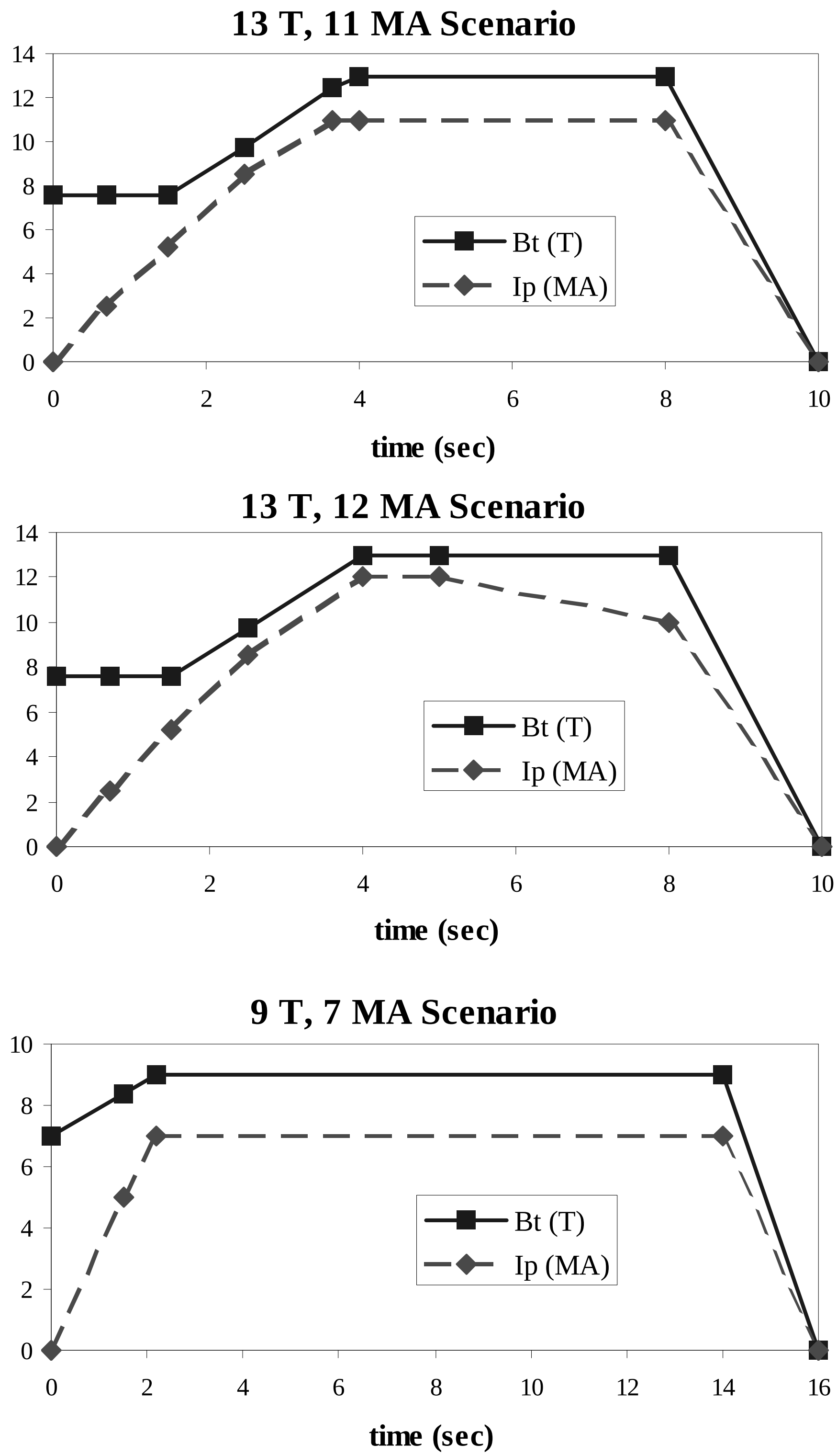
$\langle\ \rangle$ = volume average

$$\beta_p = 2\mu_0 \langle p \rangle \Big/ \overline{B}_P^2(a)$$

$$\tau_E = W/(P_{OH} + P_\alpha + P_{ICRH} - dW/dt)$$

$$n_\alpha^* = n_D n_T \langle \sigma \mathrm{v} \rangle \tau_{\alpha,sd}$$

$$\tau_{\alpha,sd} = 0.012 T_{e0}^{3/2}(\mathrm{keV}) / n_{e0}(10^{20})$$

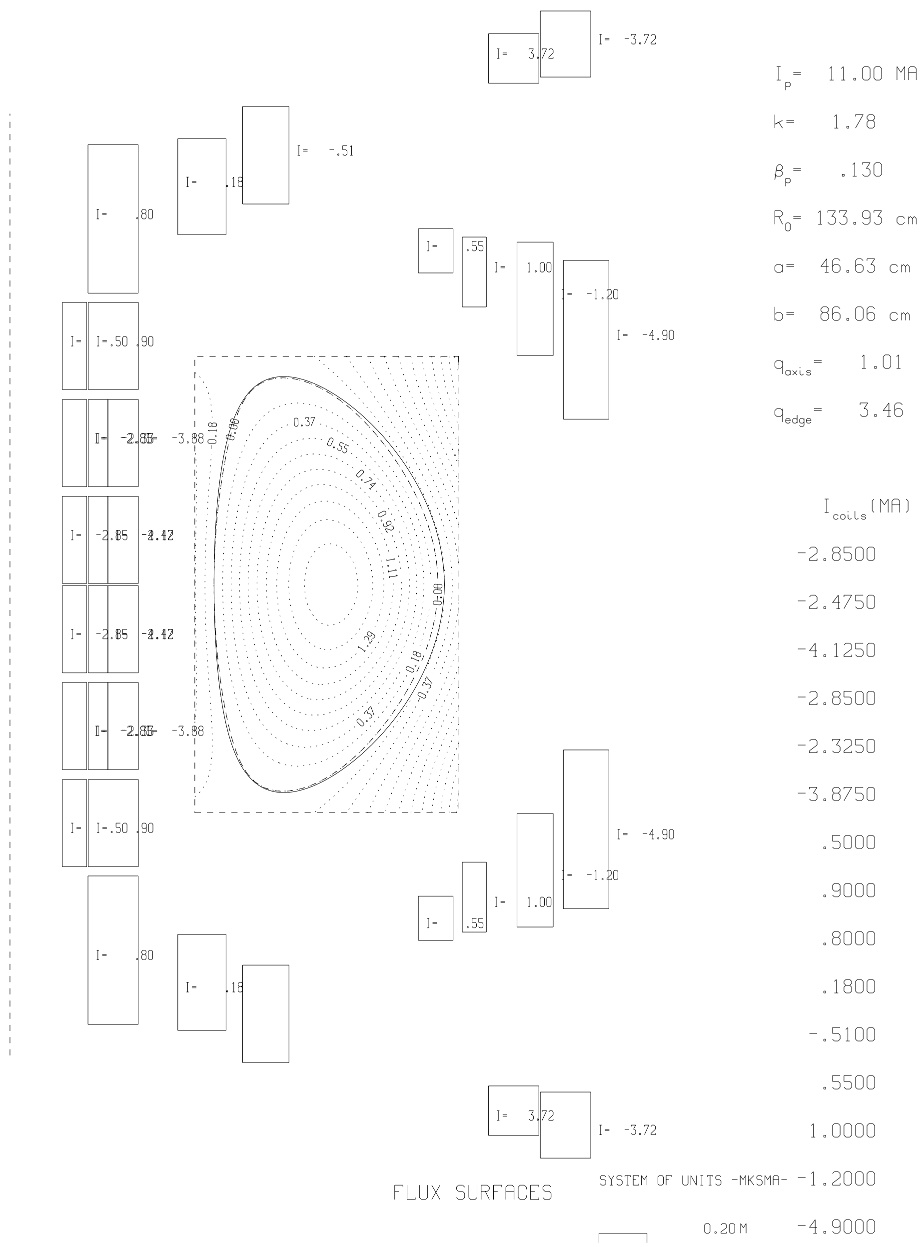


a)

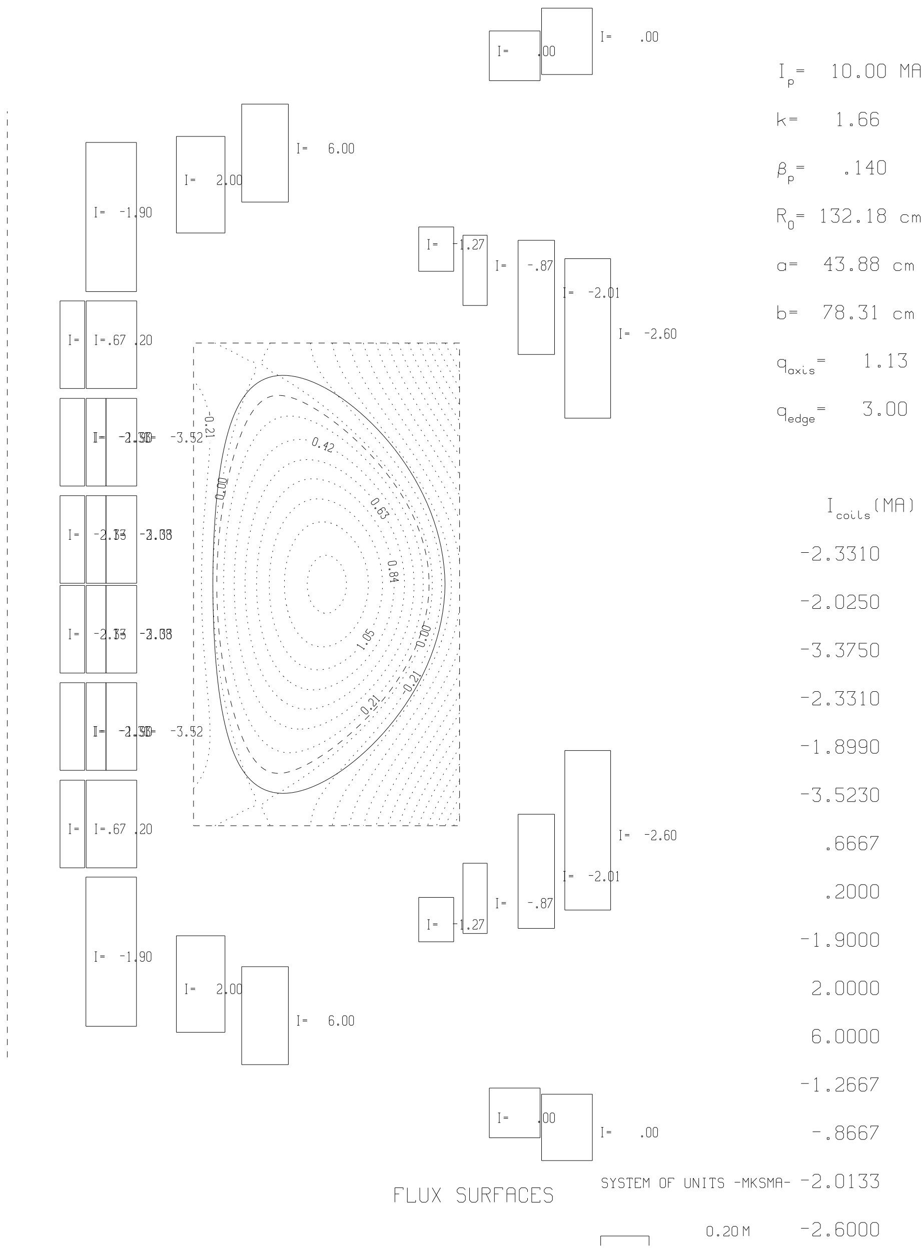
b)

c)

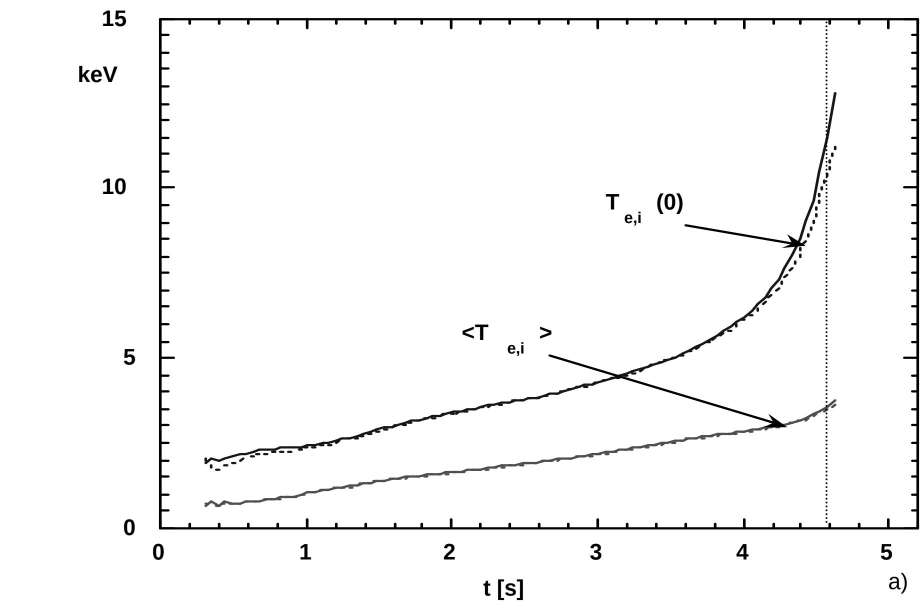
Examples of operating scenarios.



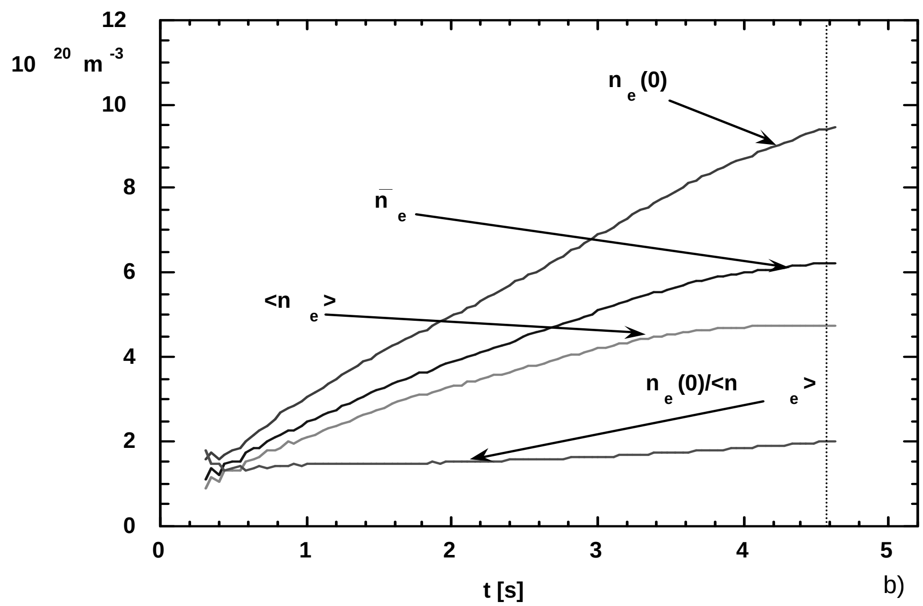
Equilibrium configuration for 11 MA and 13 T, as evaluated by the EQUISL code, with $q_0 \simeq 1$



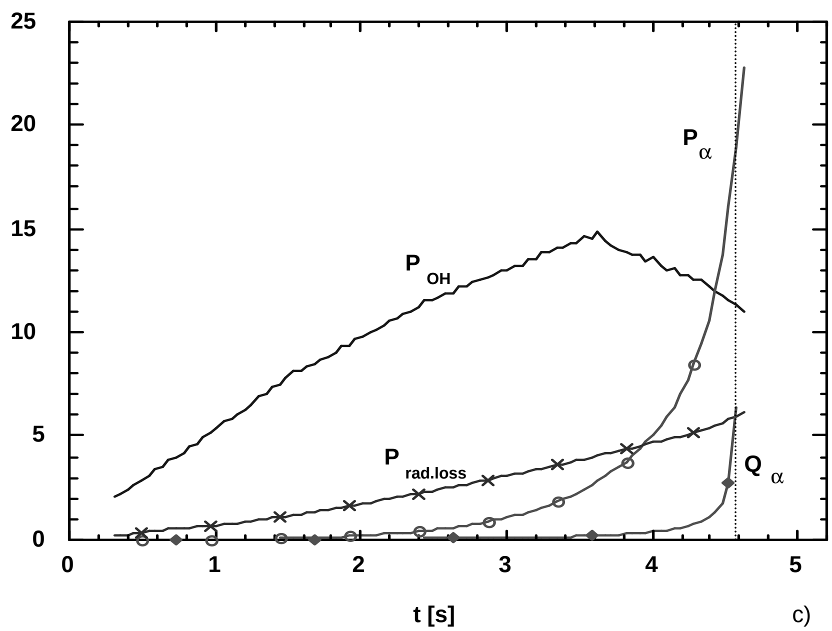
Example of an equilibrium configuration for 10 MA and 13 T, as evaluated by the EQUISL code, with a double X-point laying just outside the first wall



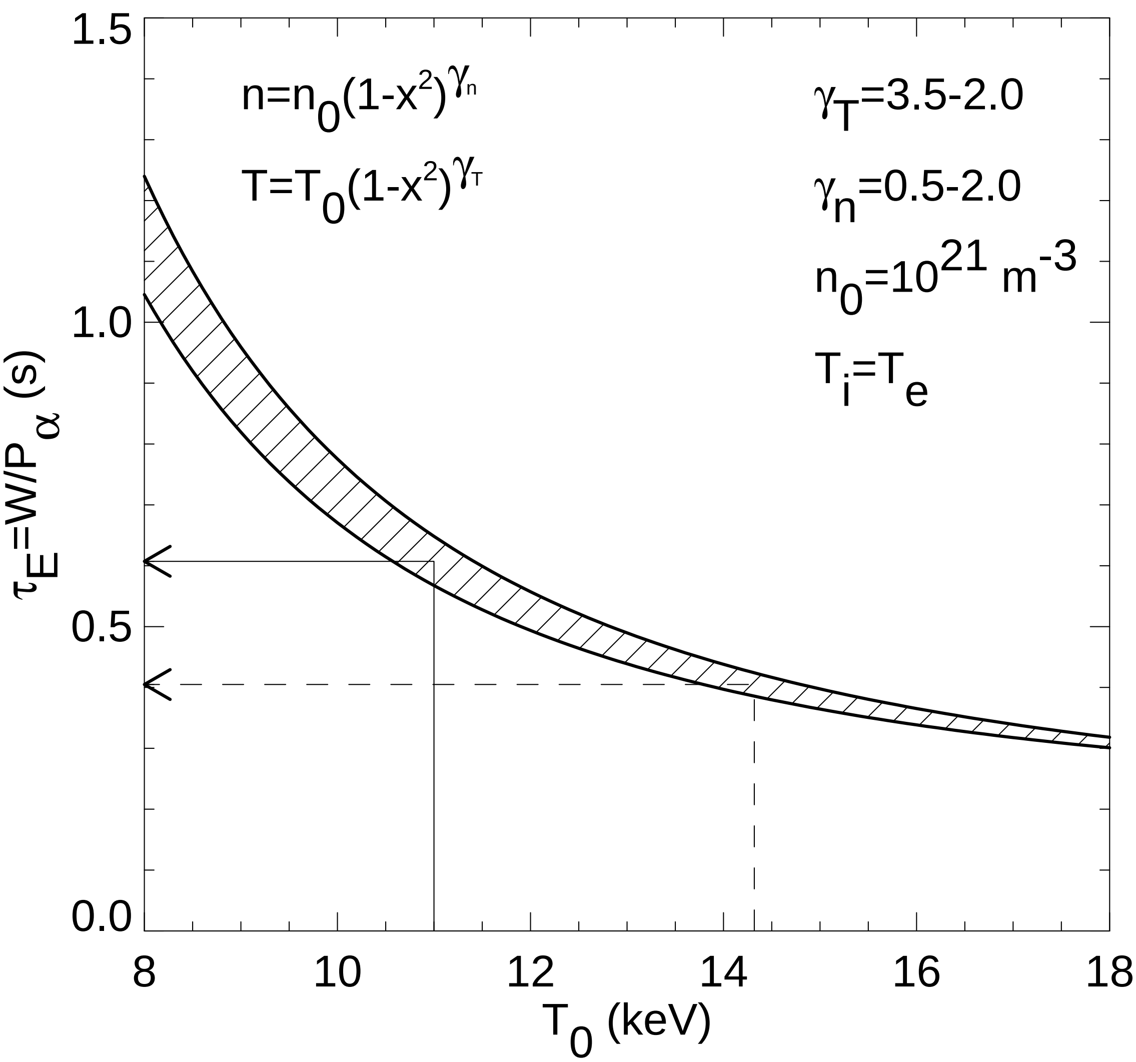
15
keV
10
5
0
T e,i (0)
<T e,i >
0 1 2 3 4 5
t [s]
a)



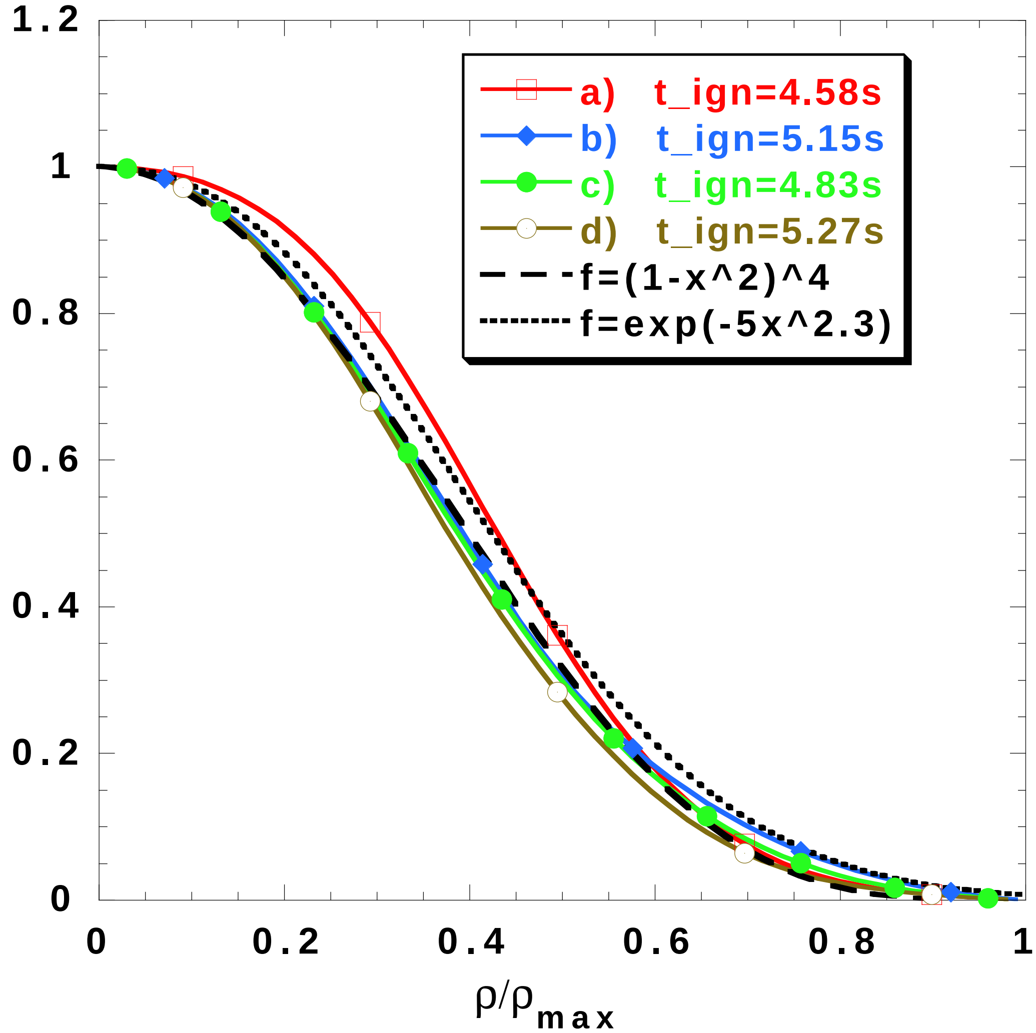
12
10 20 m -3
10
8
6
4
2
0
n e (0)
n̄ e
<n e >
n e (0)/<n e >
0 1 2 3 4 5
t [s]
b)



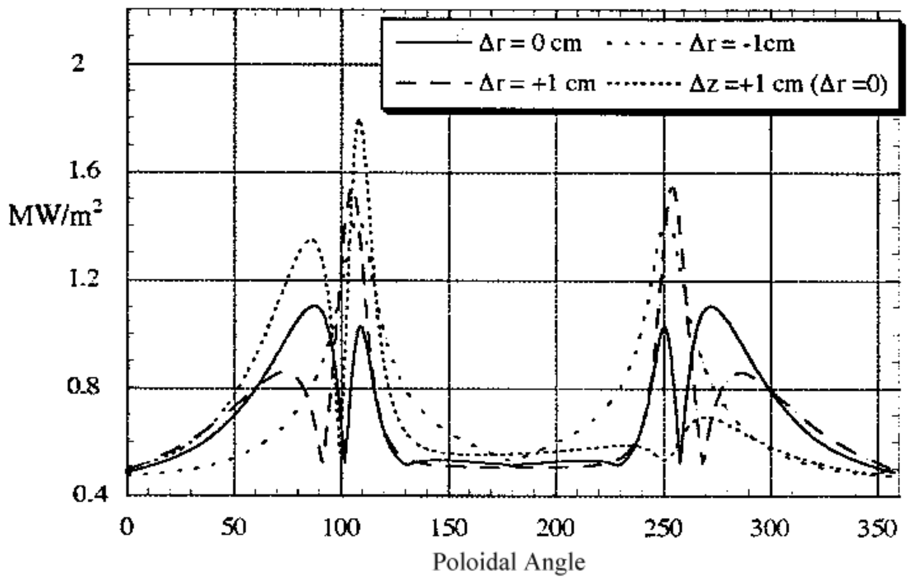
Time evolution of a discharge with 11 MA and 13 T simulated by the JETTO code, showing a) temperature, b) density, c) powers in MW and the parameter Q_α. Ignition is marked by the vertical dotted line.



Confinement time at ignition as a function of the peak temperature, for a range of density and temperature profile factors. The plasma stored thermal energy is $W = 3\int dV n_e T$ *, the fusion power is* $P_\alpha = \varepsilon_\alpha \int dV n_D n_T \langle \sigma v \rangle_{fus}$ *,* $T_e = T_i$ *, and* $n_D = n_T = n_e/2$*.*



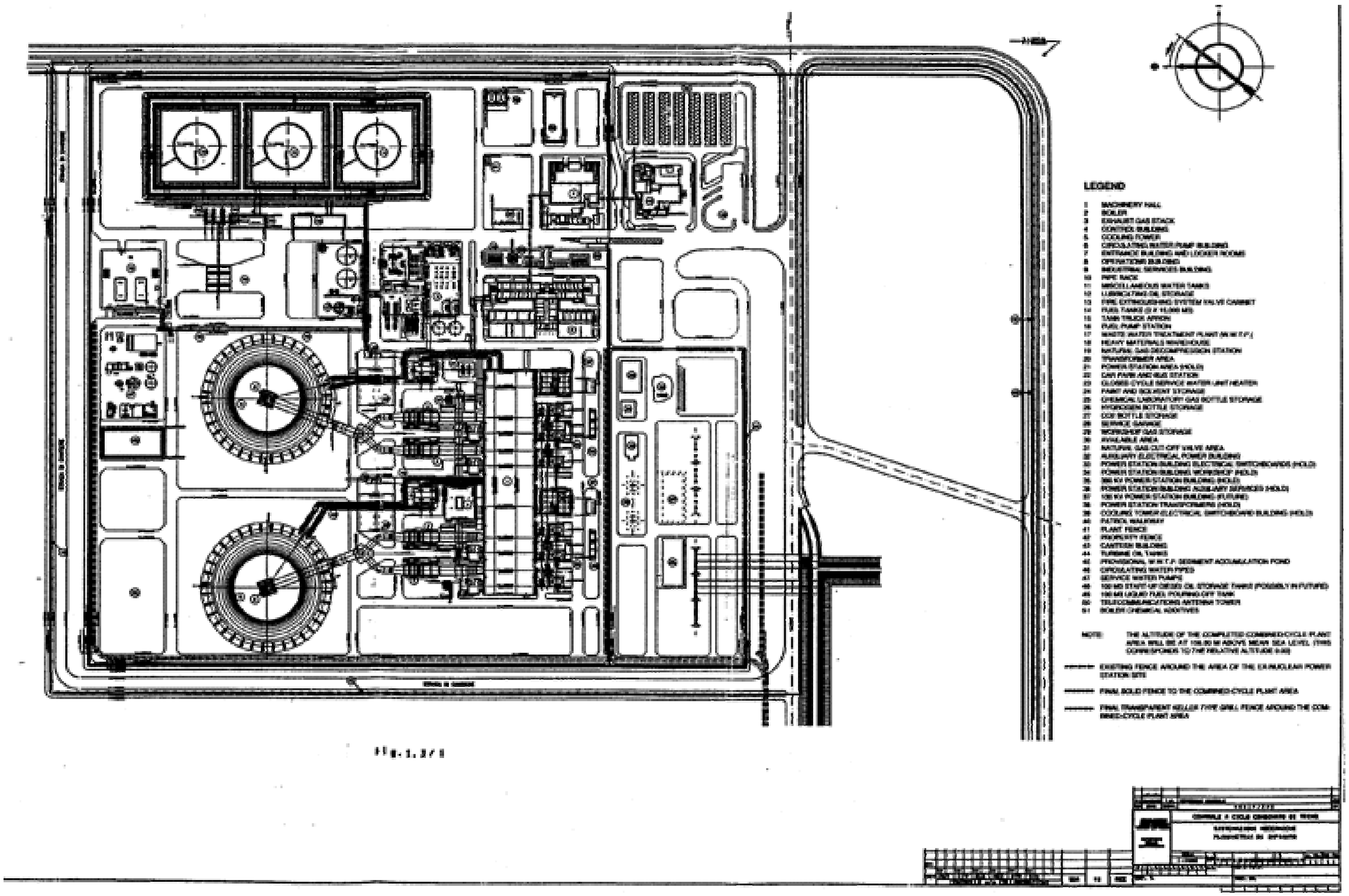
Normalized plasma pressure profiles at ignition. The dashed and dotted curves represent the analytical fit of the four profiles.



Thermal load distribution under ignition condition for different radial shifts.

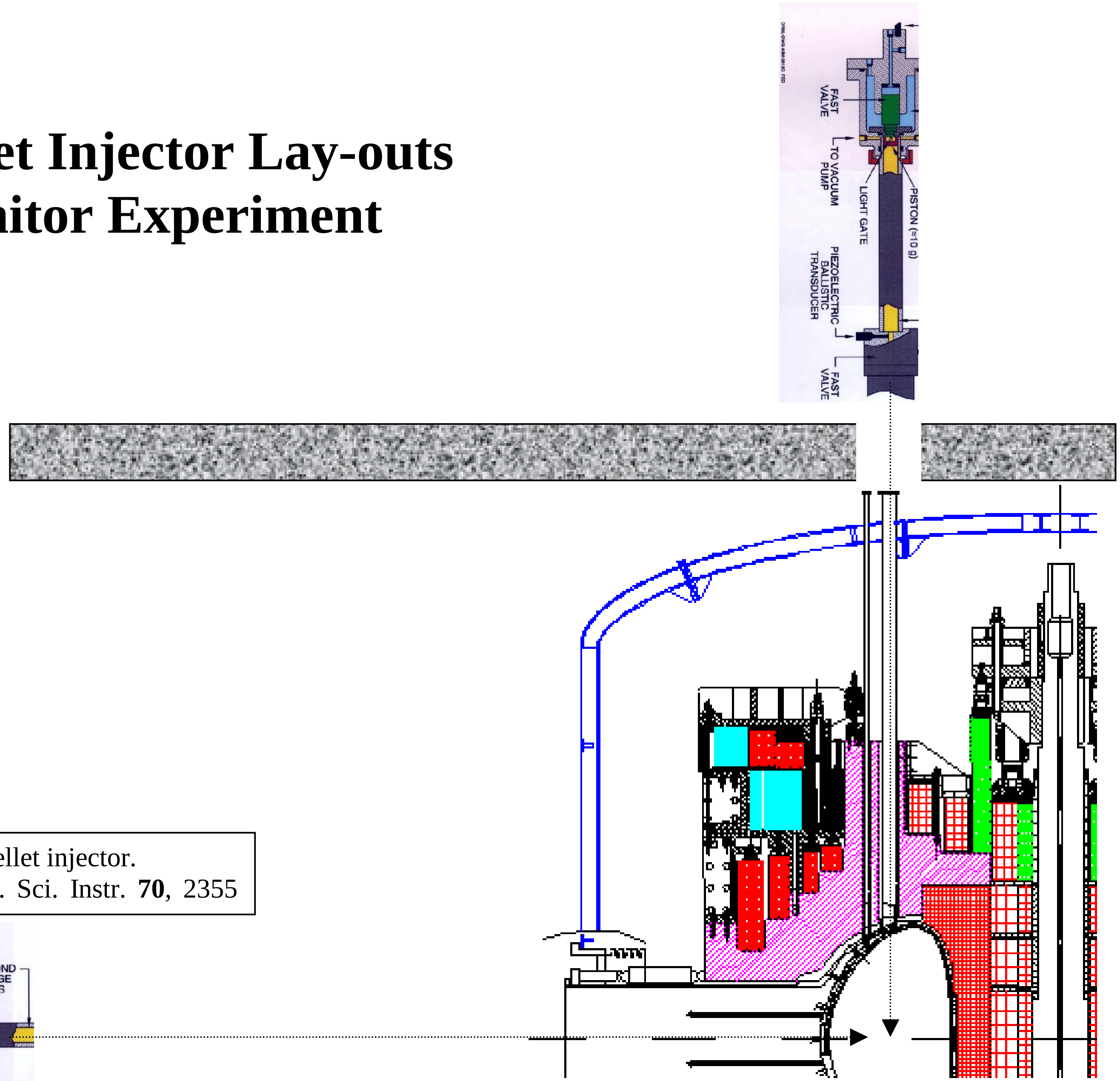
TRINO COMBINED-CYCLE POWER STATION

ENEL
Società per azioni

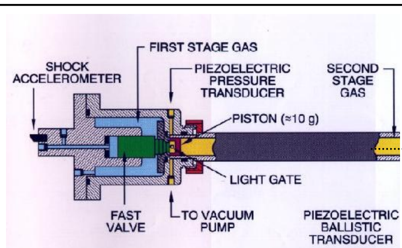

LEGEND
1 MACHINERY HALL
2 BOILER
3 EXHAUST GAS STACK
4 CONTROL BUILDING
5 COOLING TOWER
6 CIRCULATING WATER PUMP BUILDING
7 ENTRANCE BUILDING AND LOCKER ROOMS
8 OPERATIONS BUILDING
9 INDUSTRIAL SERVICES BUILDING
10 PIPE RACK
11 MISCELLANEOUS WATER TANKS
12 LUBRICATING OIL STORAGE
13 FIRE EXTINGUISHING SYSTEM VALVE CABINET
14 FUEL TANKS
15 TANK TRUCK APRON
16 FUEL PUMP STATION
17 WASTE WATER TREATMENT PLANT
18 HEAVY MATERIALS WAREHOUSE
19 NATURAL GAS DECOMPRESSION STATION
20 TRANSFORMER AREA
21 POWER STATION AREA (HOLD)
22 CAR PARK AND BUS STATION
23 CLOSED CYCLE SERVICE WATER UNIT HEATER
24 PAINT AND SOLVENT STORAGE
25 CHEMICAL LABORATORY GAS BOTTLE STORAGE
26 HYDROGEN BOTTLE STORAGE
27 CO2 BOTTLE STORAGE
28 SERVICE GARAGE
29 WORKSHOP GAS STORAGE
30 AVAILABLE AREA
31 NATURAL GAS CUT-OFF VALVE AREA
32 AUXILIARY ELECTRICAL POWER BUILDING
33 POWER STATION BUILDING ELECTRICAL SWITCHBOARDS (HOLD)
34 POWER STATION BUILDING WORKSHOP (HOLD)
36 POWER STATION BUILDING AUXILIARY SERVICES (HOLD)
38 POWER STATION TRANSFORMERS (HOLD)
39 COOLING TOWER ELECTRICAL SWITCHBOARD BUILDING (HOLD)
40 PATROL WALKWAY
41 PLANT FENCE
42 PROPERTY FENCE
43 CANTEEN BUILDING
44 TURBINE OIL TANKS
46 CIRCULATING WATER PIPES
47 SERVICE WATER PUMPS
50 TELECOMMUNICATIONS ANTENNA TOWER
51 BOILER CHEMICAL ADDITIVES
NOTE:
FINAL SOLID FENCE TO THE COMBINED-CYCLE PLANT AREA
Fig. 1.2/1


Trino/Leri
76 Km
53 Km
TORINO
MILANO
NOVARA
Vercelli
Casale Monf.
ALESSANDRIA
Pavia
Chivasso
Trino
Vigèvano
Mortara
Asti
COMO
MONZA
Busto-Arsizio
Biella
Ivrea
Moncalieri (240)
Chieri
Voghera
Tortona
Valenza
Lodi
Po
Ticino
Tanaro

Possible Pellet Injector Lay-outs on the Ignitor Experiment



Schematics of the FTU pellet injector.
A. Frattolillo at al., Rev. Sci. Instr. **70**, 2355



IGNITOR MAGNET SYSTEM AND MACHINE STRUCTURE

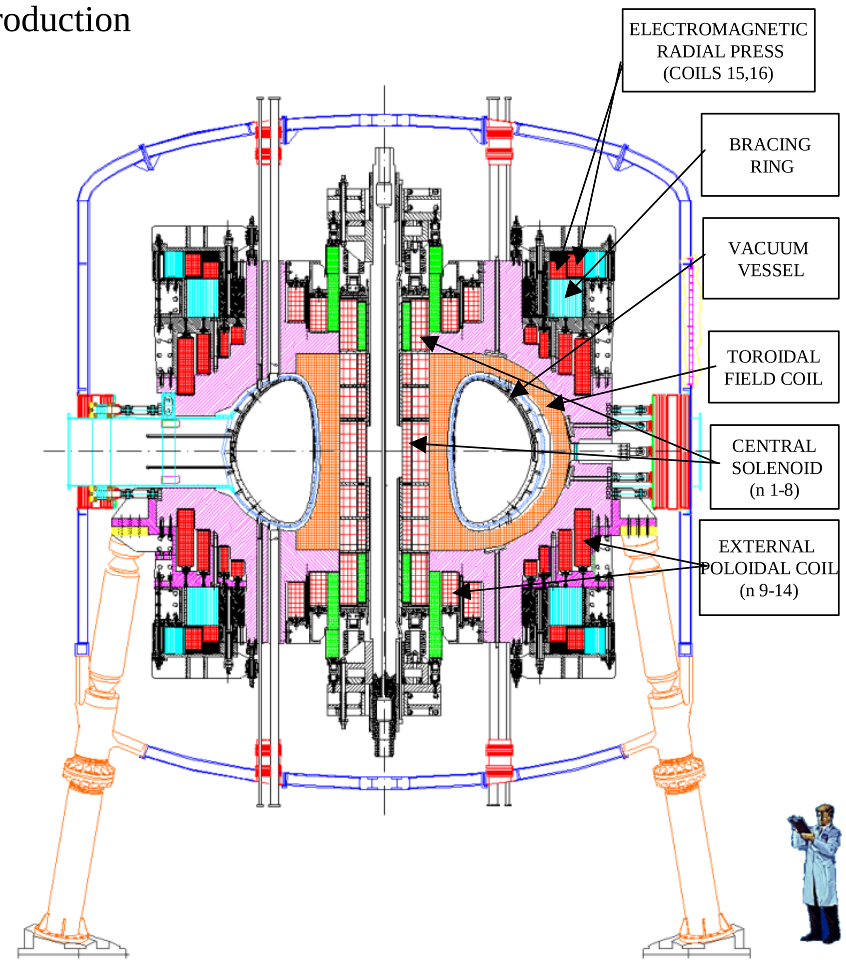
Introduction

- Ignitor is a high field compact machine proposed and designed to achieve ignition in D-T plasmas. The machine has been conceived as completely integrated system of its major components (toroidal field system, poloidal field system and plasma chamber).

- The toroidal field magnet is made of 12 modules, each including two toroidal field coils (TFC), contained by 4 C-Clamp elements.

- The structural performance of the machine relies on an optimised combination of “wedging”, in the TFC inboard legs and in the outboard of the C-Clamp, and “bucking” between the TFC and the central solenoid (CS).

- The inboard legs of the TFC are preloaded to resist the vertical components of the Lorenz forces. The preload is applied through the upper and lower parts of the C-Clamp (the C-clamp “noses”) by means of bracing rings (passive system) and an electromagnetic radial press (active system).



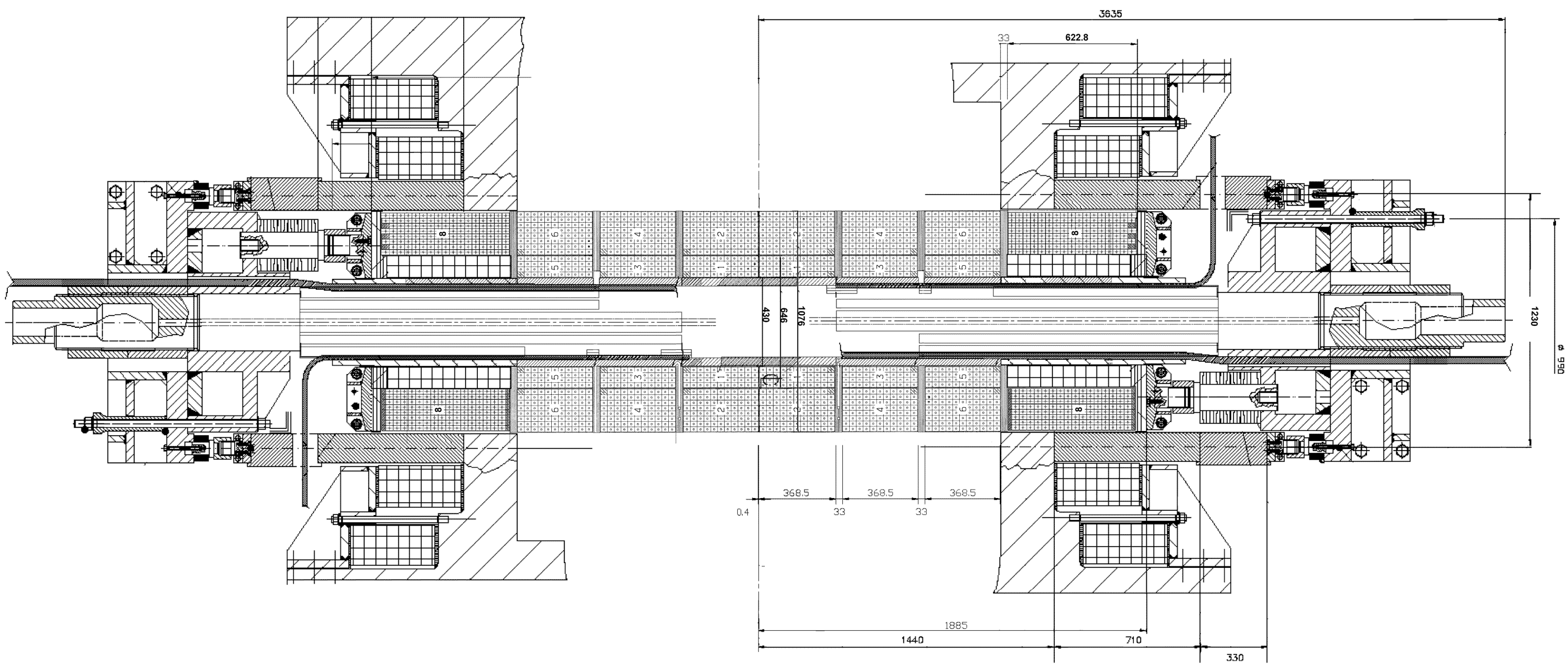
IGNITOR machine cross section

A. Cucchiaro, ENEA-Frascati-FUS-TN, 1 November 2000. Assistant of Vicedirector of Fusion Technology. E-Mail:cucchiaro@frascati.enea.it.

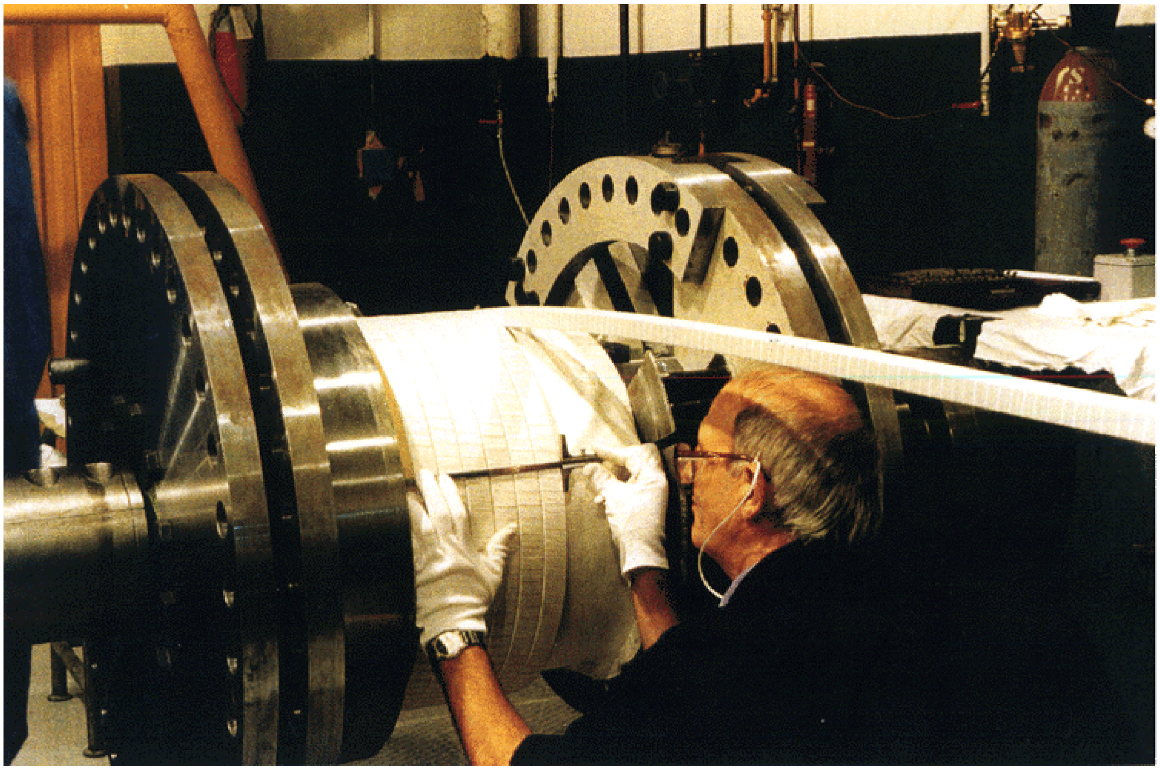
IGNITOR MAGNET SYSTEM AND MACHINE STRUCTURE

Poloidal Field Coils

- The primary function of the CS is to produce most of the magnetic flux variation needed to drive the plasma current according to prescribed scenarios. The radial subdivision of the CS into two concentric groups has been adopted to maximise the magnetic flux variation while keeping the coils within their thermal and mechanical limits. The axial subdivision in four layers is required to match the plasma shape with the first wall profile and to make the coil manufacturing easier; it also provides the CS with the suitable flexibility to avoid localized stresses resulting from the fact that the stiffness of the inner leg of the Toroidal Field Coils (TFCs) changes continuously and significantly along the height.



Central Solenoid System (CS)

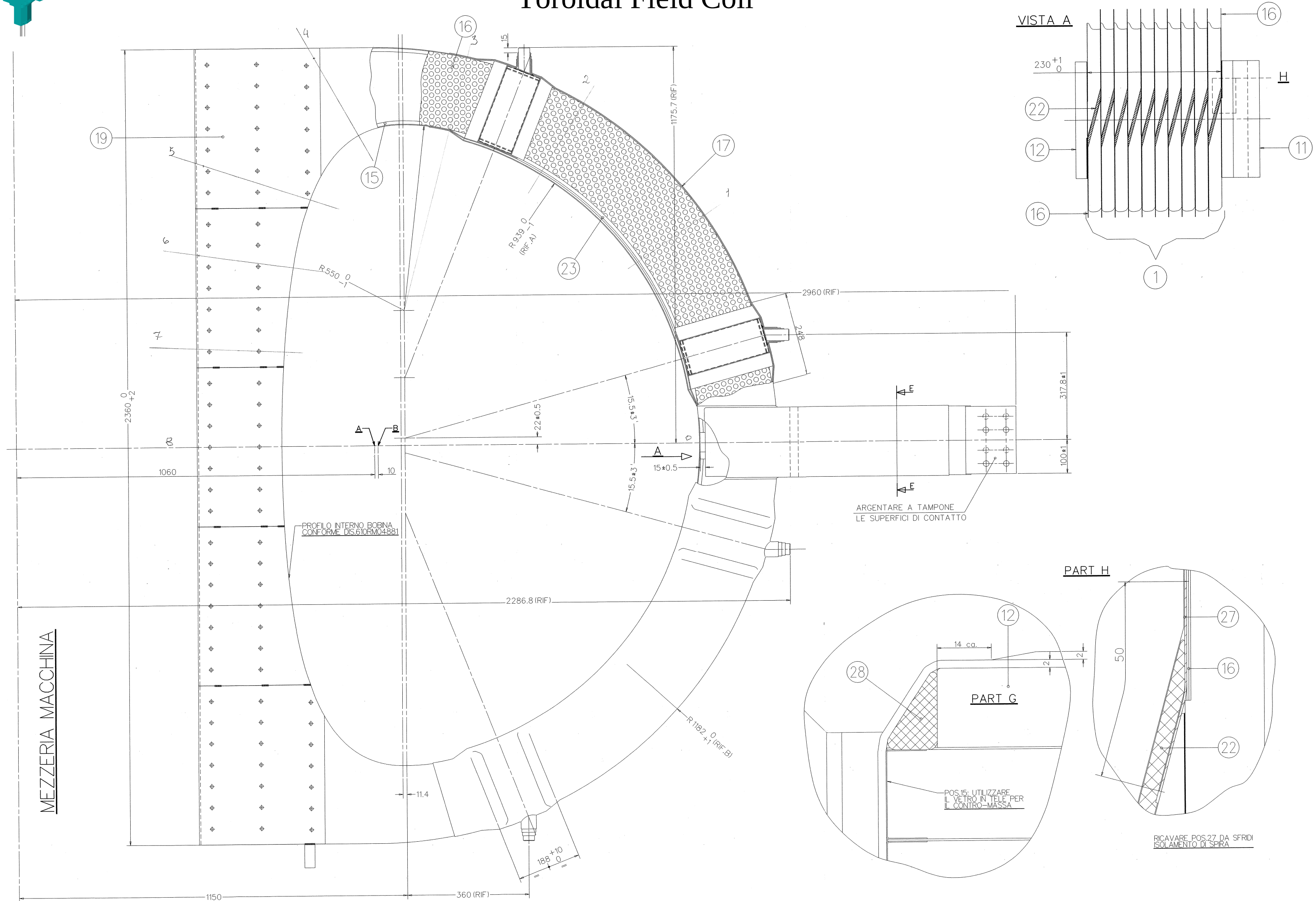


Winding of the conductor for the prototype of the innermost coil of the central solenoid.

Completed prototype of the innermost coil of the central solenoid.

IGNITOR MAGNET SYSTEM AND MACHINE STRUCTURE

Toroidal Field Coil



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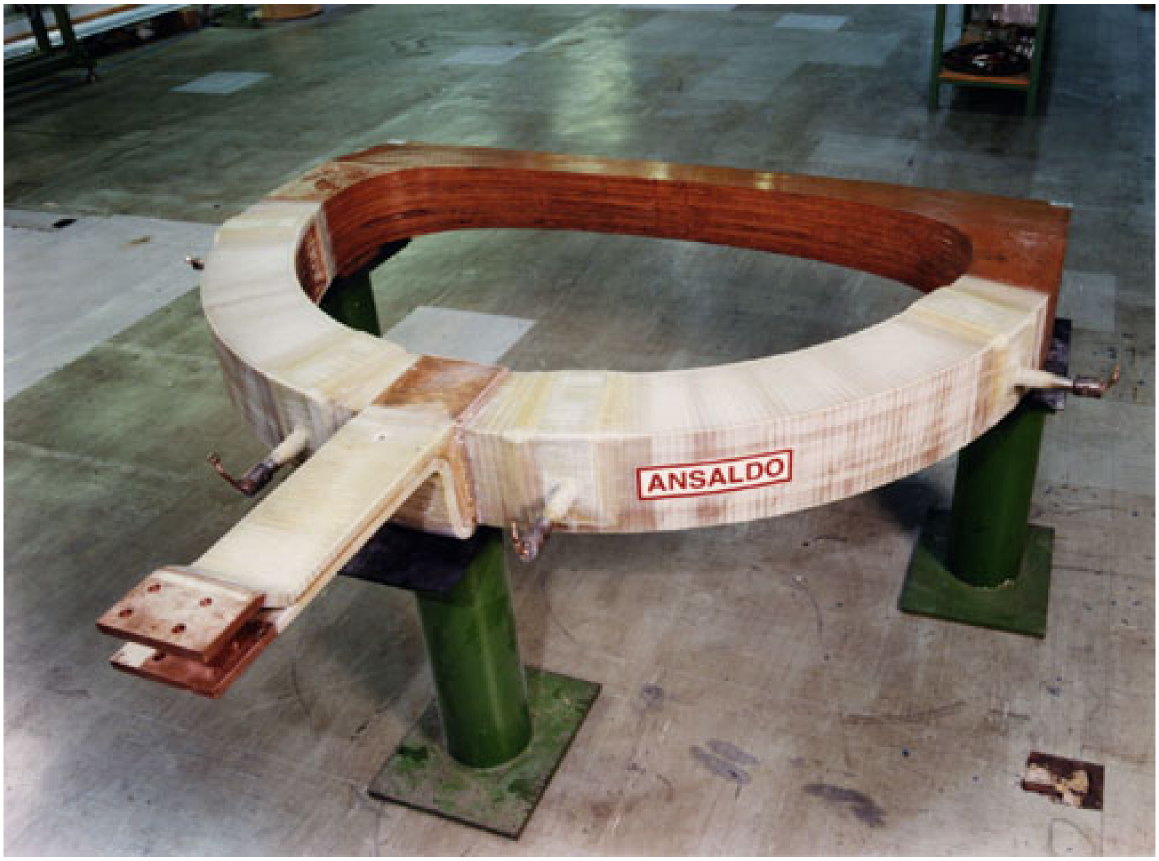
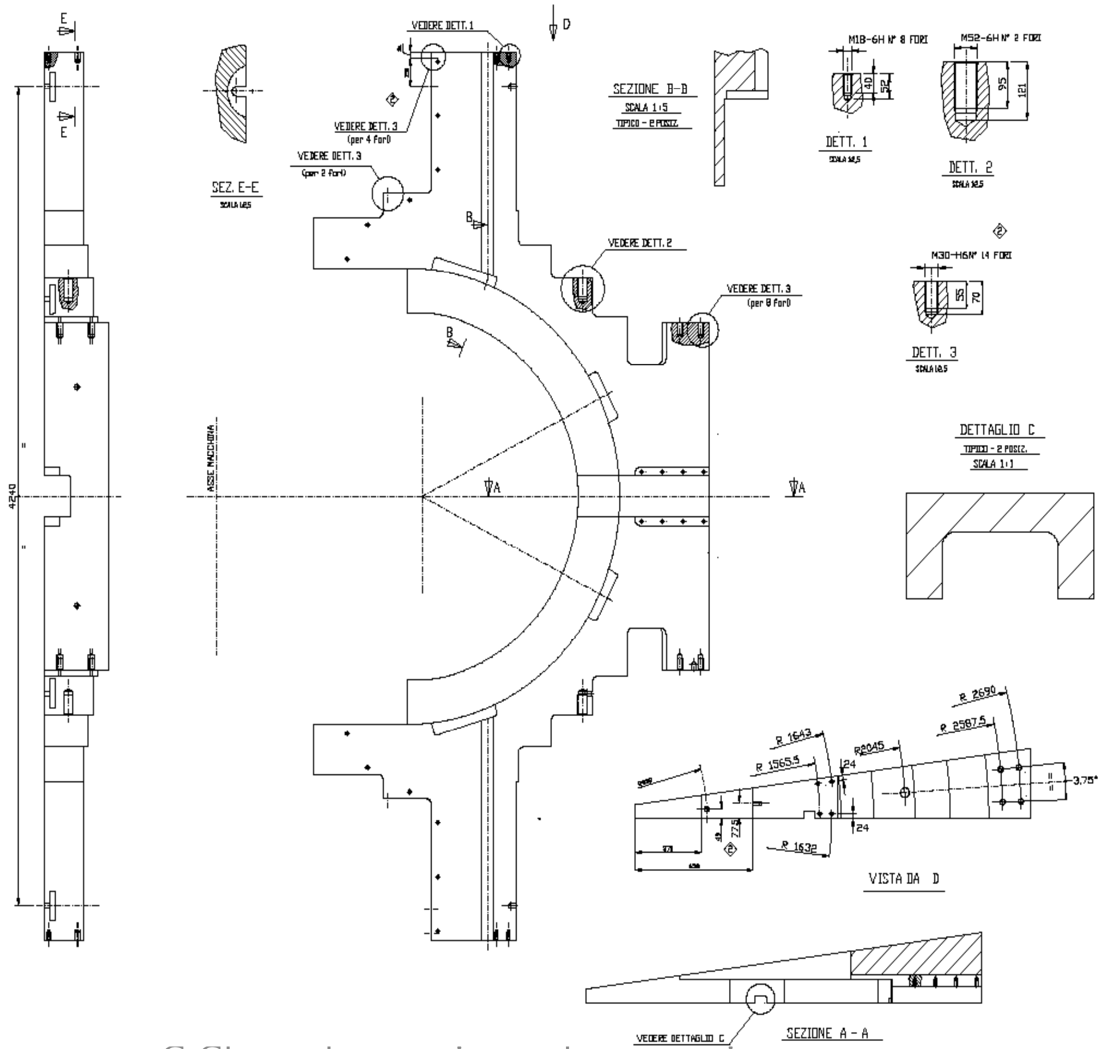


The toroidal field coil prototype.

IGNITOR MAGNET SYSTEM AND MACHINE STRUCTURE

C-Clamp

- The C-clamps, the basic mechanical structural components of the machine, provide support to the toroidal and poloidal coils and to the vacuum vessel and accommodate the vertical and horizontal ports of the vacuum vessel, as well as the electrical connections of the toroidal field coils. Each C-Clamp is a massive large piece and has to be manufactured according to very tight tolerances to assure the mutual fitting between the CS coils and the adjacent C-clamp and wedging on the outboard region.



C-Clamp element view and cross section

Finished C-clamp.

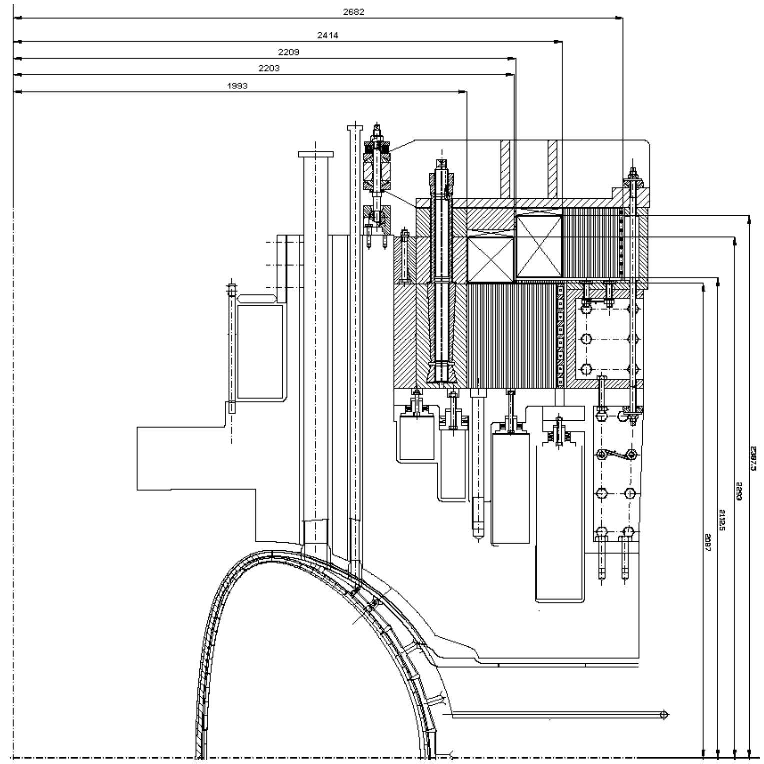
IGNITOR MAGNET SYSTEM AND MACHINE STRUCTURE

Radial press system

- The TFCs load bearing capability is enhanced by two radial press systems (upper and lower). Each one consists of two loading system acting both on the C-Clamp “nose”: the mechanical permanent preloading and the active electromagnetic press.

- The first system envisages a radial bracing ring and 48 wedges, located between the ring and the C-clamp nose ; the ring reacts against the wedges applying a radial inward force of 180 MN at 30 K. The second loading system consists of an electromagnetic press producing a nominal force of 193 MN in the radial direction (redundant force of 25% is available). Supporting beams keep the press systems in position and withstand vertical electromagnetic loads. The design is such to allow the C-Clamp nose movement and thermal expansion of the coils.

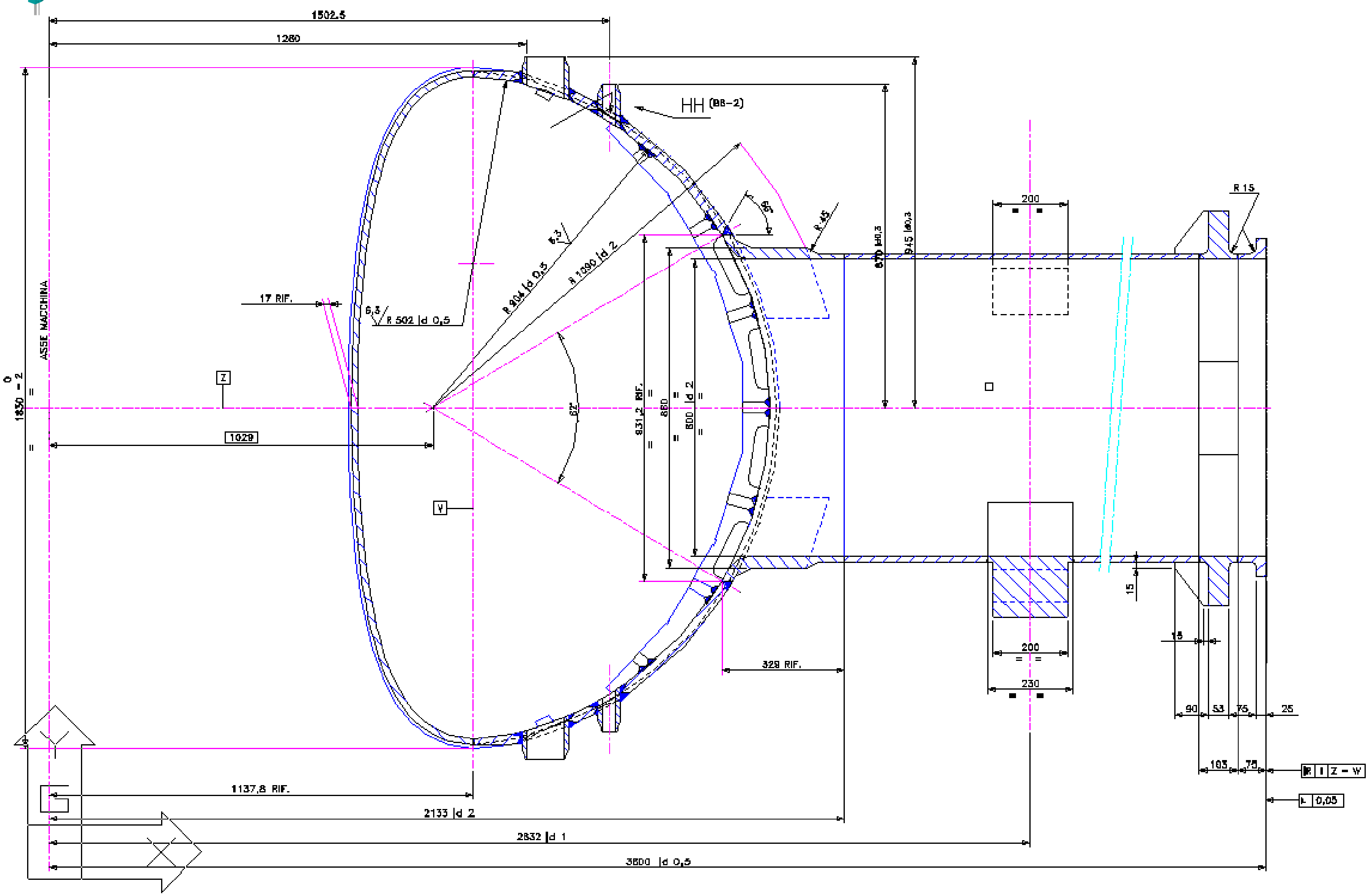
- The radial electromagnetic press is made of two concentric coils (inner coil 210x210 mm^2; outer coil 210x275 mm^2) made of oxygen free copper (OFHC). The inner coil pushes the C-clamps “nose” inward through a steel tapered spacer (0.72 mm); the outer coil is fitted with a reinforcing ring. The insulation system is made of glass fabric plus kapton tapes; the coil is vacuum impregnated with an epoxy resin.



Radial press system cross section

IGNITOR MAGNET SYSTEM AND MACHINE STRUCTURE

Plasma chamber vertical section



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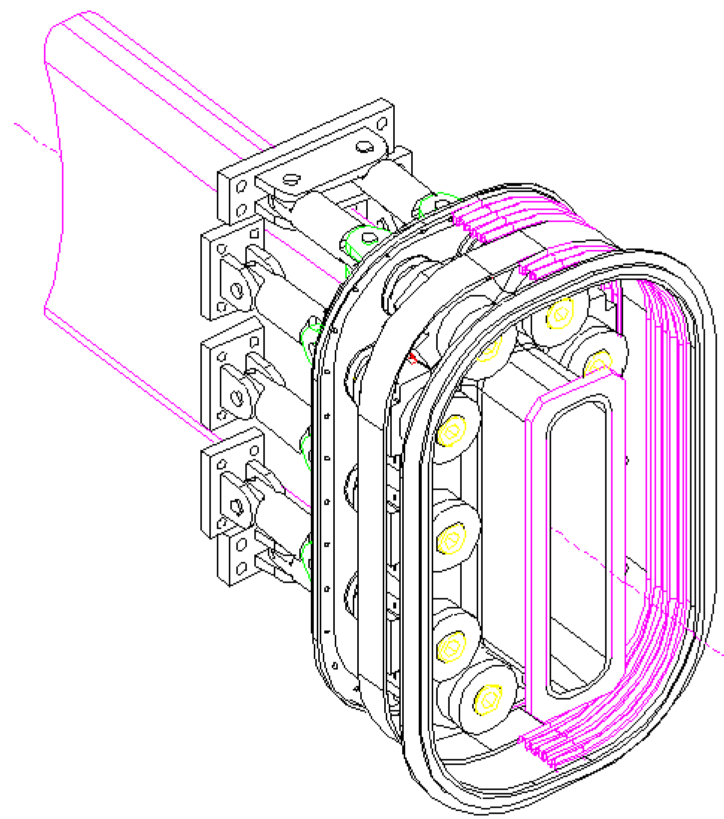
IGNITOR MAGNET SYSTEM AND MACHINE STRUCTURE

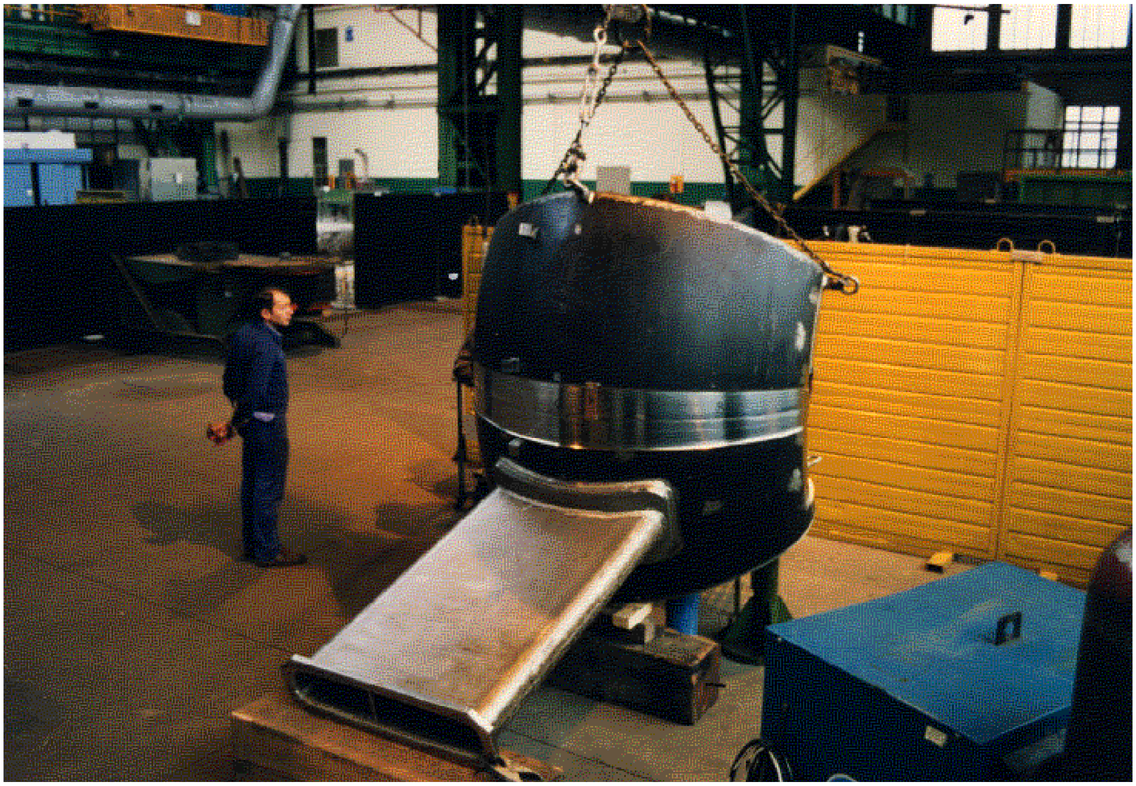
Plasma chamber supports design

- Radial supports (10 off) are acting in both versus (centripetal and centrifugal) with high stiffness. The end of radial ports are connected to the C-Clamp structure. This connection will be free to allow for thermal movement; only during the pulse the connection will be locked by clamping sleeves hydraulically operated. Radial supports are designed to resist up to a maximum of 3.5 MN radial force. The stiffness of the plasma chamber wall will contribute to share the radial loads with the other port. A structural analysis is needed to assess the loads values.

- Lateral supports between radial ports and C-Clamp are needed to resist out of plane forces due to disruptions as well as to accommodate thermal expansion. Each of this support can react to a force normal at the port axis about 0.75 MN.



Radial support.


Finished sector of the vacuum vessel.

IGNITOR MAGNET SYSTEM AND MACHINE STRUCTURE

First Wall

- To withstand the heat and the electromagnetic loads in normal operating conditions and disruptions.

- To cover with tiles the entire inner surface of the plasma chamber, so that the first wall (FW) basically works as well as extended limiter.

- To reach a position accuracy of:

  - ± 0.1 mm between adjacent tiles, on the same tile carrier;

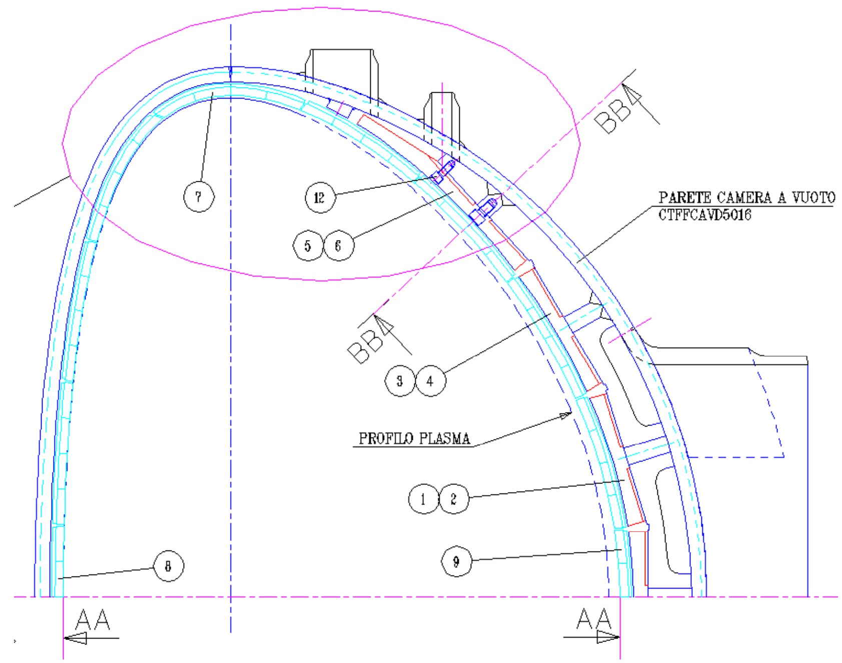
  - ± 1 mm overall assembly tolerances with respect to their theoretical position.

- No active cooling is required.

- During normal operating conditions:

- operating temperature at plasma start-up T=293 K

- maximum thermal load Q=1.25 MW/m^2, for t= 4.0 s



First wall poloidal cross section