Status of the Proto-Sphera Load Assembly

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Talk Outline

1) PROTO-SPHERA: (Experiment)^3
2) PROTO-SPHERA Engineering Design and Analysis
3) Anode & Cathode Concept
4) Timetable
5) Conclusions

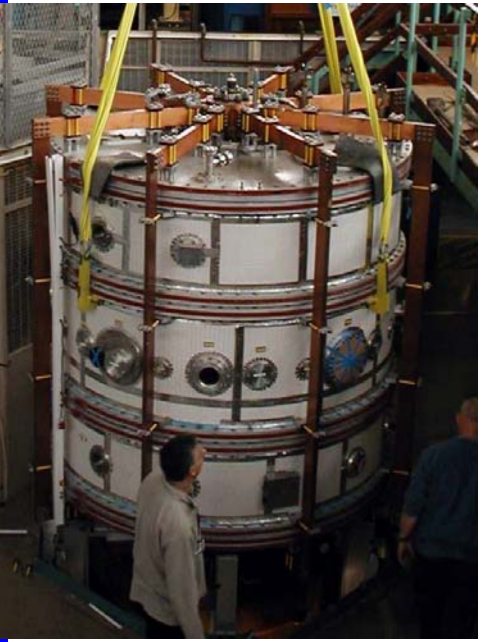
Results of the PROTO-SPHERA Panel held in Frascati on March 2002

Interesting Concept Exploration Experiment, adequate size & useful contribution to magnetic fusion programs.

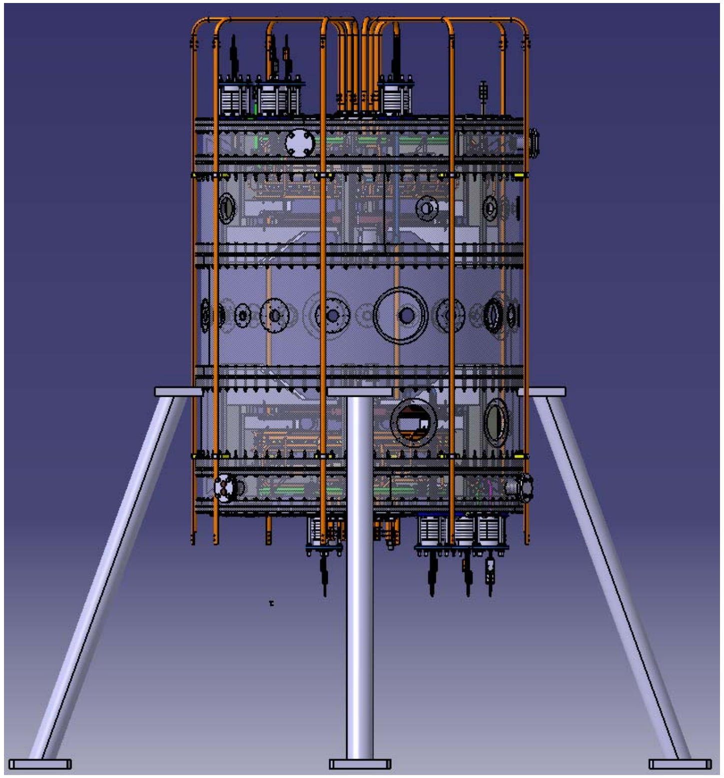
- **....**
- **Are the PROTO-PINCH electrode experiments a sufficient technical basis for a reliable electrode operation in PROTO-SPHERA?**

  YES, BUT… are not yet adequate for reliable multi-electrode operation...

START -> 3D Modelling -> Real 3D



Start Arrival
May 2004



Project & Design
Anode&Cathode
Construction
2004-2008

ProtoSphera Panel
March 2002:OK

Coils :June2005/Dec.2007
LoadA:Oct.2008/Dec/2009

Engineering Design of PROTO-SPHERA

Thanks to
Ing. S. Papastergiou
P.I. L. Bettinali

Resource Avalaibility

Thanks to
Ing. G. Lelli
Dott. A. Renieri
Ing. A. Pizzuto

A way to build a complex Experiment

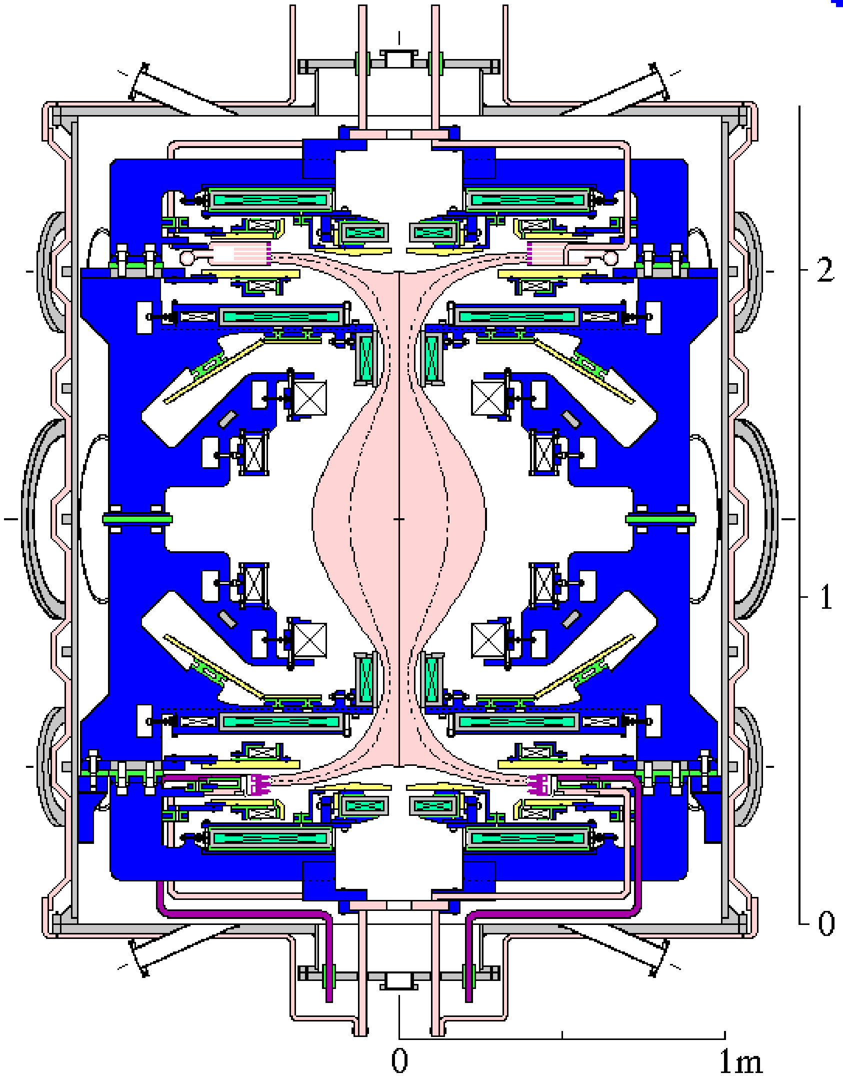
- More conventional items:
  - 3D CATIA Modelling (ENEA)
  - Exec.Design, Building & Assembly (ASG Superconductors)
- Less conventional items:

  Cathode, Filaments, Molybdenum Modules

  Anode, W-Cu interfaces to the arc

  (All designed and supplied by ENEA)

Main Breakdown features



- **Screw pinch (SP) formed by a hot cathode breakdown**
- **Filling pressure p_H~10^{-3}÷10^{-2} mbar**
- **Cathode filaments heated to 2700 °C**
- **V_e~100 V applied on the anode**
- **Electrode arc current limited to I_e~10 kA**

Design Philosophy

- Simplicity, symmetry, conservatism.
- Viewing capability and good access to electrodes.
- All connections to PF coils from top and bottom flanges, external to the Machine.
- Bellows in coil feedthroughs for adjustment.
- Operation and disruption (but no fault) conditions considered.

Design Aims

- ✓Easy handling, Reliability, Repairability of Machine.
- ✓Reliability of electrodes and avoidance of arc anchoring.
- ✓Minimise Technological Risks: provide appropriate electrical insulation, avoid local coil overheating (>100°C) due to hot anode and cathode (12MJ, 2700°C)
- ✓Minimise electromagnetic stresses (Filaments).
- ✓Accurate insulation study to avoid arc anchoring

& flexibility to realize future Helicity Injection.

Operating conditions

Temperature 20°C

Vacuum $< 1 \cdot 10^{-7}$ mbar
(predicted outgassing rate: $\sim 3 \cdot 10^{-5}$ mbar•l/s)

Baking

80-90°C

Adequate for water removal, coil protection; compatible to Viton O-rings

Possibility of N_2 1 mbar contact gas

Machine Parameters

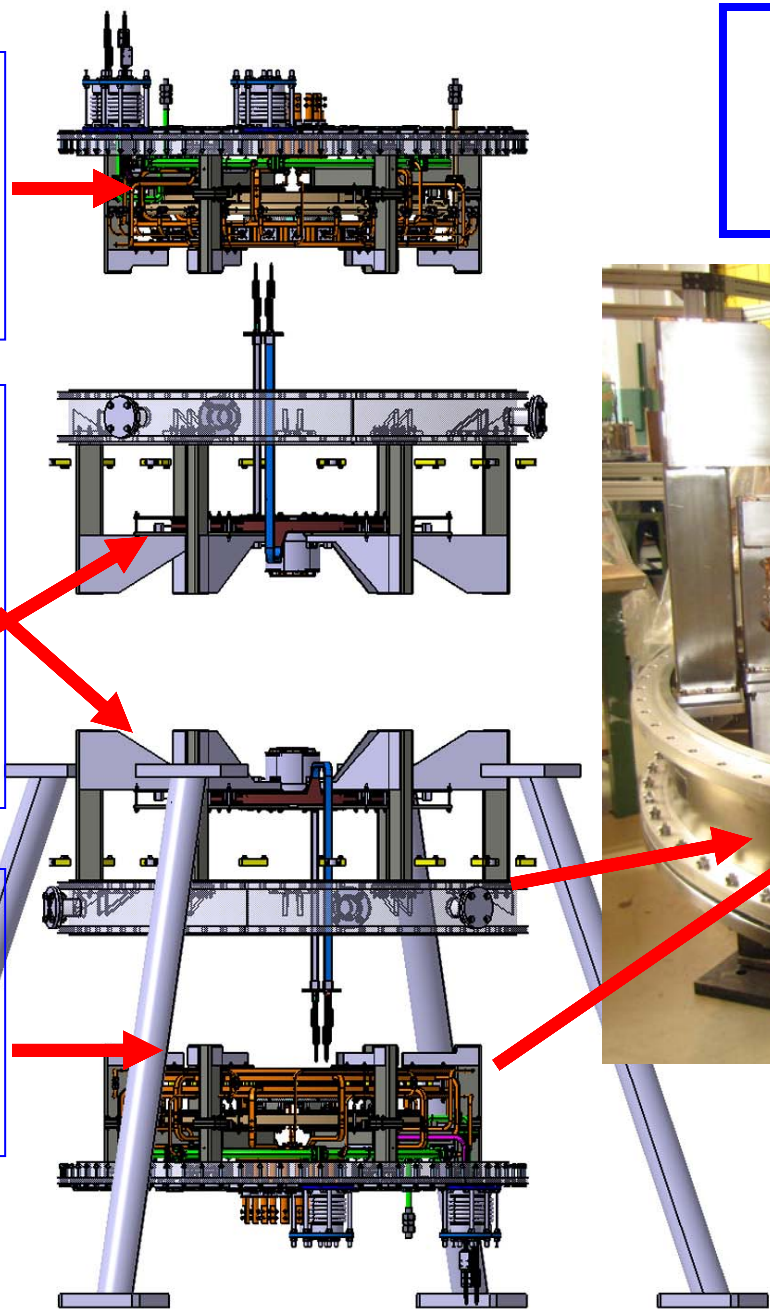
Spherical Torus (ST) diameter	0.7 m
Longitudinal Screw Pinch current	Phase I&II 10kA,III 60 kA
Toroidal ST current	120÷240 kA
Plasma pulse duration	1 s
Minimum time between two pulses	5 min.
Maximum heat loads on first wall components in divertor region	2 MW/m^2 , for 1 ms
Maximum current density on the plasma-electrode interface	1 MA/m^2

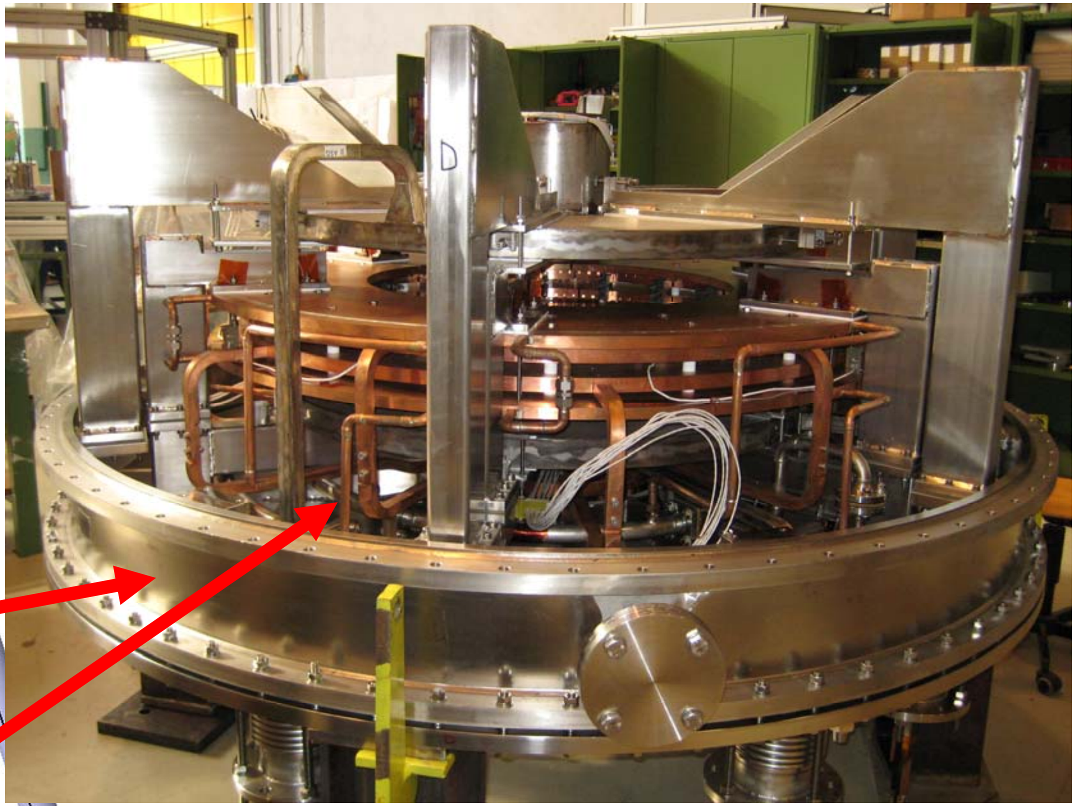
Load Assembly 4-Groups

GM_I: Anode

GM_III(1&2): Coils

GM_II: Cathode



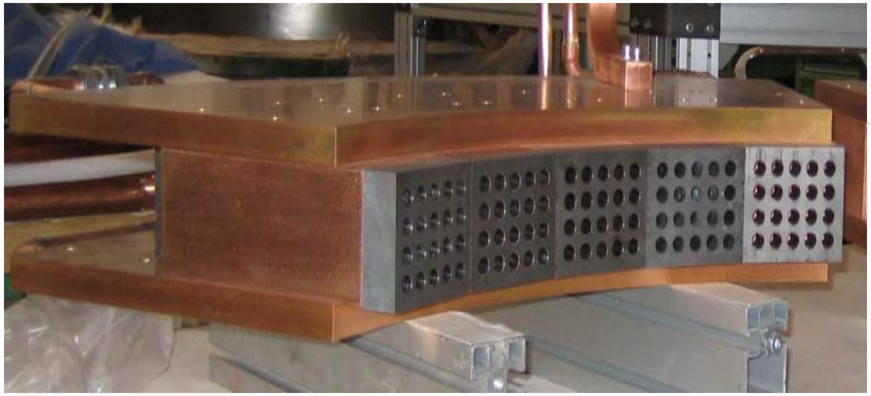


- Easy Accessibility

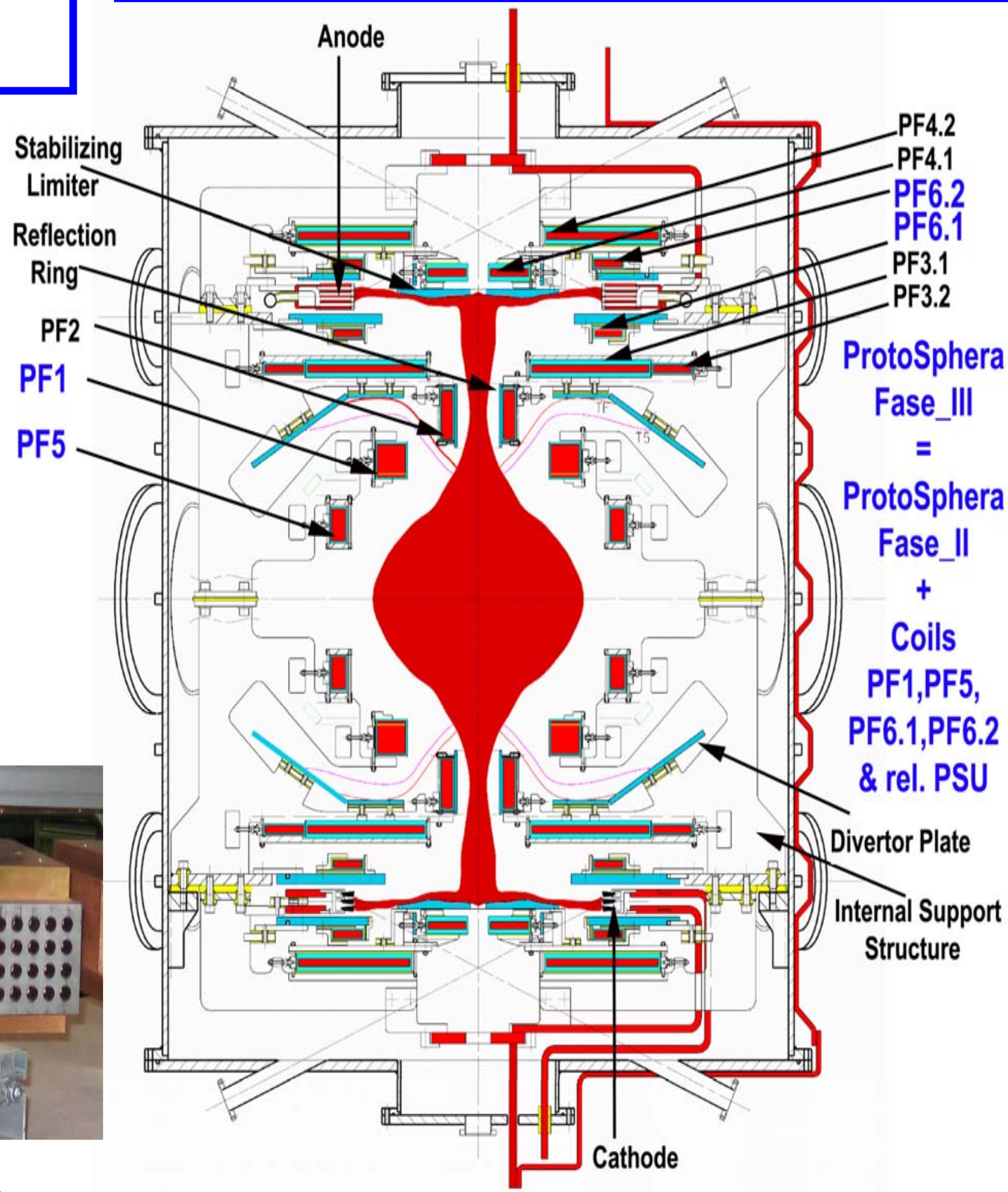
Proto-Sphera Phase I & II & III

Phase I: Axial Anode

Phase II: Radial Anode



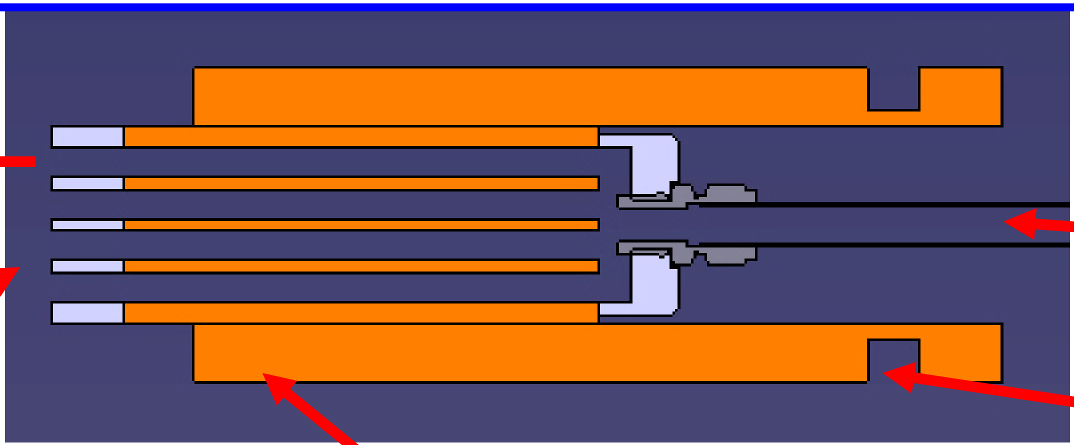
Phase III: Shaping Coils & PSU



Puffed Anode Design Capability:

ProtoPinch$_{Tested}$ = 30 MW/m^2 ProtoSphera$_{Max}$ = 30 MW/m2

GAS

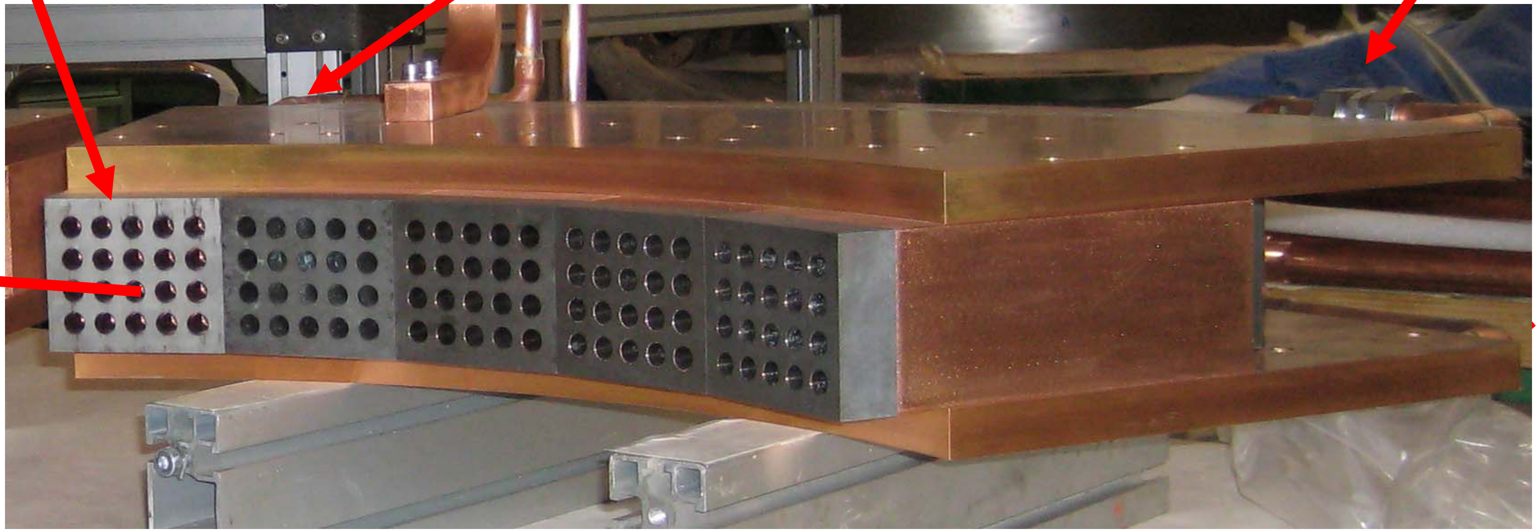


GAS

W90%-Cu10%
T
≤1000°C

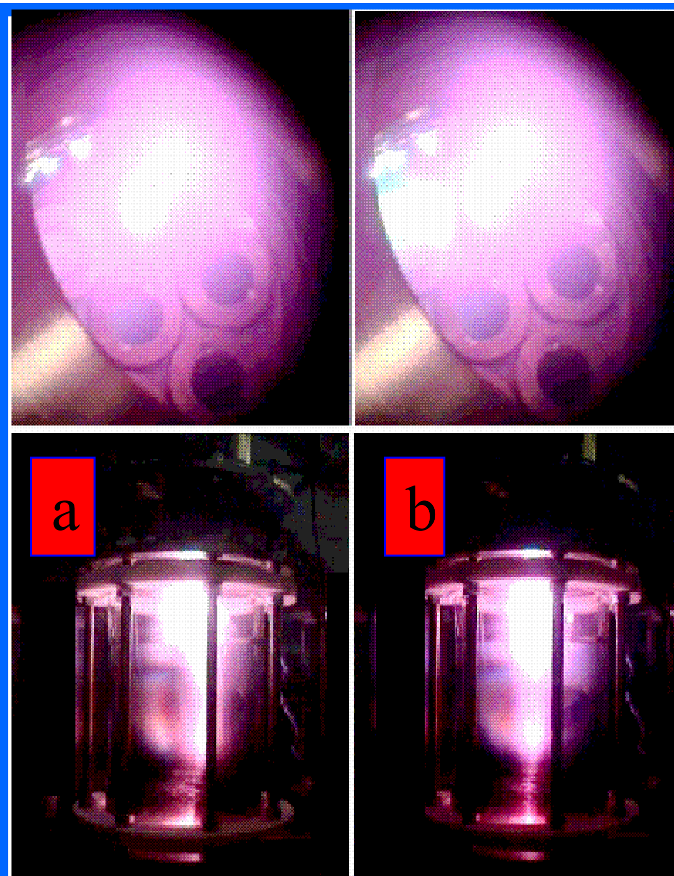
H2O

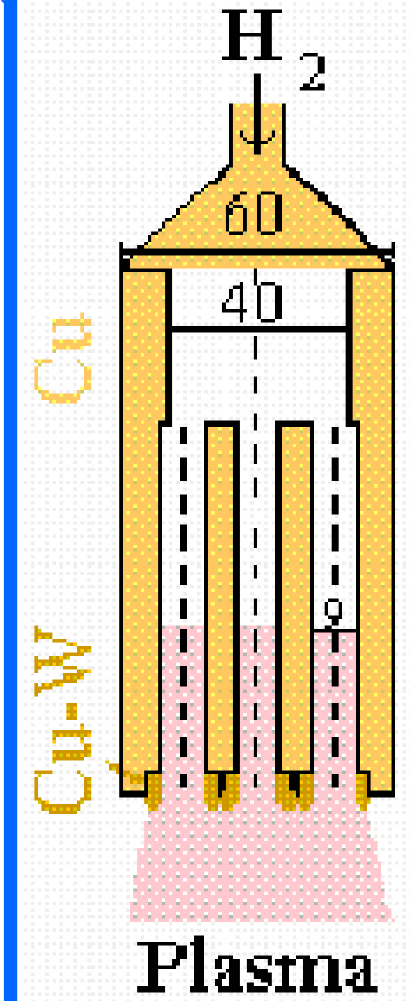
Protection Plate Cu



GAS

Anode

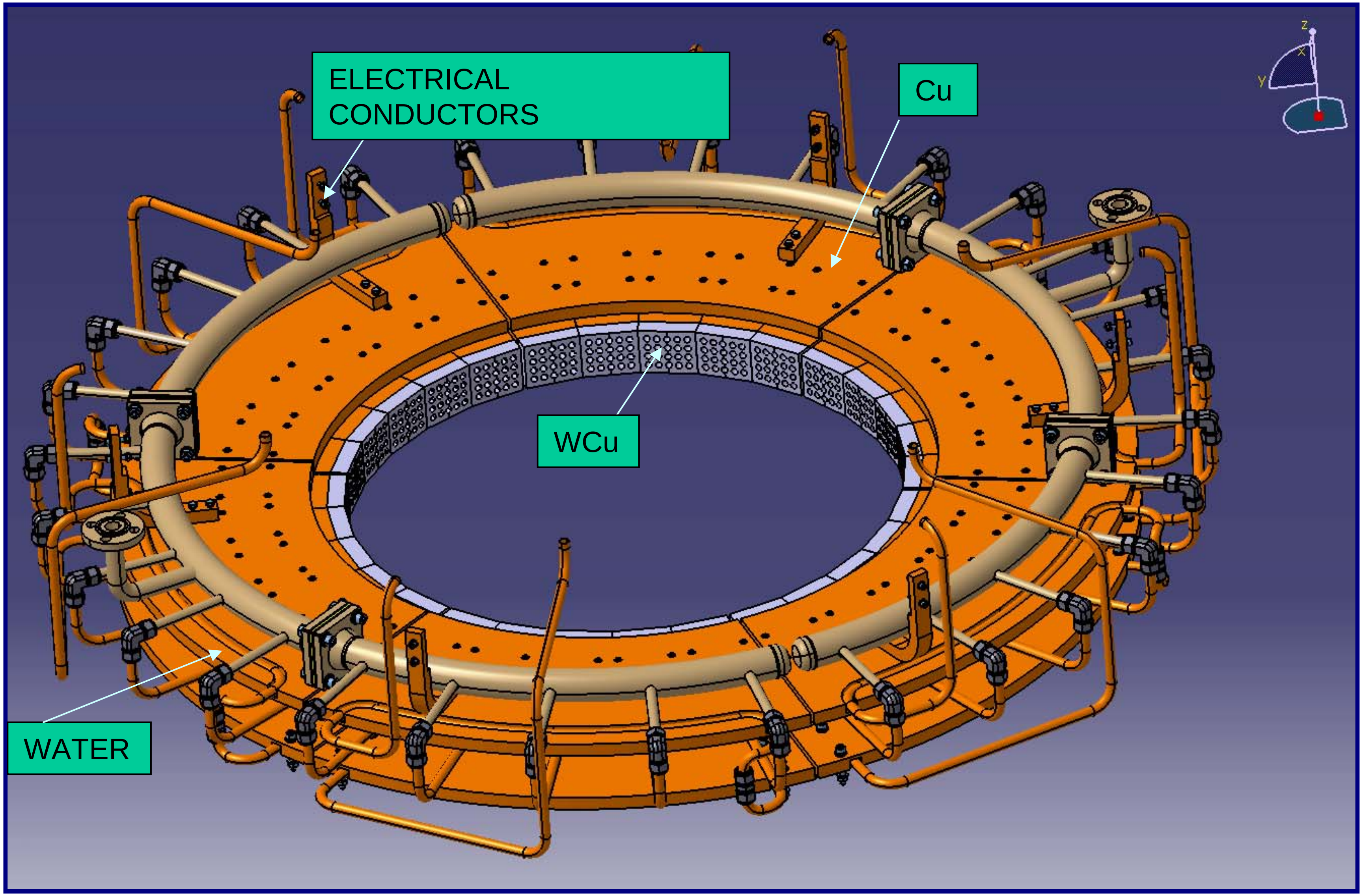




- **P_{WAnode}** = 2/3 (670 120) KW » 56 KW (module)
- **$A_{surface}$**= 1.8 10^{-3} m^2
- **D_{pw}** = P_W/ **$A_{surface}$**» **30 MW/m^2**
- anode arc anchoring with Cathode **DC** heated (a)
- No Anode anchoring with **AC** cathode heating (b)

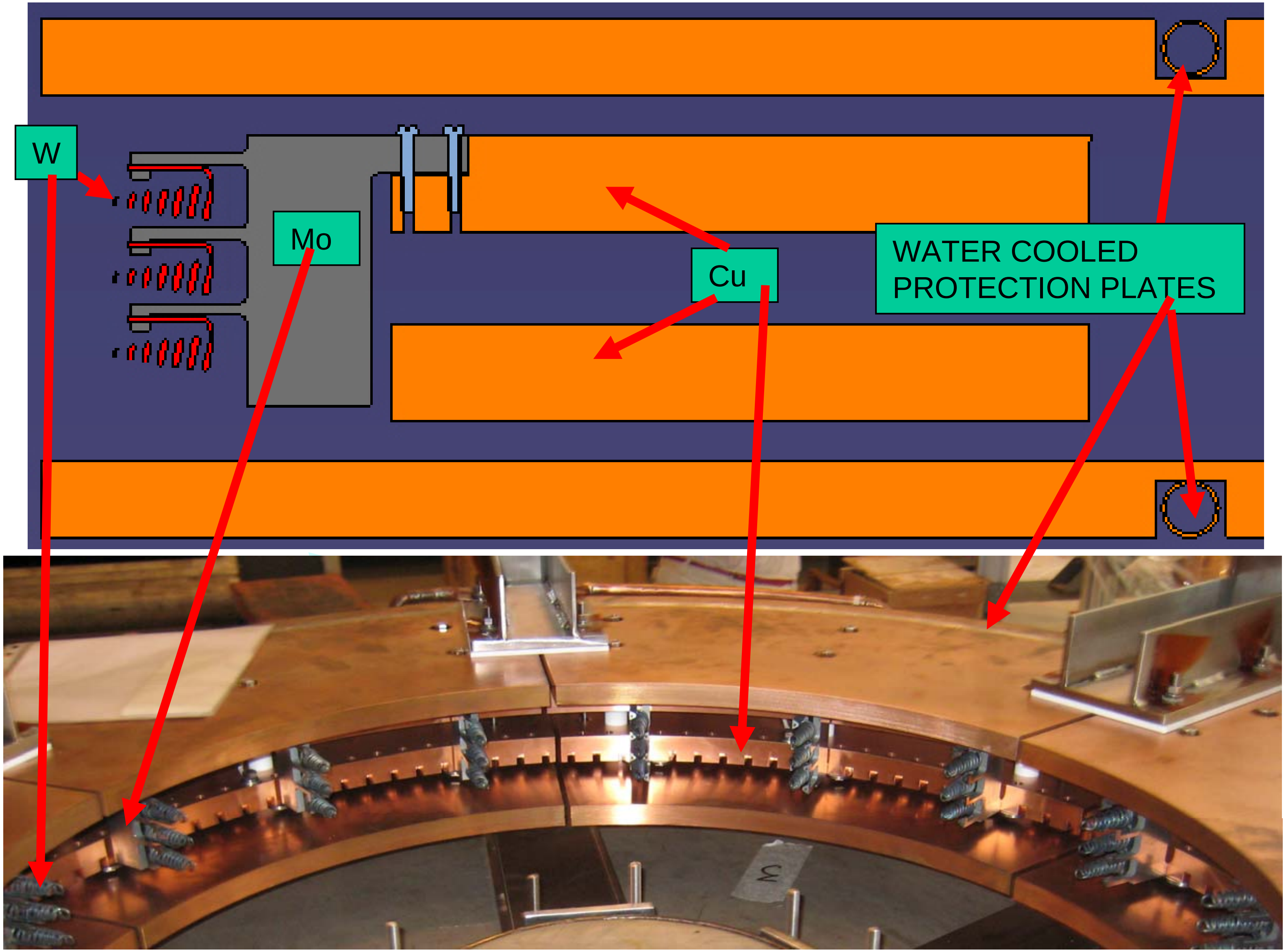
- ➢No Damages after 1000 discharge
- ➢Material W 90% Cu10%.
- ➢Scheme : Puffed Hollow Anode

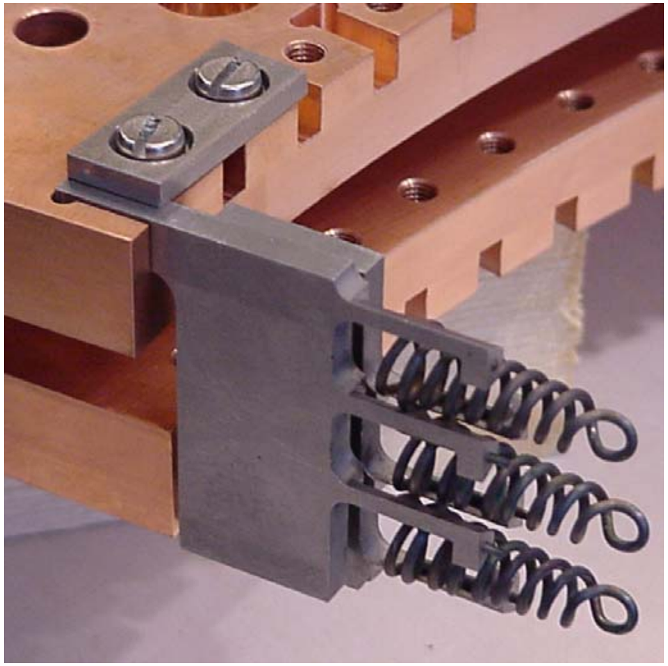
ANODE PHASE 2 - ASSEMBLY

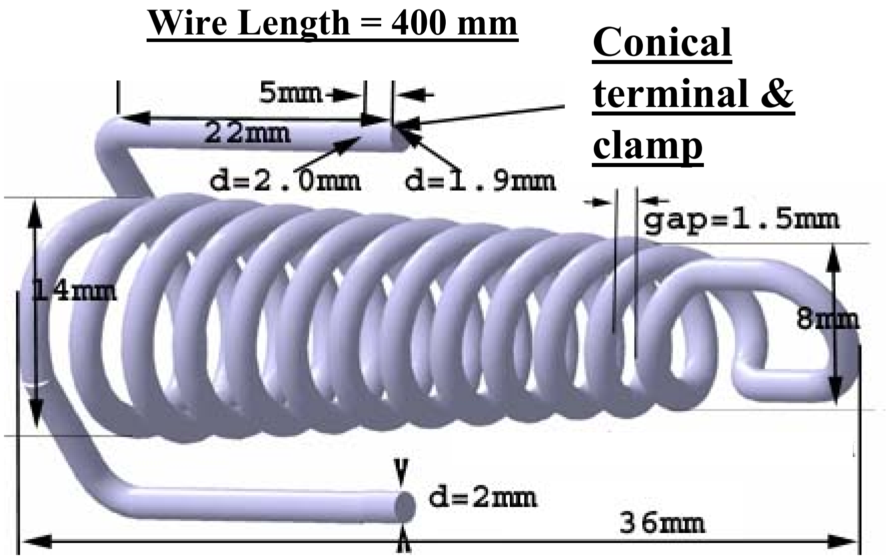


Anode Phase II Assembled

CATHODE - CROSS SECTION





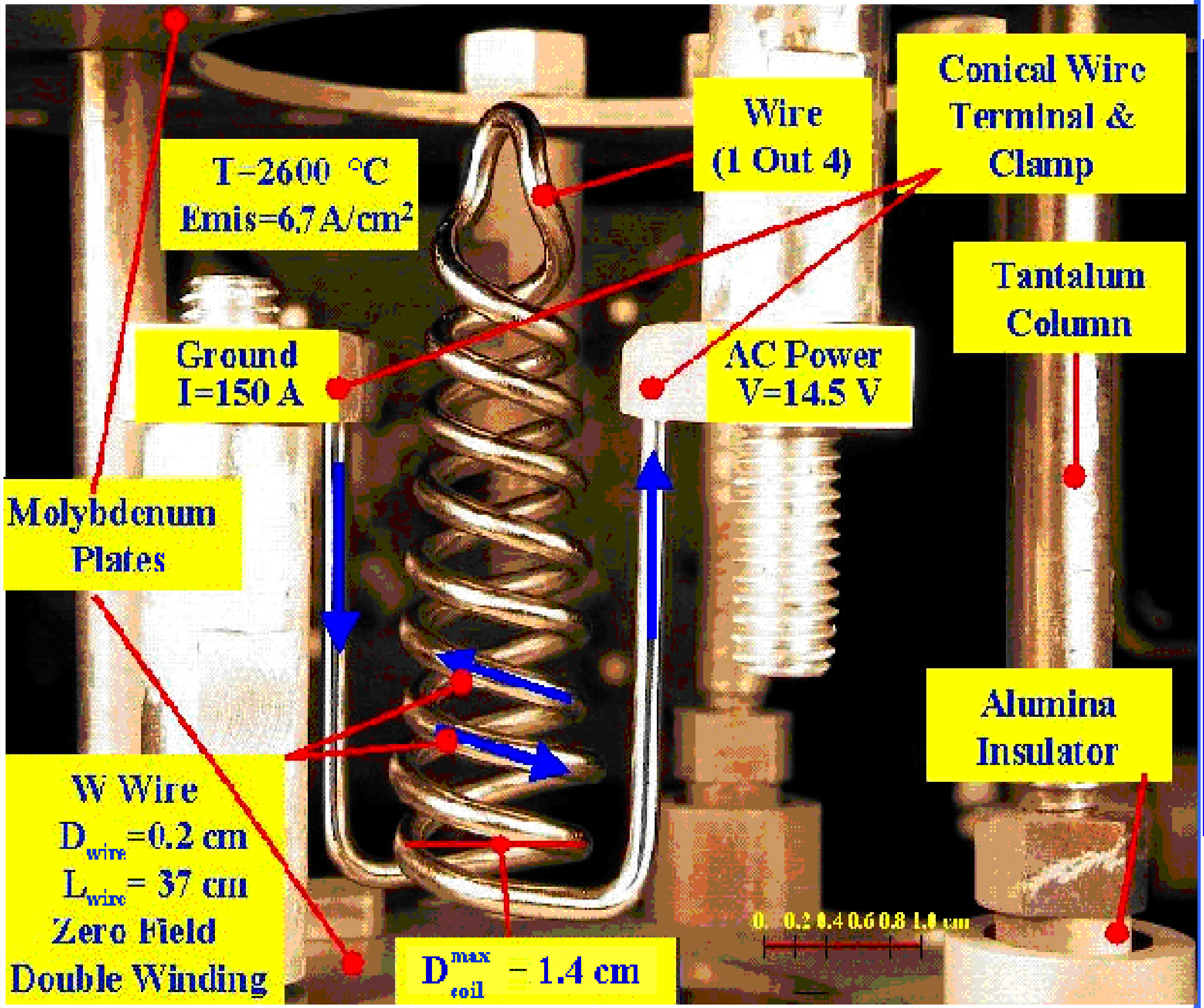


Multi-Pinch Cathode

- Limited number of cathode filaments (54 vs. 378)

- Coils will drive a total limited current (10 kA vs. 60 kA) Each coil will be capable of delivering the design current (150 A).

HeliConical Coil

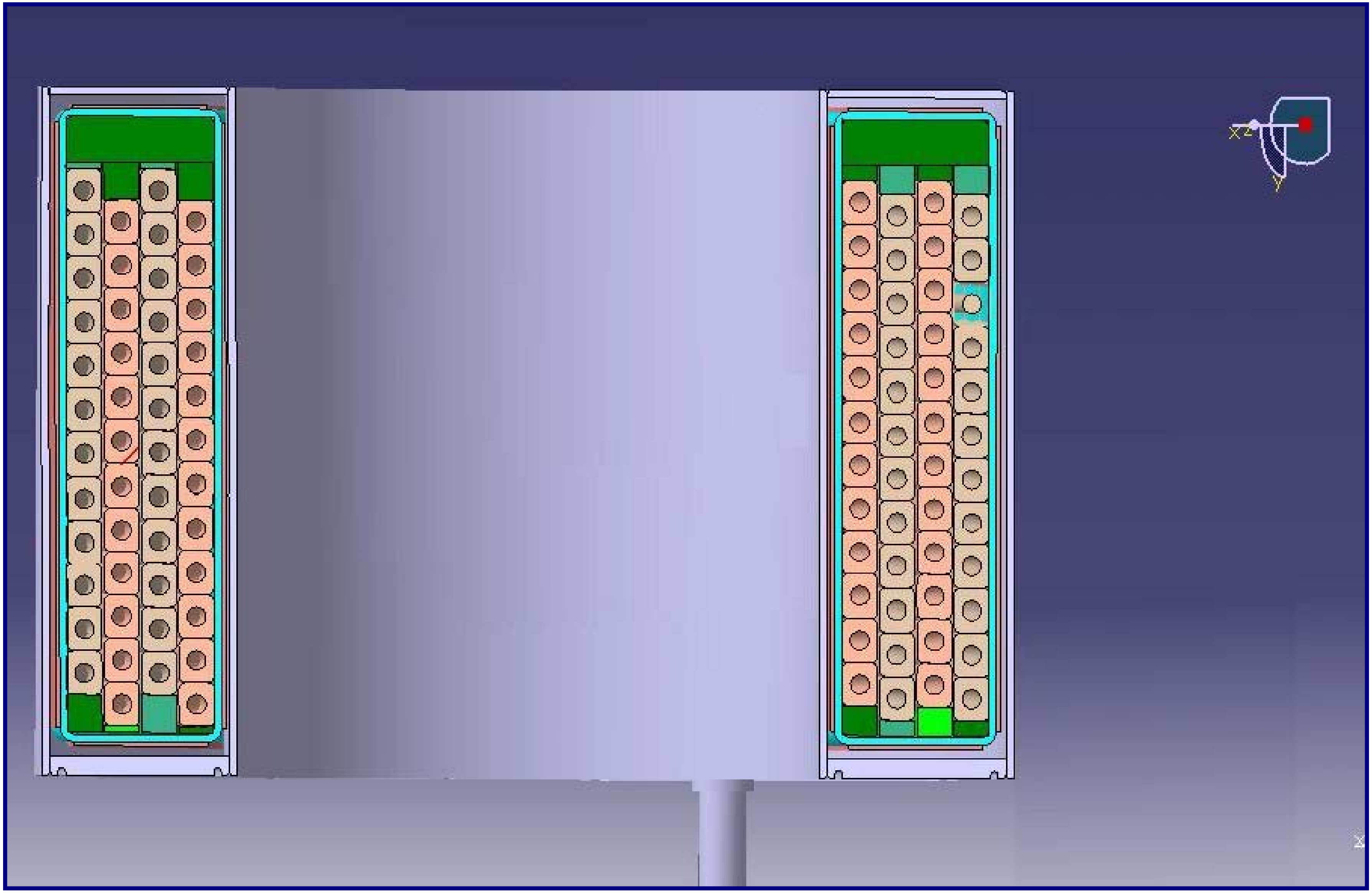


- **Null Field**
- Optimize **Temperature** Distribution
- Optimize **Weight** Distibution
- Ie =**167 A** (each coil)

MultiPinch Coils Delivery: June/2007

EURATOM, ENEA & ASG Personnell

SECTION OF PF2



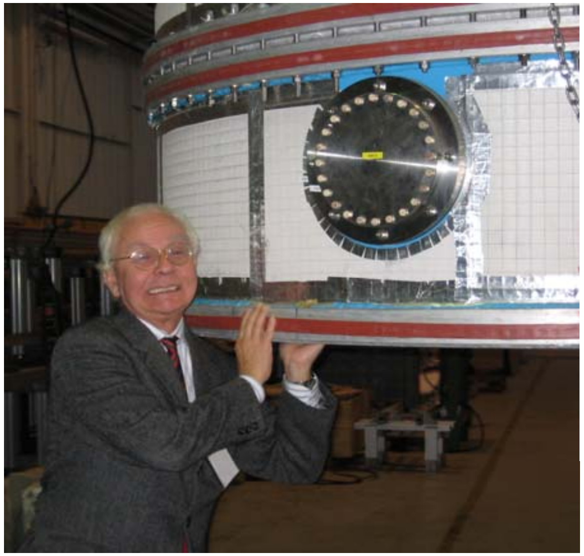
ProtoSphera Timetable

I.	Delivery of Load Assembly	* December 2009
II.	Power Supplies International Tender Action	* March 2010
III.	Delivery of Power Supplies	* June 2011
IV.	Site Preparation	* February 2010
V.	Services (Vacuum, Electricity, Diagnostics)	* June 2010
VI.	Commissioning	* September 2011
VII.	ProtoSphera Fase I Start	* September 2011

CONCLUSIONS

- The ProtoSphera Phase I&II design & construction has been properly done.
- There are medium/good probability to be able to avoide Filamente low lifetime & arc anchoring
- There is high degree of confidence that the formation and the stability of the PROTO-SPHERA initial arc will be achieved
- First Plasma can be obtained in September 2011
- PROTO-SPHERA Phase III can be obtained by simply adding PF coils to current configuration
- finally the LoadAssembly was a heavy task but ..

Load Assembly Heavy but Happy End

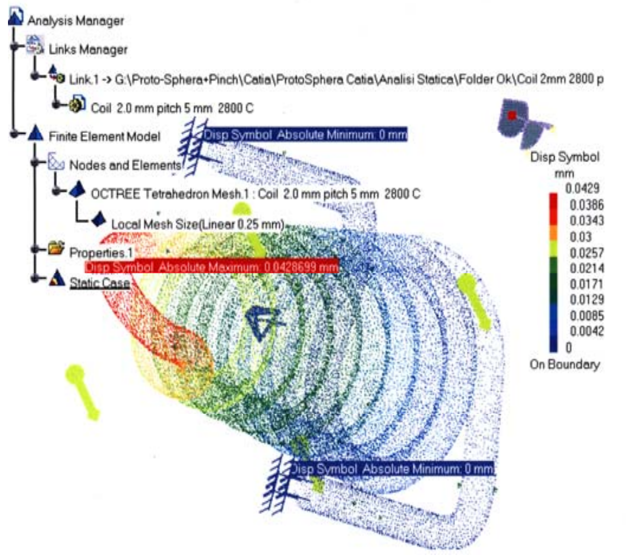


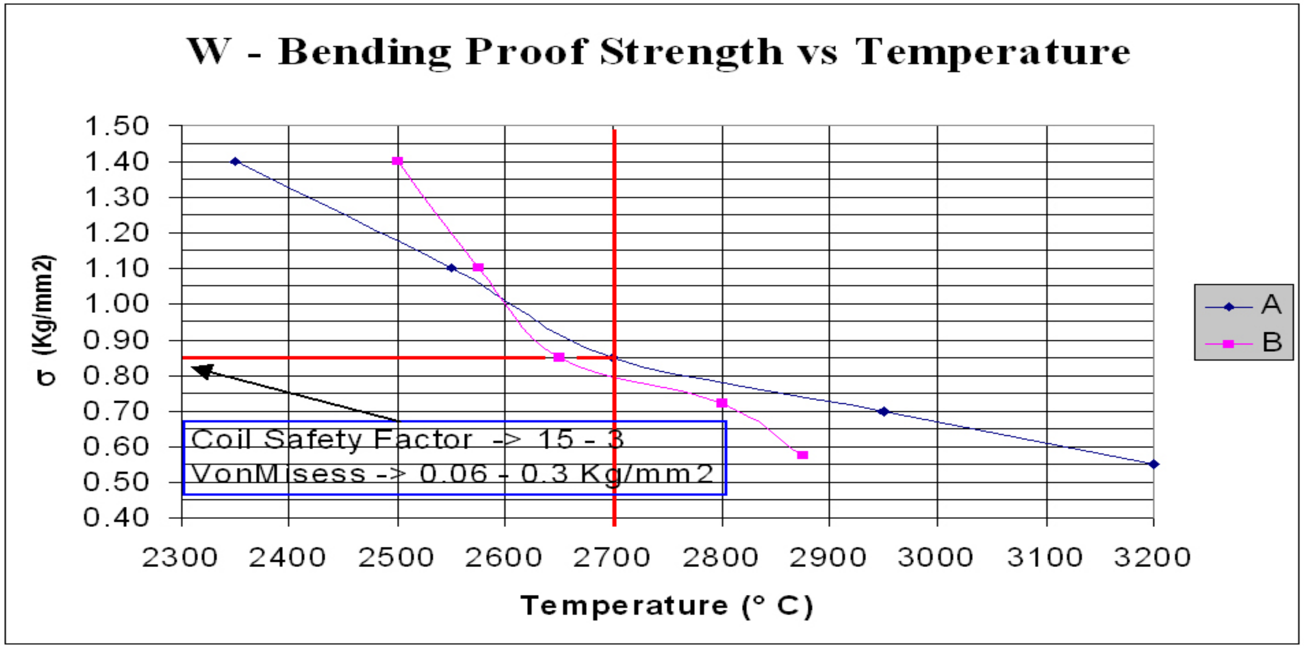
- Help to share load:

HeartlyWelcomed

- Subscrition list: Opened

Structural Analysis





- ➢Max VonMisess **Stress 0.16 Kg/mm^2**
- ➢Max Displacement **42.9 µm**
- ➢ **Coil Safety Factor = 5.3**

Electromagnetic Forces and Stresses

B=50T/s B=500G t≤1 ms

Subdivision of Cu and 304LN plates to achieve ≤100 MPa of eddy current stresses.

Unaccounted skin effects (t ~1ms) significant. Conservative prediction of eddy current effects.

Electromagnetic forces in the coils (~x10 weight) require to be sustained.

Predicted and Permitted Stresses

ASME III-NB 3221 Stainles Steel

Allowable S_m for 304LN 100°C : 200MPa [304L S_m~150MPa]

Predicted e-m stresses : 320MPa

Thermal local stresses : 320 MPa (2 MW/m^2 ,1s)

Criterion 1 : 100 <200x1.5

Criterion 2 : 100+320 <200x3

Copper

Minimum required allowable at 100°C> 70 MPa (100MPa<70x1.5)

Thus σ_y >115 Mpa and σ_u > 230 MPa at 20°C i.e. Cu hardenned

Thermal and Heat transfer Behaviour

- **Solution:**

1. Use of Cu componenets to collect or reflect the heat away from coils. Conservative (but symmetrical) design for the anode. Thermal mass of these components results in operational temperature < 100°C. Water cooled! Optimum design; i.e. one circuit/component, D~10-15mm, v~2m/s, duty cycle 5min.

2. Use of thermocouples in no water cooled componenets to avoid >100°C with frequent pulses; every 5min.

3. Use of 10mm divertor AISI 304LN plates. 2 MW/m^2 for 1 s gives $\Delta T \sim 120°C$, $\sigma_{th} \sim 320 MPa$

4. Use of optical diagnostics to view the electrodes which are relatively easily accessible.

Protection Componenets

•Thermal and Heat Transfer Behaviour

Philosophy: collect the heat (via radiation) from the electrodes to black resilient componenet and then conduct or radiate it away in a controlled way. Hot spots are thus avoided.
(Will be done in ProtoSphera with black copper oxidization)

Danger: the hot cathode (less the anode) radiates at 2750°C with ~3.5MW/m^2 and even a 10mm thick coil casing cannot sustain this power density for more than 0.5s without exceeding 100°C