

Harnessing the Sun's energy

Vojtěch Svoboda

18. listopadu 2011

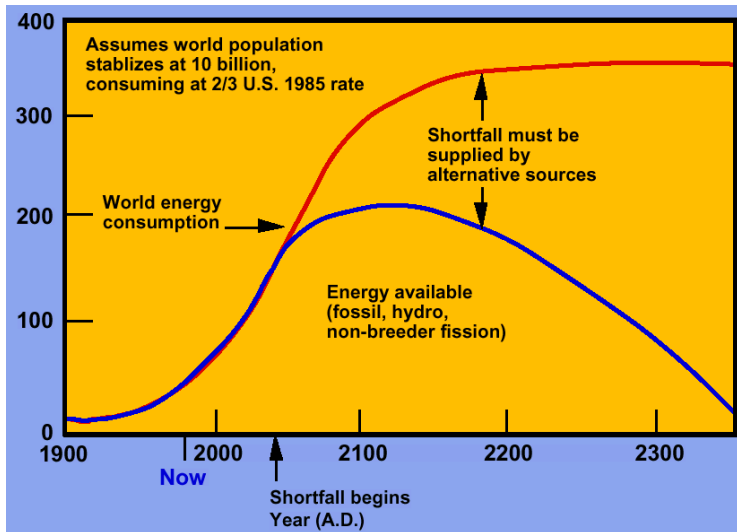
Outline of the talk

- 1 Introduction
- 2 Thermonuclear fusion
- 3 Tokamak GOLEM
- 4 Other Tokamaks

Content

- 1 Introduction
- 2 Thermonuclear fusion
- 3 Tokamak GOLEM
- 4 Other Tokamaks

Energy needs



The 1GW (approx. Prague) annual power requirement

Coal

250 trains



Oil

11 super tankers



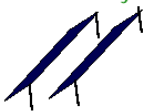
Fission

1.5 rail car load
Uranium Oxide



Solar

5000 acres of collectors
plus energy storage for
night and cloudy days

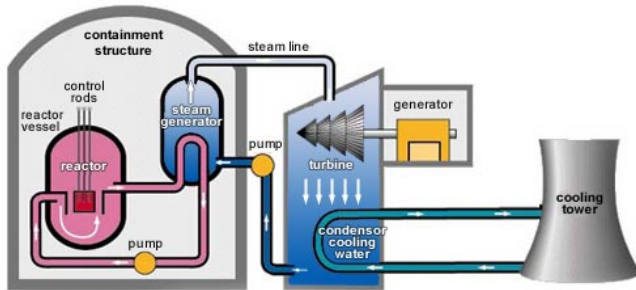


Fusion

1/2 ton pickup truck
Deuterium & Tritium



Thermal power plant - basic principle



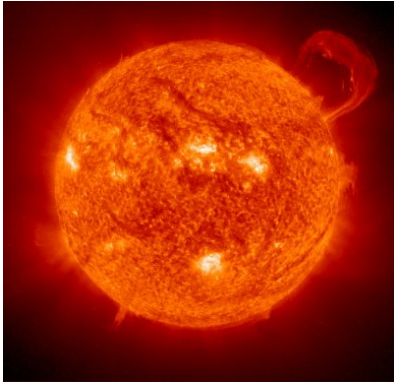
The question:

?? WHAT TO BURN ??

Content

- 1 Introduction
- 2 Thermonuclear fusion**
- 3 Tokamak GOLEM
- 4 Other Tokamaks

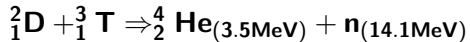
Harnessing the Sun's (star's) energy



Core Burning Stages in a 25 Solar Mass Star:

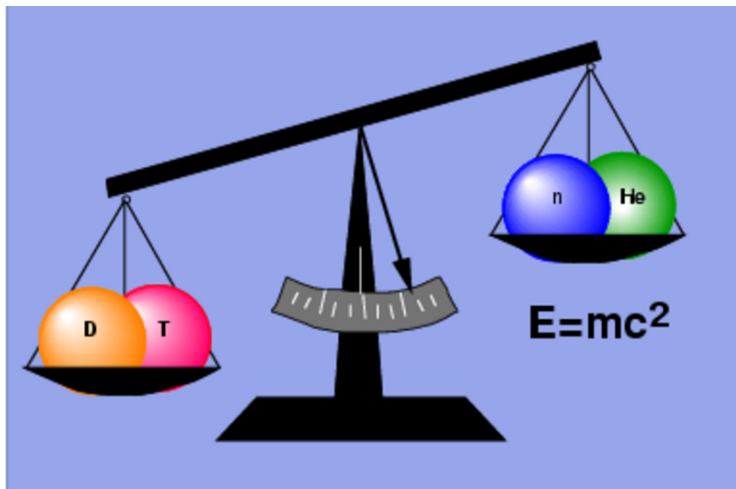
<u>Fuel:</u>	<u>Products:</u>	<u>Temperature</u> <u>(K):</u>	<u>Minimum</u> <u>Mass:</u>	<u>Burning</u> <u>Period:</u>
H	He	4×10^6	0.1	7×10^6 years
He	C, O	1.2×10^8	0.4	5×10^5 years
C	Ne, Na, Mg, O	6×10^8	4	600 years
Ne	O, Mg	1.2×10^9	~8	1 year
O	Si, S, P	1.5×10^9	~8	~0.5 years
Si	Ni - Fe	2.7×10^9	~8	~1 day

On the Earth the most feasible candidate:

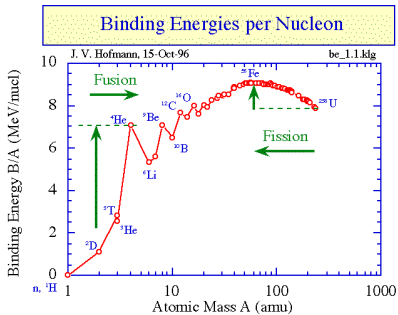
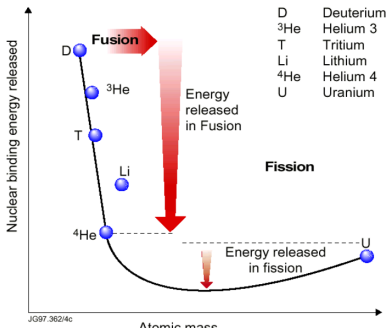


→ Confine & Heat & Measure ←

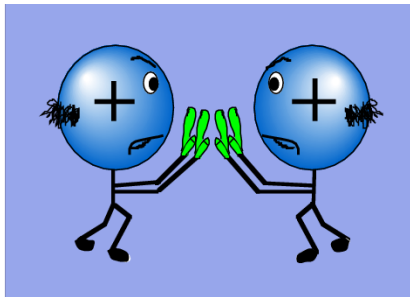
Binding energy releasing I



Binding energy releasing II

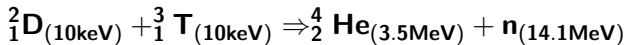


Problem: Like charges repel

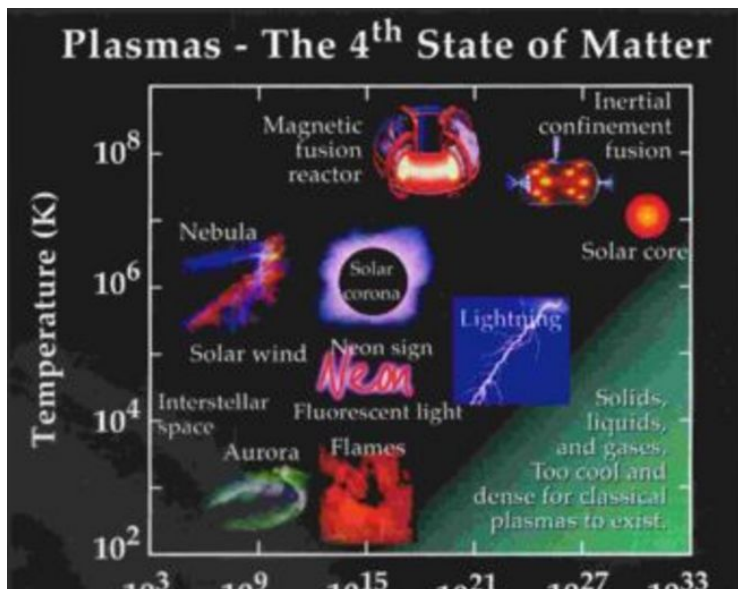


- Coulomb law:

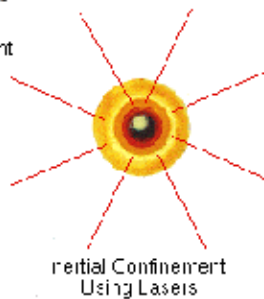
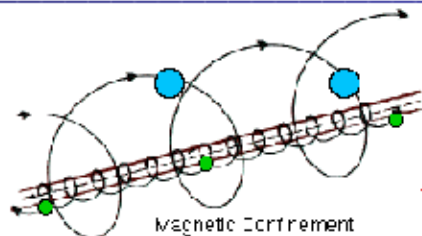
$$F_E = \frac{1}{4\pi\epsilon_0} \frac{Q_1 Q_2}{r^2}$$



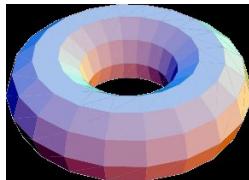
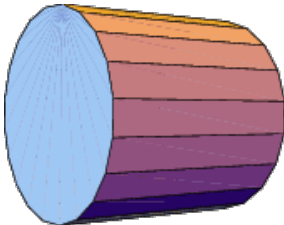
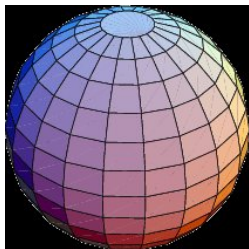
Plasma



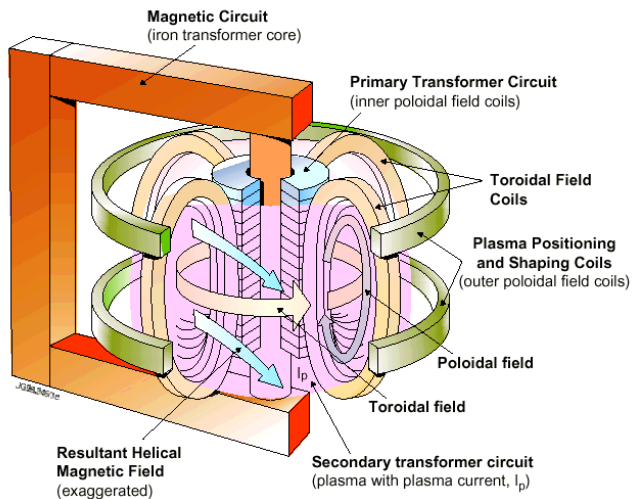
Three ways to confine plasma



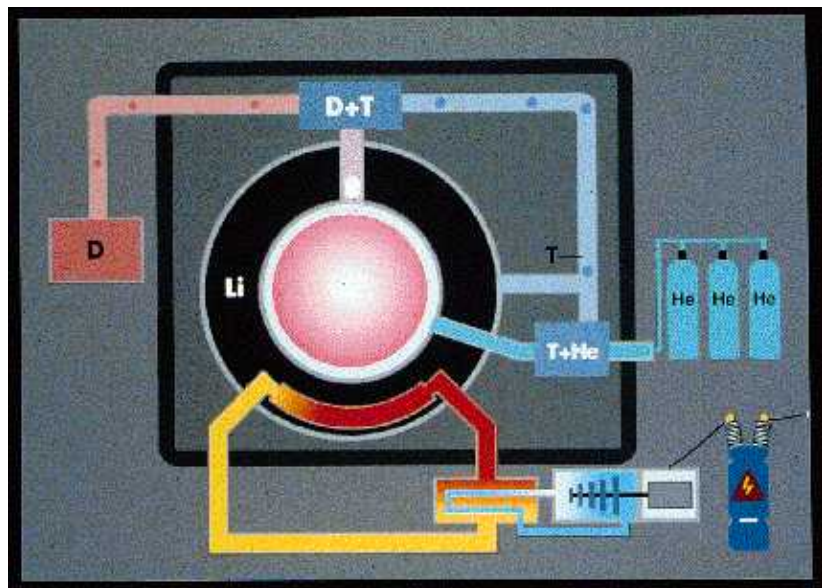
Confinement geometry?



Magnetic confinement - Tokamak



Future reactor



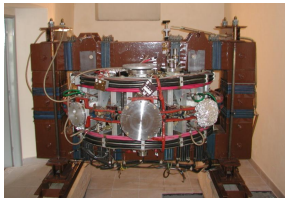
Content

- 1 Introduction
- 2 Thermonuclear fusion
- 3 Tokamak GOLEM**
- 4 Other Tokamaks

Tokamak GOLEM for Education - Historical Background

Kurchatov Institute near Moscow,
Soviet Union
1960: **TM1-MH**

Culham Centre for Fusion Energy
Great Britain
1989: **COMPASS-D**



1974

2006

Institute of Plasma Physics
Czech republic
CASTOR **COMPASS**

2006: new curricula at FNSPE:
**Physics and Technology
of Thermonuclear Fusion**

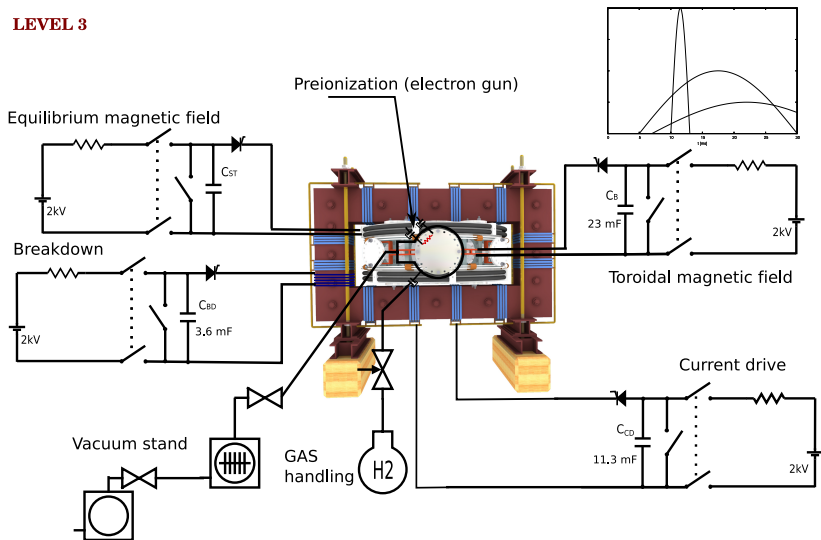
2008

Czech Technical University Prague
Czech republic
GOLEM

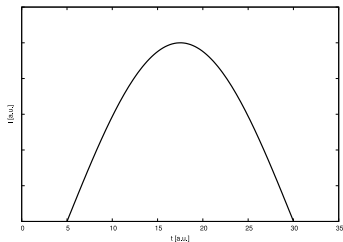
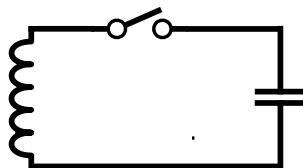
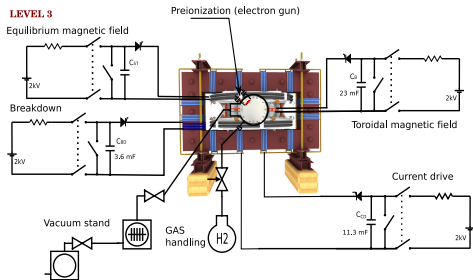
?virtual or real experiments?

Tokamak GOLEM - engineering scheme

LEVEL 3

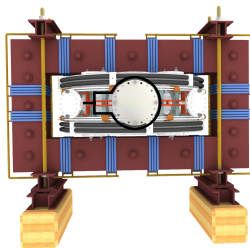


Insertion - LC circuit



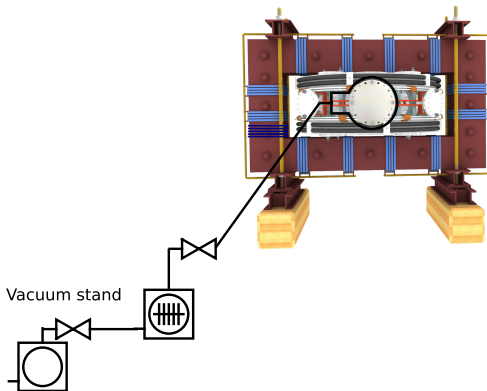
Tokamak GOLEM - basic

LEVEL 0



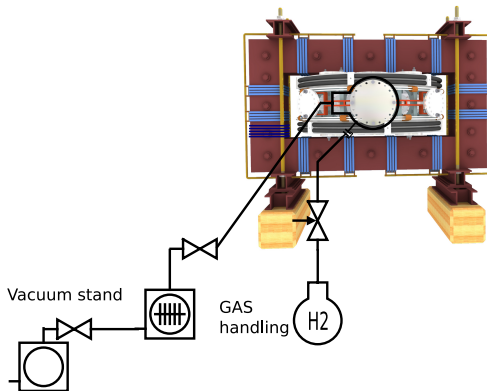
Tokamak GOLEM + vacuum pumping system (100 kPa → 1 mPa)

LEVEL 0



Tokamak GOLEM + working gas management (H₂ or He)

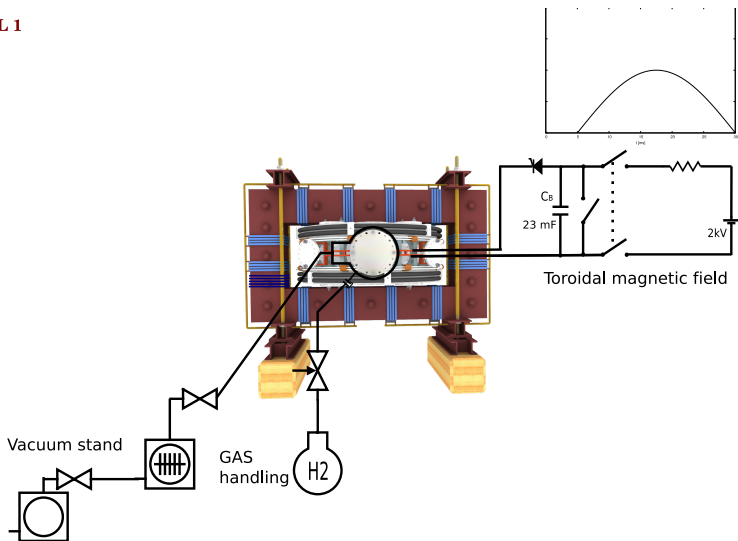
LEVEL 0



Tokamak GOLEM + B (toroidal magnetic field)

Plasma confinement

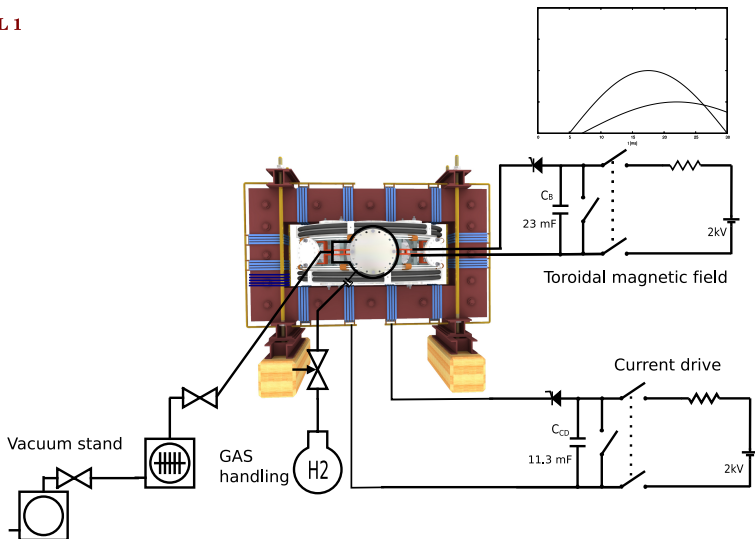
LEVEL 1



Tokamak GOLEM + CD (toroidal electric field)

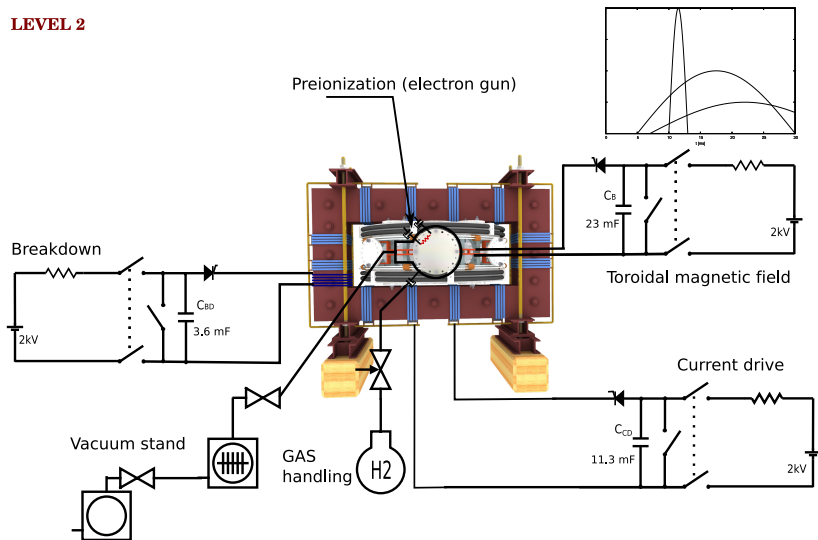
Plasma heating

LEVEL 1



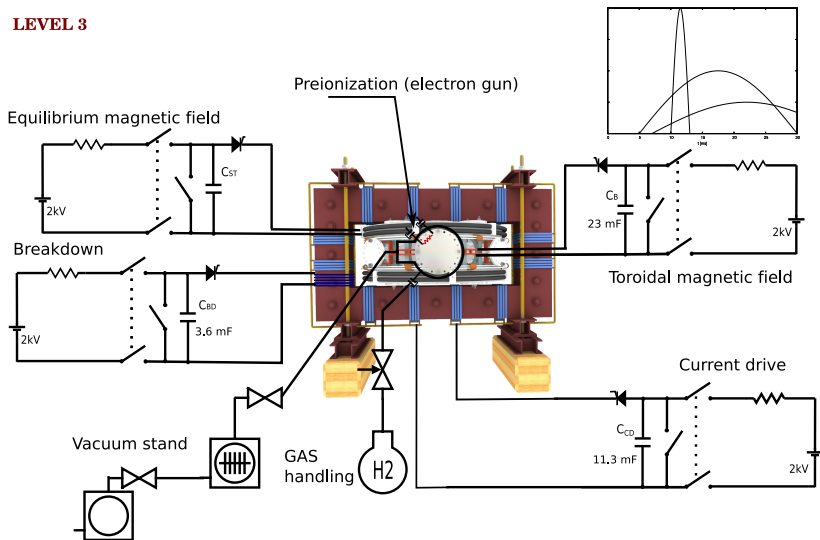
Tokamak GOLEM + breakdown the neutral gas plasma creation

LEVEL 2

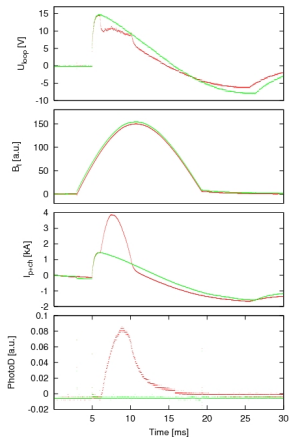
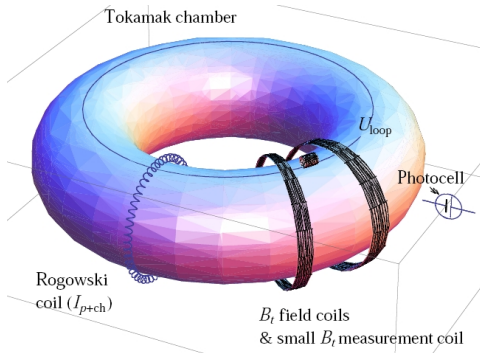


Tokamak GOLEM + plasma stabilization vertical magnetic field

LEVEL 3



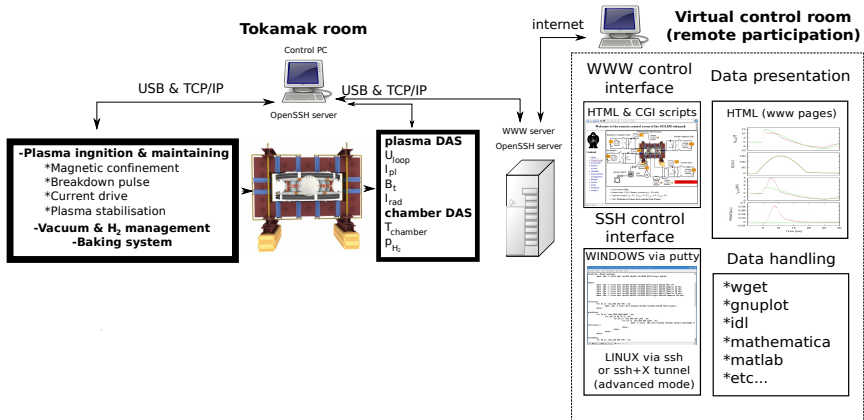
Basic plasma diagnostics in tokamak GOLEM



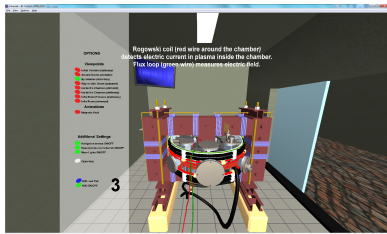
Data Acquisition System based on:



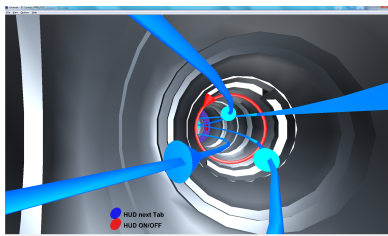
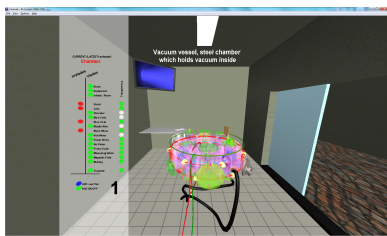
Unique remote operation capability



The GOLEM tokamak virtual model



Tokamak Room & Infrastructure Room



Inner view & Inside chamber

The GOLEM tokamak virtual Control Room

http://golem.fjfi.cvut.cz/CR/V1/events/PROMOTION/1011IBA2011/exp_L1.php

Tokamak Golem ****VIRTUALLY**** for IBA2011

Home

Control Room **L1** **L2** **L3**

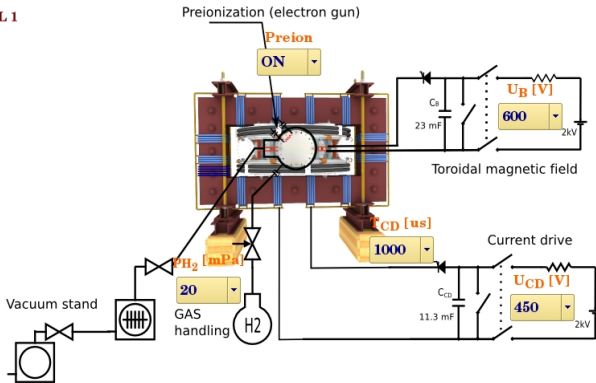
Queue

Live

Results

Manual **R**

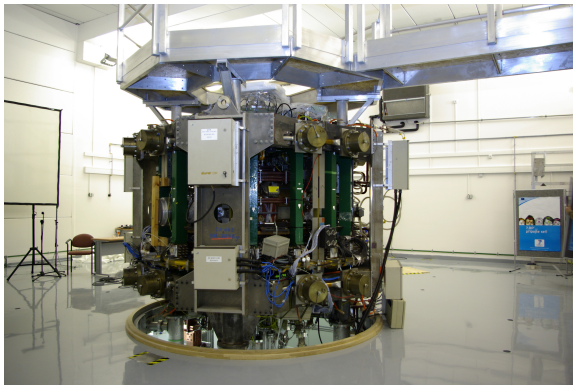
LEVEL 1



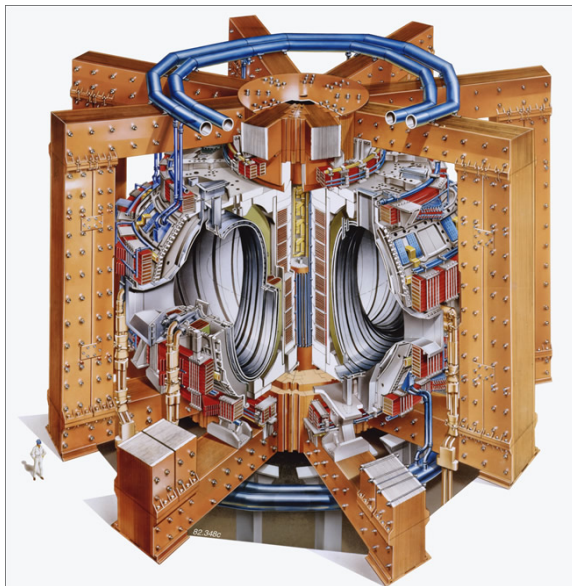
Content

- 1 Introduction
- 2 Thermonuclear fusion
- 3 Tokamak GOLEM
- 4 Other Tokamaks**

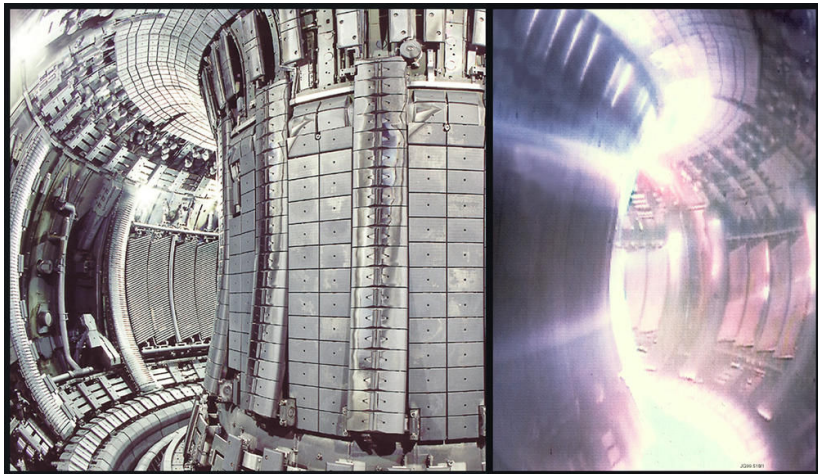
Compass



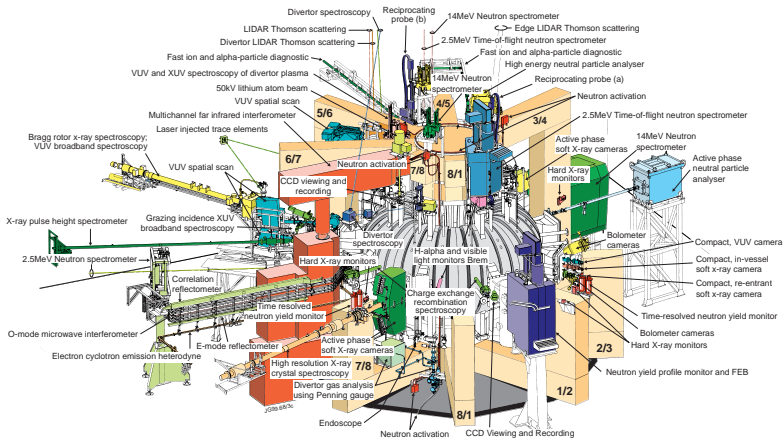
JET



Plasma discharge in tokamak



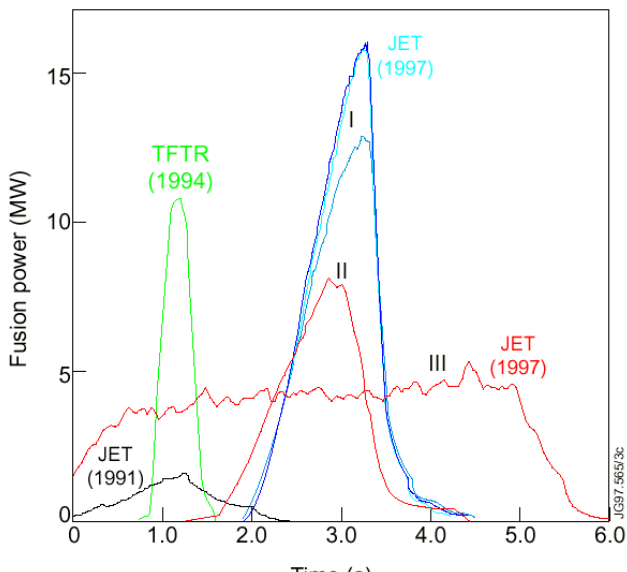
Joint European Torus (diagnostics)



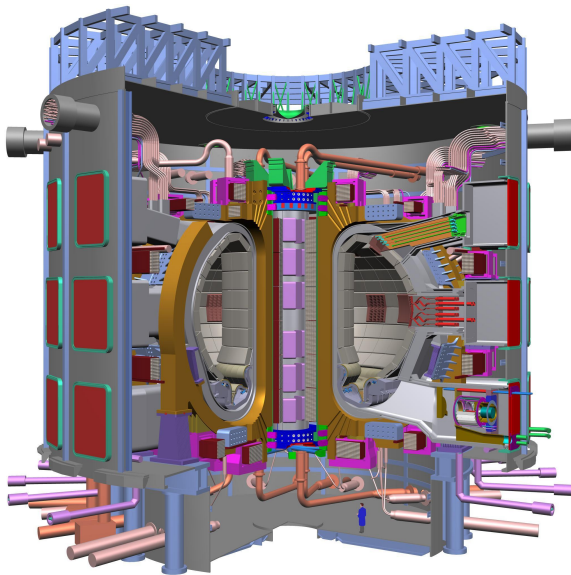
The challenge of characterising extreme conditions of nuclear fusion plasmas both spatially and temporally has inspired JET to produce an impressive array of diagnostic techniques. Drawing from fields as diverse as neutronics, spectroscopy, lasers and microwaves, JET is a leader in the art of measurement."

Andrea Murari, Task Force Leader - Diagnostics.

Fusion power at the JET (DT fuel)



ITER



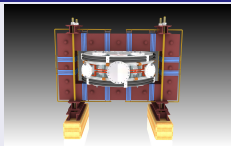
14.9.2009; ČVUT; PRAHA ...



Winter school of Plasma Physics - Marianska 2011 (Tokamak, probably COMPASS, with NBI)



Thank you for your attention



<http://golem.fjfi.cvut.cz>,
you and your students are welcome