

Introduction to the tokamak operation (GOLEM specific) - Level 1

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on behalf of the tokamak GOLEM team
for the TU Eindhoven, Netherlands

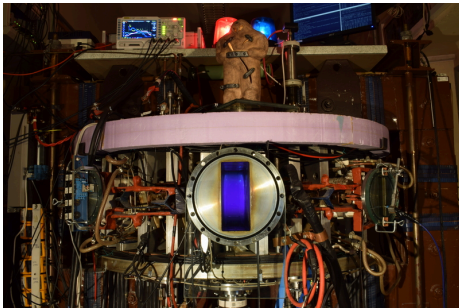
March 29, 2022

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- 2 The Tokamak (GOLEM)
- 3 The Tokamak GOLEM (remote) operation
- 4 Conclusion
- 5 Appendix

The GOLEM tokamak basic characteristics

The grandfather of all tokamaks (ITER newslines 06/18)



- Vessel major radius: $R_0 = 0.4$ m
- Vessel minor radius: $r_0 = 0.1$ m
- Maximum plasma current:
 $I_p^{\max} < 8$ kA
- Maximum toroidal magnetic field: $B_t^{\max} < 0.5$ T
- Typical electron density:
 $\langle n_e \rangle \in (0.2, 3) \cdot 10^{19} \text{ m}^{-3}$
- Maximum electron temperature:
 $T_e^{\max} < 80$ eV
- Maximum discharge duration:
 $\tau_p^{\max} < 25$ ms

Tokamak GOLEM @ Wikipedia ..

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home Kalendarj Produkce Forecast Slovnik Rano

Wikipedia logo

WIKIPEDIA
The Free Encyclopedia

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Tokamak

From Wikipedia, the free encyclopedia

This article is about the fusion reaction device. For other uses, see [Tokamak \(disambiguation\)](#).

A **tokamak** (Russian: **токамак**) is a device that uses a powerful magnetic field to confine plasma in the shape of a torus. Achieving a stable plasma equilibrium requires magnetic field lines that move around the torus in a helical shape. Such a helical field can be generated by adding a toroidal field


it decays into a proton and electron with the emission of energy. When the time comes to actually try to make electricity from a tokamak-based reactor, some of the neutrons produced in the fusion process would be absorbed by a liquid metal blanket and their kinetic energy would be used in heat-transfer processes to ultimately turn a generator.

Experimental tokamaks [edit]


Currently in operation [edit]

(in chronological order of start of operations)

- 1960s: TМ1-MH (since 1977 Castor; since 2007 Golem^[12]) in Prague, Czech Republic. In operation in Kurchatov Institute since early 1960s but renamed to Castor in 1977 and moved to IPP CAS,^[13] Prague; in 2007 moved to FNSPE, Czech Technical University in Prague and renamed to Golem.^[14]
- 1975: T-10, in Kurchatov Institute, Moscow, Russia (formerly Soviet Union); 2 MW
- 1983: Joint European Torus (JET), in Culham, United Kingdom
- 1985: JT-60, in Naka, Ibaraki Prefecture, Japan; (Currently undergoing upgrade to Super, Advanced model)
- 1987: STOR-M, University of Saskatchewan; Canada; first demonstration of alternating current in a tokamak.
- 1988: Tore Supra,^[15] at the CEA, Cadarache, France
- 1989: Aditya, at Institute for Plasma Research (IPR) in Gujarat, India
- 1980s: DIII-D,^[16] in San Diego, USA; operated by General Atomics since the late 1980s
- 1989: COMPASS,^[13] in Prague, Czech Republic; in operation since 2008, previously operated from 1989 to 1999 in Culham, United Kingdom
- 1990: FTU, in Frascati, Italy
- 1991: Tokamak ISTTOK,^[17] at the Instituto de Plasmas e Fusão Nuclear, Lisbon, Portugal;
- 1991: ASDEX Upgrade, in Garching, Germany

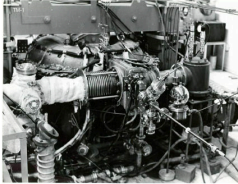


Alcator C-Mod



The GOLEM tokamak for education - historical background

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



1974



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



2006



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



2008



Czech Technical University Prague
Czech republic
GOLEM



GOLEM

... somewhere, in the ancient cellars of Prague,

there is hidden indeed "infernal" power. Yet it is the very power of celestial stars themselves. Calmly dormant, awaiting mankind to discover the magic key, to use this power for their benefit. . .

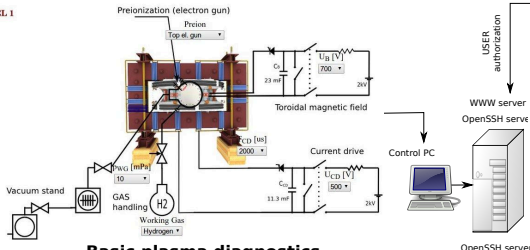


At the end of the 16th century, in the times when the Czech lands were ruled by Emperor Rudolf II, in Prague, there were Rabbi Judah Loew, well known alchemist, thinker, scholar, writer and inventor of the legendary GOLEM - a clay creature inspired with the Universe power that pursued his master's command after being brought to life with a shem, . Golem is not perceived as a symbol of evil, but rather as a symbol of power which might be useful but is very challenging to handle. To learn more of the Golem legend, see e.g. [1].

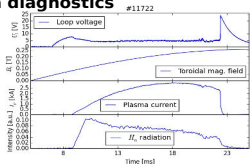
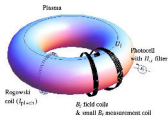
The global schematic overview of the GOLEM experiment

LEVEL 1

Tokamak technology setup



Basic plasma diagnostics



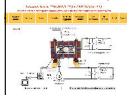
internet



**Virtual control room
(remote participation)**

WWW control interface

HTML & PHP scripts



SSH control interface

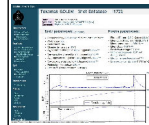
WINDOWS via putty



LINUX via ssh
or ssh+X tunnel
(advanced mode)

Data presentation

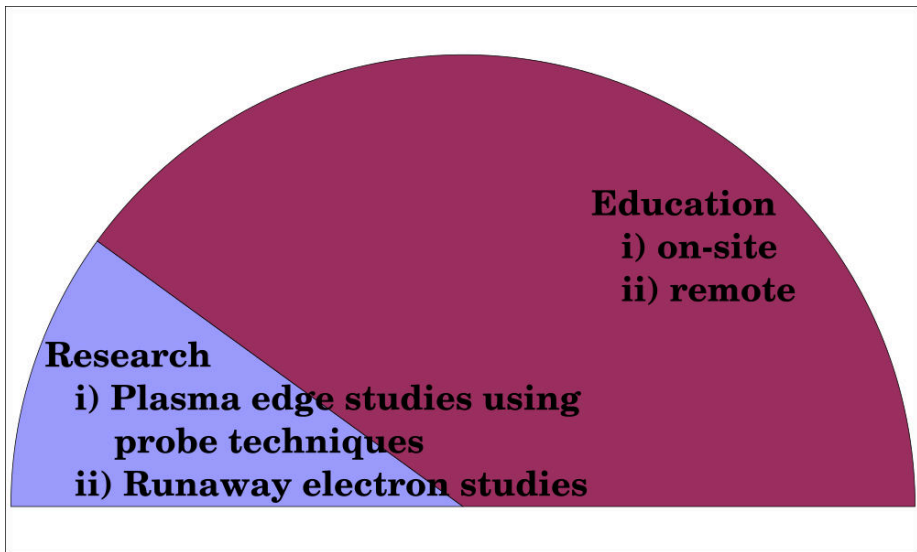
HTML (www pages)



Data handling

- *wget
- *gnuplot
- *idl
- *mathematica
- *matlab
- *etc...

The GOLEM tokamak mission



- Everything via <http://golem.fjfi.cvut.cz/Eindhoven>
 - This presentation
 - Control rooms
 - Contact: Vojtech Svoboda,
+420 737673903,
svoboda@fjfi.cvut.cz
 - Chat:
tokamak.golem@gmail.com or
skype: tokamak.golem

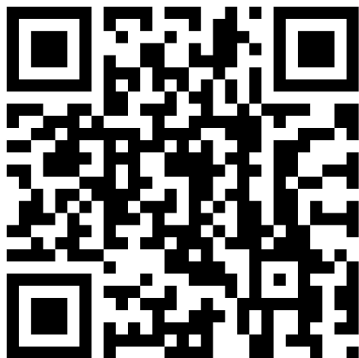
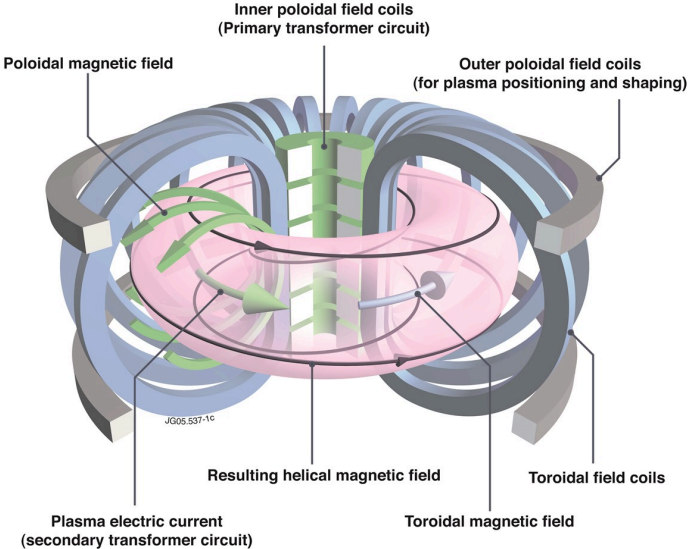


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Tokamak magnetic confinement concept



Tokamak (GOLEM) basic concept to confine and heat the plasma

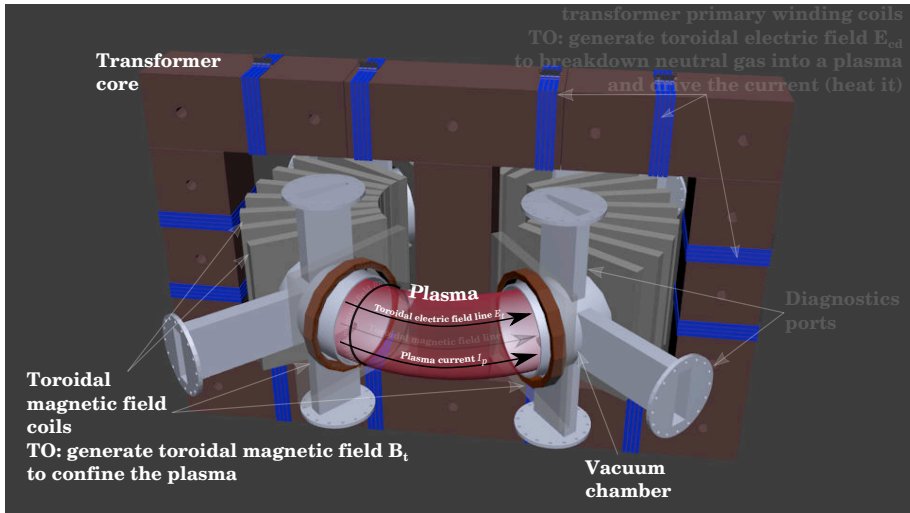


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- The GOLEM tokamak - guide tour

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The GOLEM tokamak - basic diagnostics

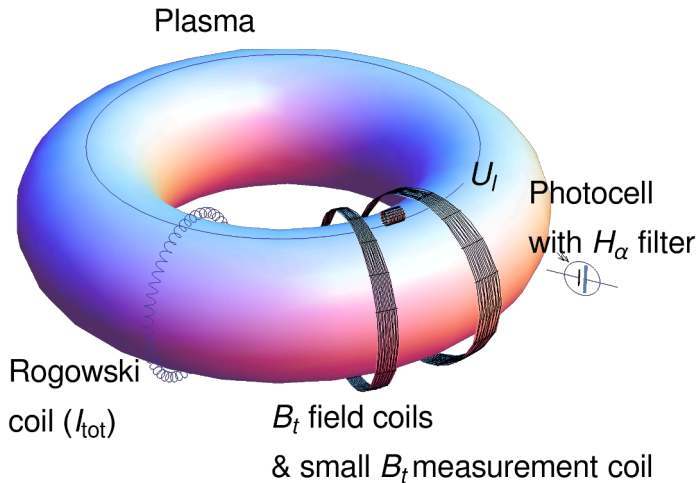


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Infrastructure room (below tokamak) 10/16



Infrastructure room (below tokamak) 10/16

Current drive CD field
and toroidal magnetic Bt field
circuits

To the tokamak
GOLEM

Rotary
pump

Vacuum
control

Current drive CD
capacitors

Plasma
stabilization

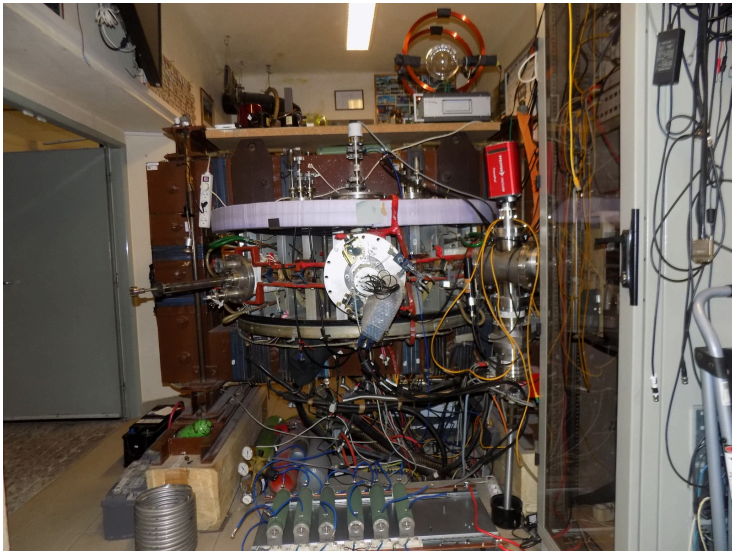
power
supply
2kV

Toroidal
magnetic field B
capacitors

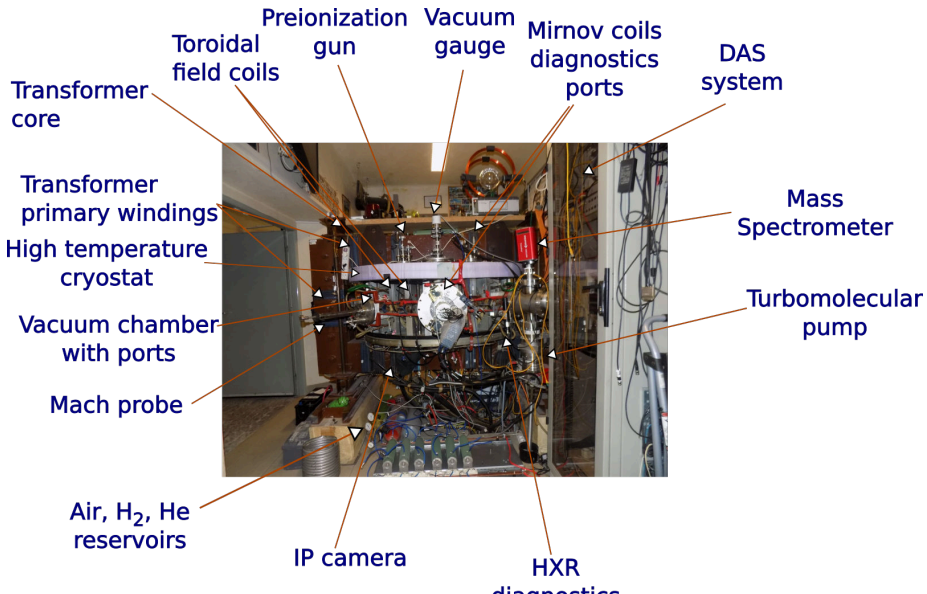
fire
protection
system



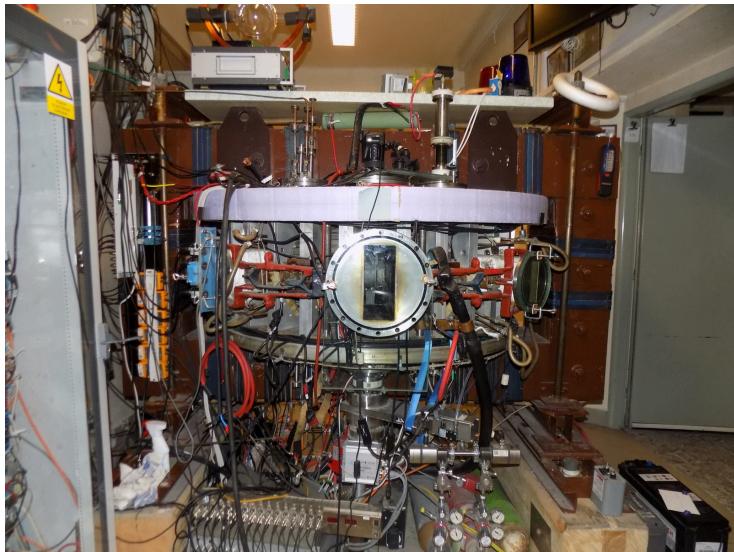
Tokamak room (North) 10/16



Tokamak room (North) 10/16



Tokamak room (South) 10/16



Tokamak room (South) 10/16

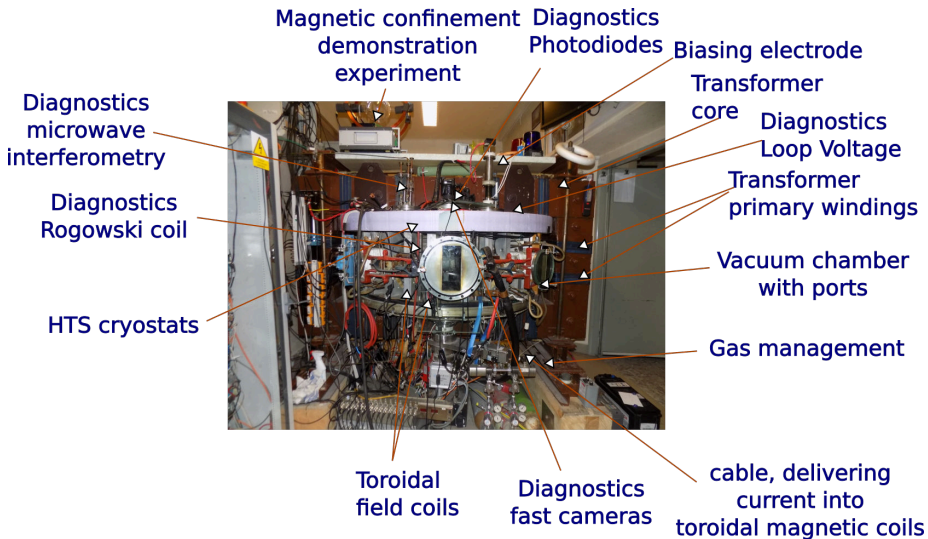


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Control room: Introduction

GOLEM remote Introduction **Control room** Live Results

Prague Access: Level 1 Help

Introduction Working gas Preionization Magnetic field Current drive Submit

This web interface will walk you through the process of configuring a discharge in the GOLEM tokamak. All settable values are perfectly safe. Proceed through each step by setting the desired values and then clicking the [Next](#) button. You can always go to a specific step by clicking its tab.

Preionization (electron gun)

Vacuum stand

Preionization (electron gun)

Toroidal magnetic field

Current drive

GAS handling

C_g 23 mF

C_0 11.3 mF

2kV

2kV

[Next](#)

3D model rendering method: [Static image \(fast\)](#) [Interactive X3DOM \(slower\)](#)

Control room: Working gas

GOLEM remote Introduction Control room Live Results

Introduction Working gas Preionization Magnetic field Electric field Submit

Set the pressure and type of the working gas from which the plasma is formed. Pressure must be high enough for plasma to form, but low enough for gas breakdown to occur.

Preionization (electron gun)

Vacuum stand

Toroidal magnetic field

Toroidal electric field

GAS handling

H_2/H_9

Gas type and pressure p_{gas} : 38 mPa

Hydrogen Helium

Next Set recommended value

3D model rendering method Static image (best) Interactive X3DOM (preview)

Control room: Preionization

GOLEM remote Introduction Control room Live Results

Introduction Working gas Preionization Magnetic field Electric field Submit

The neutral working gas must first be ionized in order to break down into a plasma. Using the electron gun will locally ionize the gas. Without any ionization, no plasma can form.

Preionization (electron gun)

Vacuum stand

GAS handling

Toroidal magnetic field

Toroidal electric field

67.5 mF

13.5 mF

20V

20V

ionization method

Electron gun No ionization

Next

3D model rendering method Static image (best) Interactive X3DOM (viewer)

Control room: Magnetic field B_t

GOLEM version: Introduction Control room Live Results

Press F11 to exit full screen
3D model rendering method: Static image (best) Interactive X3DOM (viewer)

Introduction Working gas Preionization **Magnetic field** Electric field Submit

Set the voltage on the capacitors to be discharged into the toroidal field coils. The higher the voltage, the larger the magnetic field confining the plasma.

Preionization (electron gun)

Vacuum stand

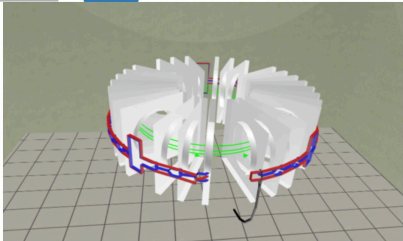
Toroidal magnetic field

Toroidal electric field

GAS handling

Capacitor voltage $U_{C_2} = 600$ V

Next Set recommended value



Control room: Current drive E_{cd}

GOLEM remote Introduction Control room Live Results

the Torneo Politecnico, Italy Group 1 Access: Level 2 Help

Introduction Working gas Preionization Magnetic field **Electric field** Submit

Set the voltage on the capacitors to be discharged into the [primary transformer winding](#). The higher the voltage, the larger the electric field creating and heating the plasma. The electric field capacitors are discharged after a configurable delay with respect to the magnetic field capacitors.

Preionization (electron gun)

Vacuum stand

Toroidal magnetic field

Toroidal electric field

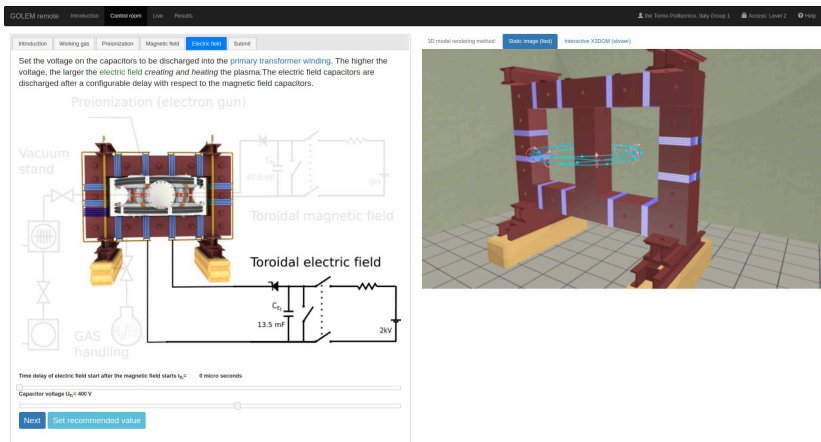
GAS handling

Time delay of electric field start after the magnetic field starts t_{cd} : 0 micro seconds

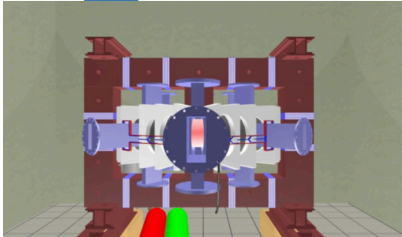
Capacitor voltage U_{cd} : 400 V

Next Set recommended value

3D model rendering method Static image (best) Interactive X3DOM (viewer)



Control room: ... and Submit



The screenshot displays the GOLEM control room interface. At the top, a navigation bar includes 'GOLEM remote', 'Introduction', 'Control room', 'Live', and 'Results'. On the right, it shows the user 'The Torneo Politecnico, Italy Group 1', the current level 'Access: Level 2', and a 'Help' icon.

The main content area is divided into two sections. The left section is a form titled 'Submit'. It features a tabbed interface with 'Introduction', 'Working gas', 'Preionization', 'Magnetic field', 'Electric field', and 'Submit' (which is currently selected). Below the tabs, there is a text input field with the instruction: 'Write a comment describing your discharge configuration, i.e. the scientific aim of your experiment. Or just leave a friendly message.' Below the input field is a 'COMMENT' label and a text box. Further down, there is a 'Submit' button and a note: 'Click the Submit button to send your configuration into the queue.' Below this note are two buttons: 'Watch the discharge live!' and 'Go back to introduction'. At the bottom of the form, there is a 'Submit' button.

The right section is titled '3D model rendering method' and contains two tabs: 'Static image (best)' (selected) and 'Interactive X3DOM (slower)'. Below the tabs is a 3D rendering of the tokamak device, showing a central vacuum chamber surrounded by complex magnetic coils and support structures. The device is mounted on a base with red and green components visible at the bottom.

Shot homepage

GOLEM » Shot #22471 »



Diagnostics

- ✓ Interferometer
- ✓ Spectrometer
- ✗ FastCamera
- ✓ HXR

Analysis

- ✓ ShotHomepage

DAS

- ✓ TektronixDPO
- ✓ Nistandard
- ✓ Papouch_St
- ✓ Papouch_Ko
- ✓ Nloctopus

Vacuum log

Other

- Data
- References
- About
- Wiki
- Utilities

Navigation

- Next
- Previous
- Current

Tokamak GOLEM - Shot Database - 22471

Date: 2016-09-29 - 14:33:57
Session: TrainingCourses/Universities/Uni_Belgrade.rs/2016/
Comment: Standard discharge

Basic parameters: (compare)

- Gas pressure p_{ch} : 0.42->20.39 mPa (request: 20 mPa) [WIKI](#)
- Working gas: H
- Preionization: Upper el. gun
- Chamber temperature: 27.20 C
- C_B capacitors charged to: 800 V, triggered 5.0 ms [WIKI](#)
- C_{BD} capacitors charged to: 0 V, triggered 5.0 ms [WIKI](#)
- C_{CD} capacitors charged to: 400 V, triggered 6.0 ms [WIKI](#)
- C_{ST} capacitors charged to: 0 V, triggered 5.0 ms [WIKI](#)
- Probability of breakdown: 85% [WIKI](#)
- Time since session beginning: 0:07:50 h

Plasma parameters:

- Plasma life time 14.8 [ms] (from 7.8 to 22.6)
- Mean toroidal magnetic field B_t : 0.23 T [WIKI](#)
- Mean plasma current: 3.60 kA [WIKI](#)
- Mean Uloop: 5.92 V [WIKI](#)
- Break down voltage: 9.6 V [WIKI](#)
- Ohmic heating power: 21.33 kW
- Q edge: 2.9 [WIKI](#)
- Electron temperature: 41.1 eV [WIKI](#)
- Line electron density: 5.52 [$10^{17} m^{-2}$] [WIKI](#)

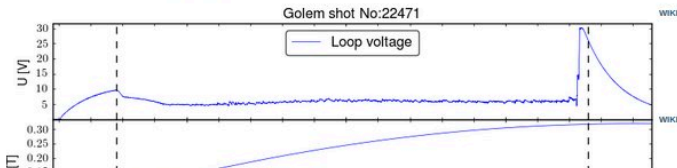


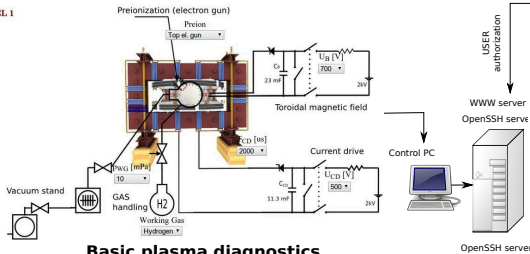
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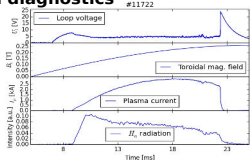
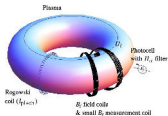
The global schematic overview of the GOLEM experiment

LEVEL 1

Tokamak technology setup



Basic plasma diagnostics



internet

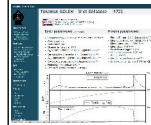
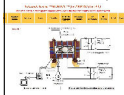
**Virtual control room
(remote participation)**

WWW control interface

Data presentation

HTML & PHP scripts

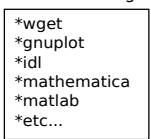
HTML (www pages)



SSH control interface

WINDOWS via putty

Data handling



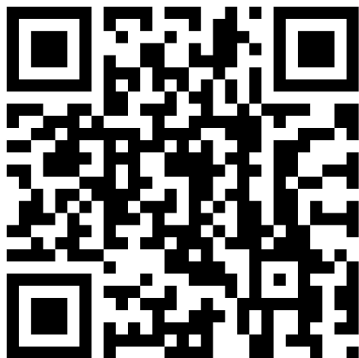
LINUX via ssh or ssh+X tunnel (advanced mode)

WWW server
OpenSSH server

OpenSSH server

Control PC

- Everything via <http://golem.fjfi.cvut.cz/Eindhoven>
 - This presentation
 - Control rooms
 - Contact: Vojtech Svoboda,
+420 737673903,
svoboda@fjfi.cvut.cz
 - Chat:
tokamak.golem@gmail.com or
skype: tokamak.golem



Fee: postcard from the venue of remote measurements



Acknowledgement

Financial support highly appreciated:

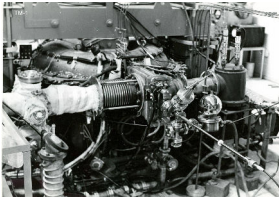
CTU RVO68407700, SGS 17/138/OHK4/2T/14, GAČR GA18-02482S, EU funds CZ.02.1.01/0.0/0.0/16_019/0000778 and CZ.02.2.69/0.0/0.0/16_027/0008465, IAEA F13019, FUSENET and EUROFUSION.

Students, teachers, technicians (random order):

Vladimír Fuchs, Ondřej Grover, Jindřich Kocman, Tomáš Markovič, Michal Odstrčil, Tomáš Odstrčil, Gergo Pokol, Igor Jex, Gabriel Vondrášek, František Žáček, Lukáš Matěna, Jan Stockel, Jan Mlynář, Jaroslav Krbec, Radan Salomonovič, Vladimír Linhart, Kateřina Jiráková, Ondřej Ficker, Pravesh Dhyani, Juan Ignacio Monge-Colepicolo, Jaroslav Čerovský, Bořek Leitl, Martin Himmel. Petr Švihra, Petr Mácha, Vojtěch Fišer, Filip Papoušek, Sergei Kulkov, Martin Imříšek.

Thank you for your attention

Tokamak TM1
@Kurchatov Institute near Moscow
~1960-1977



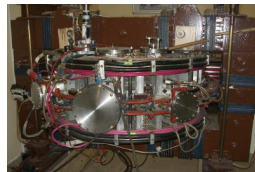
SCIENCE

Tokamak CASTOR
@Institute of Plasma Physics, Prague
1977-2007



SCIENCE
& education

Tokamak GOLEM
@Czech Technical University, Prague
2007-



EDUCATION
& science

... with the biggest
control room
in the world ..

Tokamak Golem **REMOTE for MASTER (Level 1)**
The smallest & oldest operational tokamak with the biggest control rooms in the world

Home	Wiki	Control Room	Queue	Live	Results	GOLEM Diagram	Chamber status	IP cameras	3D model	Chat	Feedback	Logout
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LEVEL 1

Preionization (electron gun)
Proton

Toroidal magnetic field

Current drive

Vacuum stand

GAS handling

Working Gas





Discharge comment

Place the discharge setup into the queue

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References I

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-  V. Svoboda, B. Huang, J. Mlynar, G.I. Pokol, J. Stockel, and G Vondrasek. Multi-mode Remote Participation on the GOLEM Tokamak. *Fusion Engineering and Design*, 86(6-8):1310–1314, 2011.
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