

## 5 let tokamaku GOLEM na FJFI ČVUT

**Vojtěch Svoboda, et al.**



- 1 Úvod
- 2 Cesta tokamaku GOLEM na FJFI ČVUT
- 3 Ovládání tokamaku GOLEM
- 4 Významné milníky
- 5 Vědecké projekty
- 6 Poděkování

# Tokamak & Tokamak (X.9.2009)



# Základní (řádková) statistika k 30.11.2012

Počet dní od instalace: 1815.

Počet operačních dní:  $\approx 438$ .

Počet hodin:  $\approx 1954$ .

Počet shotů: 10417.

Počet shotů –  $\rightarrow$  plazma:  $\approx 7600$ .

Průměrná délka výboje:  $\approx 7$  ms.

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Průměrná délka výboje:  $\approx 7$  ms.

**Celková delka trvání plazmatu:  $< 60$  s.**

# FTTF - sněhové kreace (2010)



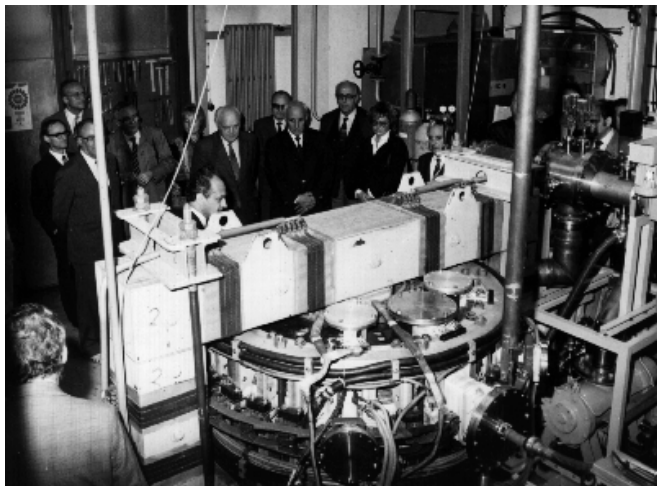
# FTTF - sněhové kreace (2011)



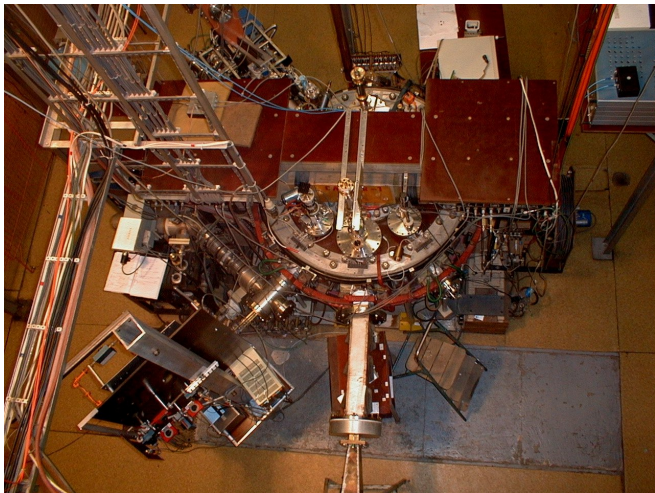
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# Tokamak CASTOR (1974)



# Tokamak CASTOR (1977-2007)



# Rozebrání tokamaku CASTOR (11.2007)



# Stěhování, na UFP AV ČR (12.12.2007)



# Stěhování, na Břehovce (12.12.2007)



# Pod stanem (12.2007-06.2008)



# Na novém místě (X.5.2008)



# První exkurze (4.6.2008)





# První plazma v magnetickém udržení (8.7.2009)

## Golem shot: 4

2009-07-08 -

Basic parameters:

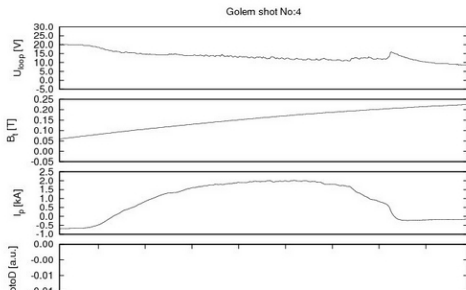
- Chamber pressure:  $\rightarrow$  mPa ()
- Chamber temperature: grad C
- Time delay: [us]
- $B_t$  capacitors ( mF) charged to: 636 V ([charging log -t,Ub\(t\),Ue\(t\)](#))
- $E_t$  capacitors ( mF) charged to: 212 V ([charging log -t,Ub\(t\),Ue\(t\)](#))
- Time since [session](#) beginning: s

Plasma parameters:

- Plasma life from 6.76 over 2.74 to 9.50 [ms]
- Mean toroidal magnetic field  $B_t$ : 0.153 T
- Mean plasma current: 1.6 kA
- Mean Uloop: 13.1 V
- Break down voltage: 20.1 V
- Plasma total charge: 4.3 C
- Ohmic heating power: 21.0 kW
- Q edge: 8.6
- Central electron temperature: 10.0 eV

Data (sampling interval  $T_s=100$  kHz):

- [Raw data \( \$U\_{loop}, B\_t, I\_p, U\_{photo}, C\$ \)](#)
- DAS data processing evolution: [raw](#)  $\rightarrow$  [integrated](#)  $\rightarrow$  [final](#)



# Inaugurace tokamaku GOLEM (X.9.2009)



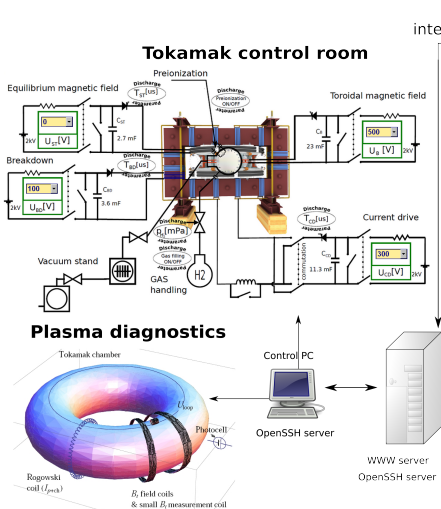
# GOLEM?



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# Schéma vzdáleného řízení



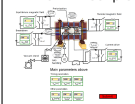
internet



**Virtual control room  
(remote participation)**

WWW control interface

HTML & PHP scripts



SSH control interface

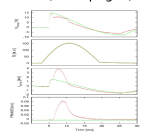
WINDOWS via putty



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

Data presentation

HTML (www pages)



Data handling

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

# Virtuální velín - level I

Location Edit View Bookmarks Tools Settings Help

[http://golem.fjfi.cvut.cz/voperation/tasks/PROMO/1212GOLEM/Level\\_1/exp.php](http://golem.fjfi.cvut.cz/voperation/tasks/PROMO/1212GOLEM/Level_1/exp.php)

## Tokamak Golem **\*\*VIRTUAL\*\*** for GOLEM (Level I)

Home Control Room Queue Live Results Manual

**LEVEL 1**

Preionization (electron gun)

Preion ON

Vacuum stand

GAS handling

$P_{H_2}$  [mPa] 20

$H_2$

Toroidal magnetic field

$C_s$  23 mF

$U_B$  [V] 600 2kV

Current drive

$C_{cd}$  11.3 mF

$U_{CD}$  [V] 500 2kV

$I_{CD}$  [us] 1000

# Virtuální velín - level II

Location Edit View Bookmarks Tools Settings Help

[http://golem.fjfi.cvut.cz/voperation/tasks/PROMO/1212GOLEM/Level\\_II/exp.php](http://golem.fjfi.cvut.cz/voperation/tasks/PROMO/1212GOLEM/Level_II/exp.php)

## Tokamak Golem **\*\*VIRTUAL\*\*** for GOLEM (Level II)

Home Control Room Queue Live Results Manual

**LEVEL 2**

Preionization (electron gun)  
Preion ON

Breakdown  
 $U_{BD}$  [V] 100 2kV  
 $C_{BD}$  3.6 mF  
 $T_{BD}$  [us] 4000

Toroidal magnetic field  
 $C_s$  23 mF  
 $U_B$  [V] 600 2kV

Current drive  
 $C_{CD}$  11.3 mF  
 $U_{CD}$  [V] 500 2kV  
 $T_{CD}$  [us] 3000

Vacuum stand  
 $P_{H_2}$  [mPa] 20  
GAS handling H<sub>2</sub>





## Diagnostics

- ✗ PlasmaPosition
- ✓ Flukes
- ✗ MirnovCoils
- ✓ HXR
- ✓ FastCamera
- ✗ Spectrometer

## Analysis

- ✓ AdvancedAnalysis
- ✓ ShotHomepage
- ✗ MagFieldEvolution
- ✗ MultiCWT
- ✗ MHD

## DAS

- ✓ Niturbo
- ✓ Nistandard
- ✗ Papouch
- ✓ Nibasic
- ✗ Papouch

## Vacuum + Energetics

Log

## Other

- Data
- References
- About

## Navigation

- Next
- Previous
- Current

## Go to shot

9694

## Tokamak GOLEM - Shot Database - 9694

**Date:** 2012-09-07 - 121544  
**Session:** Technological/Software/Debugging/0912Optimization  
**Comment:** USER\_A - three

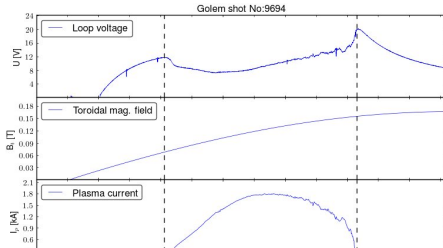
[Template source]  
[WebLog]

### Basic parameters:

- Chamber pressure  $p_{\text{chamber}}$ : 1.27 → 19.28 mPa (request: 20 mPa)
- Working gas: N/A
- Chamber temperature: N/A C
- $C_{B1}$  capacitors (23.0 mF) charged to: 600 V, triggered 5.0 ms
- $C_{BD}$  capacitors (3.6 mF) charged to: 0 V, triggered 5.0 ms
- $C_{CD}$  capacitors (11.2 mF) charged to: 500 V, triggered 8.0 ms
- $C_{ST}$  capacitors (2.7 mF) charged to: 0 V, triggered 5.0 ms
- Max saturation of iron core transformer: 47%
- Time since session beginning: 0:51:47 h

### Plasma parameters:

- Plasma life time **6.2** [ms] (from 8.1 to 14.3)
- Mean toroidal magnetic field  $B_t$ : 0.12 T
- Mean plasma current: 1.43 kA
- Mean Uloop: 9.71 V
- Break down voltage: 11.9 V
- Ohmic heating power: 13.87 kW
- Q edge: 7.6
- Central electron temperature: 25.3 eV



# Reálný velín - <http://golem.fjfi.cvut.cz/current>

Location Edit View Bookmarks Tools Settings Help

[http://golem.fjfi.cvut.cz/roperation/tasks/PROMO/1212GOLEM/Level\\_1/exp.php](http://golem.fjfi.cvut.cz/roperation/tasks/PROMO/1212GOLEM/Level_1/exp.php)

## Tokamak Golem **\*\*REMOTE\*\*** for GOLEM (Level I)

Home Control Room Queue Live Results Manual

**LEVEL 1**

Preionization (electron gun)

Preion ON

Vacuum stand

GAS handling

$P_{H_2}$  [mPa] 20

$H_2$

Toroidal magnetic field

$C_B$  23 mF

$U_B$  [V] 600 2kV

Current drive

$C_{CD}$  11.3 mF

$U_{CD}$  [V] 500 2kV

$I_{CD}$  [us] 1000

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# ITER news No:1 - Global Tokamak Experiment (12.2010)



the way to new energy

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## News in Brief

**38th International Conference on Plasma Science (ICOPS) - Second Announcement**

**15th International Conference on Fusion Reactor Materials (ICFRM-15)**

## Links

"InterFaces "

"Worldwide Fusion Links"

"ITER on Facebook"

"ITER on YouTube"

## Conferences

**02 Dec - 06 Dec, 2012**  
**6th ITER International School**  
**Ahmedabad, India**

**18 Mar - 21 Mar, 2013**  
**6th Int'l Workshop on Stochasticity in Fusion Plasmas**  
**Jülich, Germany**

**20 Jul - 23 Aug, 2013**

# iter newsline

## Launch of the world's first global tokamak experiment

03 Dec, 2010 - #156

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[<< return to Newsline #156](#)

Fusion World

Culham Centre for Fusion Energy (CCFE) PhD student Billy Huang has set up a website for the world's first global tokamak experiment, which began today. The project allows anyone in the world with a physics background and internet access to apply to have a go at running shots on the GOLEM tokamak in Prague, a machine that has been made remotely operable by Tokamak Engineer Dr Vojtech Svoboda and his team.

"The Tokamak Global Experiment is an innovative project that gives participants the opportunity to change real parameters on a real machine, from anywhere in the world," said Billy Huang (pictured right). "Our goal with this project is to get people participating and interested in fusion research around the globe."

GOLEM is one of the oldest tokamaks in the world, originating from Russia. Although not nearly as large as JET, GOLEM still produces small amounts of fusion energy and is used as an educational device.

Promotion of this initiative, which is run in conjunction with the Institute of Plasma Physics of the Czech Republic and the Czech Technical University, is mainly targeted at university level physics students, but anyone with a physics background is welcome to register to run an experiment (see <http://tokamakglobal.com>).

On its debut day, the experiment was a success and received 37 applications from ten countries. The organisers plan to run more sessions in the future.

Delighted with this response to the project, Billy Huang said: "It's been a real challenge setting up the website, but to have so many people from countries across the world already participating in real live fusion experiments is great."





ELSEVIER

Contents lists available at ScienceDirect

## Fusion Engineering and Design

journal homepage: [www.elsevier.com/locate/fusengdes](http://www.elsevier.com/locate/fusengdes)



## Multi-mode remote participation on the GOLEM tokamak

V. Svoboda<sup>a,\*</sup>, B. Huang<sup>d,e</sup>, J. Mlynář<sup>a,b</sup>, G.I. Pokol<sup>c</sup>, J. Stöckel<sup>b</sup>, G. Vondrášek<sup>a</sup>

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<sup>b</sup> Institute of Plasma Physics AS CR, CZ-182 21 Prague, Czech Republic

<sup>c</sup> Institute of Nuclear Techniques, Budapest University of Technology and Economics, Association EURATOM-HAS, H-1111 Budapest, Hungary

<sup>d</sup> Culham Centre for Fusion Energy, OX14 3DB, Abingdon, Oxfordshire, United Kingdom

<sup>e</sup> Department of Physics, University of Durham, South Road, Durham DH1 3LE, United Kingdom

### ARTICLE INFO

#### Article history:

Available online 22 March 2011

#### Keywords:

Tokamak technology  
Remote participation  
Data acquisition system  
Education  
Nuclear fusion

### ABSTRACT

The GOLEM tokamak (formerly CASTOR) at Czech Technical University is demonstrated as an educational tokamak device for domestic and foreign students. Remote participation of several foreign universities (in Hungary, Belgium, Poland and Costa Rica) has been successfully performed. A unique feature of the GOLEM device is functionality which enables complete remote participation and control, solely through Internet access. Basic remote control is possible either in online mode via WWW/SSH interface or offline mode using batch processing code. Discharge parameters are set in each case to configure the tokamak for a plasma discharge. Using the X11 protocol it is possible to control in an advanced mode many technological aspects of the tokamak operation, including: i) vacuum pump initialization, ii) chamber baking, iii) charging of power supplies, iv) plasma discharge scenario, v) data acquisition system.

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# Golem pro “French Master’s in Fusion Science program” (Cadarache 02.2012)



## Quotation

*... It is fascinating to be able to work on such a device, and we're really enjoying the possibility to make our very first discharges...*

# ITER news No:2 - Cadarache Training (03.2012)



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Stochasticity in Fusion  
Plasmas  
Jülich, Germany

29 Jul - 02 Aug, 2013  
International Conference on  
Nuclear Engineering (ICONE)  
Chengdu, China

16 Sep - 20 Sep, 2013  
Int'l Symposium on Fusion  
Nuclear Technology (ISFNT)

## iter newsline

### Students command 100 plasma pulses, remotely

-Remy Guirlet, CEA

Participants in the French Master's in Fusion Science program have been hard at work since early February at the nearby IRFM (Institut de Recherche sur la Fusion Magnétique), participating in hands-on workshops and attending specialized lectures on magnetic fusion (see Newsline 208).

For the 2012 edition of this annual intensive program a new hands-on project was proposed: taking control—remotely—of the Czech tokamak GOLEM.

The GOLEM Tokamak, formerly CASTOR, was re-installed in 2009 at the Czech Technical University (CTU) in Prague by Dr. V. Svoboda and his students. The Czech team has implemented a reliable and user-friendly interface with the tokamak control and data acquisition systems, allowing graduate and post-graduate students to become acquainted with the operation of a small tokamak and to propose and perform experiments.

Under the supervision of Dr. Svoboda, GOLEM was (almost) exclusively in the students' hands for one week. More than 100 plasma pulses were performed. By groups of two or three, students studied plasma parameters' roles on performance and worked to optimize parameters to achieve the longest plasma. They also investigated conditioning techniques, ion mass number effects, and energy confinement time. Following data analysis and questioning, students presented the scientific results of their experiments at the end of their hands-on session.

The Master des Sciences de la Fusion is a collaborative training program sponsored by major French institutions of higher education (Aix-Marseille, Bordeaux, Nancy and Paris-Sud Universities, Ecole Polytechnique and CEA-INSTN). Next year's February gathering is expected to draw 40 students, including students from the pan-European Erasmus Mundus Master program.

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<< return to Newsline #213

08 Mar, 2012 - #213

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Fusion World

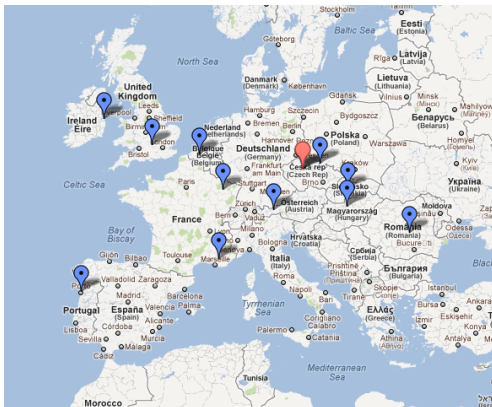


Putting theoretical knowledge to the test and "driving" a real machine.

# Remote sessions from Europe

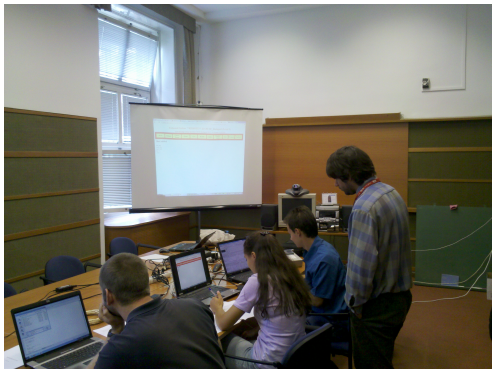
The smallest and oldest tokamak ...

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





# Remote practica (Budapest September 2012) control room in $\approx 443$ km distance



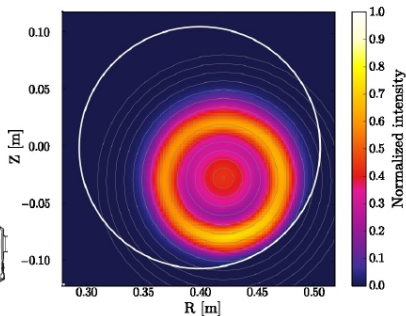
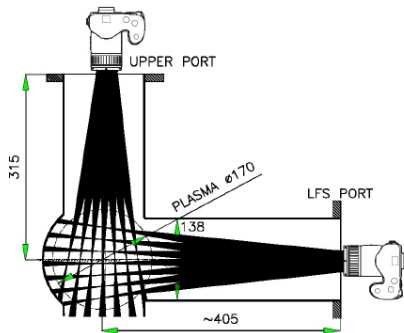
$\approx 50$  shots

## Quotation

*Thanks for the operation! The lab exercise went perfectly well, and the students were really enjoying it. Gergo Pokol (teacher)*

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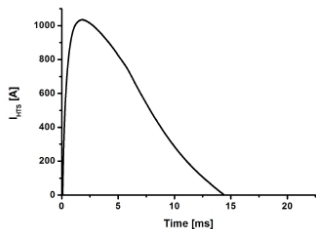
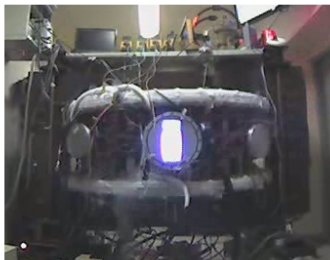
# Low Cost Alternative of High Speed Visible Light Camera for Tokamak Experiments



(HTPD conference Monterey + RSI 2012)

# RF preionization





- 6 turns of the 2nd generation HTS (Re)BCO tape SCS12050-AP.
- Current ramp-up speed of up to  $\approx 0.6$  MA/s .
- Current through the tape  $\approx 1$  kA.
- Little "quench" effects observed for perpendicular magnetic field up to 0.5T

video

- GOMTRAIC (Fusenet event.)
- Fusion & Erasmus Mundus Masters, Cadarache.
- Týden vědy
- HTS.
- SUMTRAIC

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- 6 Poděkování**

# Poděkování

**Vychování:** UFP AV ČR, oddělení Tokamak.

**Přímo:** Gabo Vondrášek, Jan Stöckel.

**Studenti nadstandardně:** Ondřej Grover, Michal Odstrčil.

**Podpora:** vedení katedry a fakulty (děkanát).

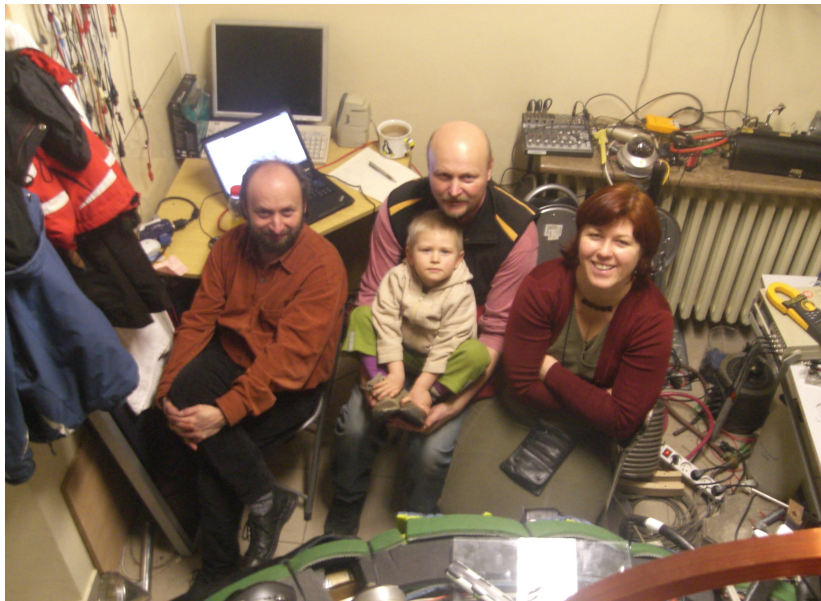
**Domácí zázemí:** VS, JS, GV.

**GA:** MŠMT, Fusenet, IAEA.

**Firmy:** National Instruments, Pfeiffer.



# Nadace VIA



To be continued ....

