

Jak se v centru Prahy zažehává hvězda

Vojtěch Svoboda
Korona přednáška - živě na FB

April 23, 2020

Fakulta jaderná a fyzikálně inženýrská (FJFI) České vysoké učení technické v Praze



Hlavní budova FJFI v Praze - Břehová



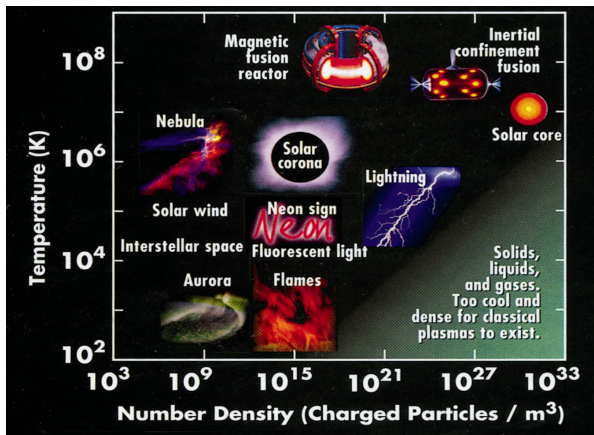
insignie FJFI



Betlémská kaple - slavnostní síň ČVUT

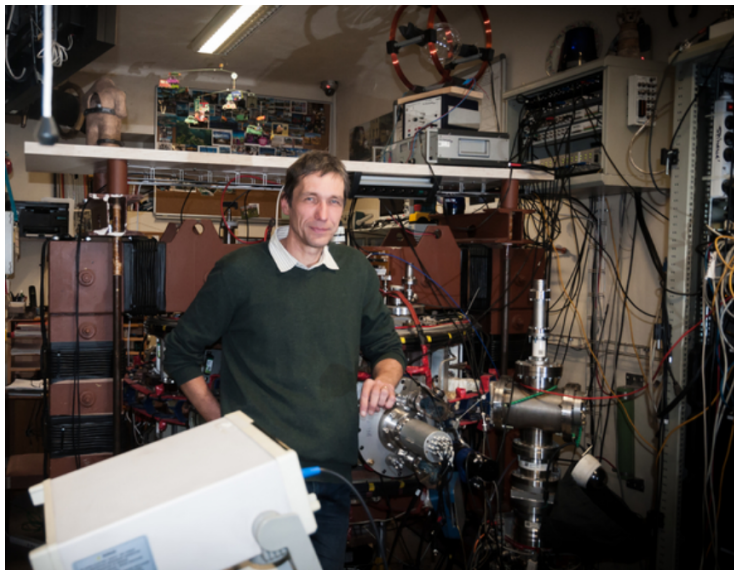
- ČVUT založena roku 1707 císařem Josefem I.
- ČVUT má přibližně 2700 zaměstnanců, 16500 vysokoškolských studentů, 1700 doktorandů. (≈ 2500 zahraničních studentů).
- FJFI byla založena v roce 1955 s posláním vyškolit nové odborníky na vznikající československý jaderný program.
- FJFI je v současné době centrem vzdělávání a výzkumu, které se specializuje na hraniční oblasti mezi moderní vědou a jejich aplikacemi v technologiích, medicíně, ekonomii, biologii, ekologii a dalších oborech.

Badatelská skupina / studijní specializace Fyzika plazmatu a termojaderné fúze



99.999 % Vesmíru je v plazmatickém stavu

Tokamak GOLEM & Vojtěch Svoboda



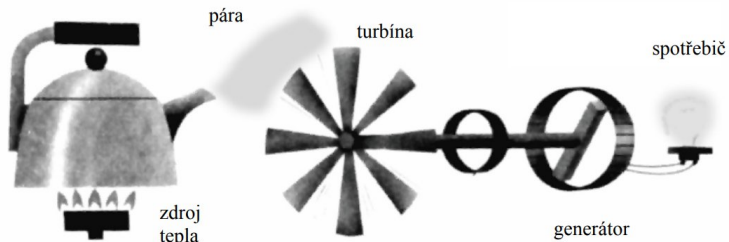
Google: Energy

About 2,950,000,000 results (0.60 seconds)

The image shows a Google search results page for the query "energy". The search bar at the top contains the word "energy" and shows a search time of 0.60 seconds with approximately 2.95 billion results. Below the search bar, there are navigation tabs for "All", "Images", "News", "Maps", "Videos", and "More". A horizontal row of topic-based icons includes power, body, light, saving, work, science, wave, healing, solar, renewable, electrical, conservation, wind, nuclear, and physics. The main content area is a grid of search results, each featuring a representative image and a title. The results include:

- Global energy in 2050 - can renewables ...** (Image: Earth with energy lines)
- Understanding and using the Energy Balance** (Image: World map with energy lines)
- Siemens signs up to blockchain energy ...** (Image: Lightbulb)
- Using Blockchain in Renewable Energy ...** (Image: Lightning bolt in a network)
- New Thermal Battery Could Be A 'Game ...** (Image: Wind turbines and solar panels)
- Energy and renewable sources: EN's ...** (Image: Sun with energy rays)
- How two IoT startups are changing the ...** (Image: Lightbulb on a circuit board)
- Business Energy - The Leading African ...** (Image: Hand holding a glowing orb)
- Line&Energy** (Image: Energy waves)
- Massachusetts university for Mass Energy** (Image: "ENERGY" text in a blue field)
- WTF is Zero Point Energy and How Cold ...** (Image: Blue energy waves)
- Wilson E. Scott Institute for Energy ...** (Image: Wind turbines in a field)
- Energy Use in Industry - Ener...** (Image: Pie chart showing energy use distribution)
- Cracked the Secret to Fusion Energy ...** (Image: Purple energy waves)
- Alternative energy technology | What we ...** (Image: Glowing particles)
- Energy Trade Surveillance Roadmap ...** (Image: Lightbulb with colorful lines)
- Will Energy Offer the Next Market I...** (Image: Lightbulb with network nodes)
- Energy from Wastewater - ASIO, spot, s r...** (Image: Pie chart showing energy sources)
- Transformation Ahead for Energy Sector ...** (Image: Wind turbines at sunset)
- Mediterranean 2040: How will the energy ...** (Image: "ENERGY" text in a blue field)
- All Forms of Energy Are Important ...** (Image: Power lines and towers)
- Energy Union Indicators | Energy** (Image: Earth with energy lines)
- Green supplier Bulb Energy predict 1n ...** (Image: Solar panels and a lightbulb)
- Energy - Wikipedia** (Image: Lightning bolt)
- Related searches**
 - body energy >
 - science energy >
 - energy human >
- Promotion of renewable energy sources ...** (Image: Green energy icons)
- Misc SELECT - Environmental Pathways for ...** (Image: Network diagram with energy icons)
- Energy Storage | Graphene Flagship** (Image: Blue energy waves)

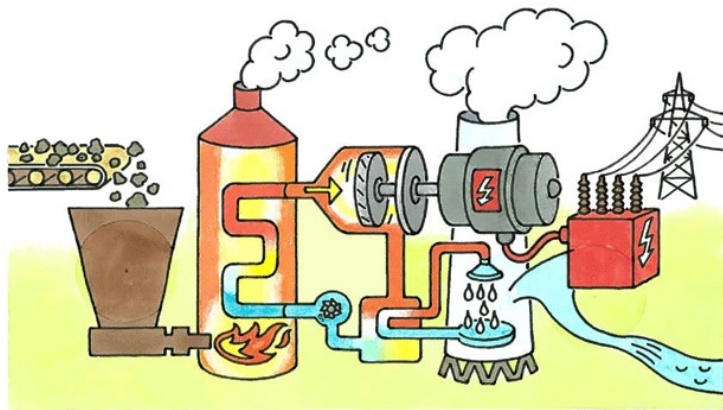
Základní princip tepelné elektrárny



Základní otázka zní:

?? Čím topit ??

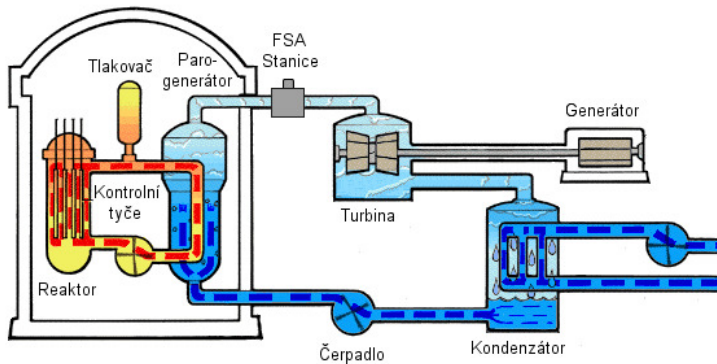
Uhelná elektrárna



Praha (~ 1 GW): denně ~ vlak uhlí

Emise

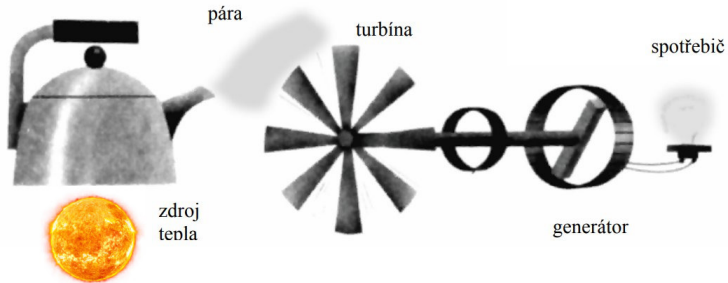
Jaderná elektrárna - štěpná



Praha (~ 1 GW): ročně \sim vagon jaderného paliva

Dotáhnout technologii: Suroviny, Odpad, Bezpečnost

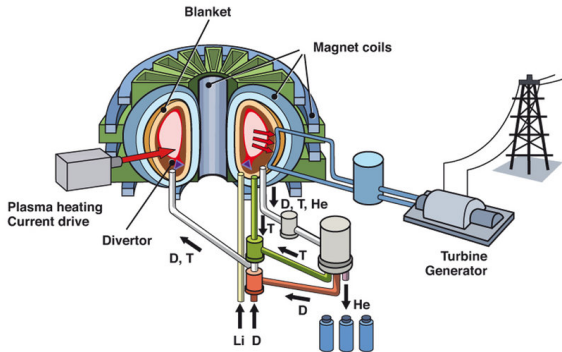
Topit malým Sluncem/hvězdou ??





Můžeme se zmocnit energie
která pohání Slunce/hvězdy?

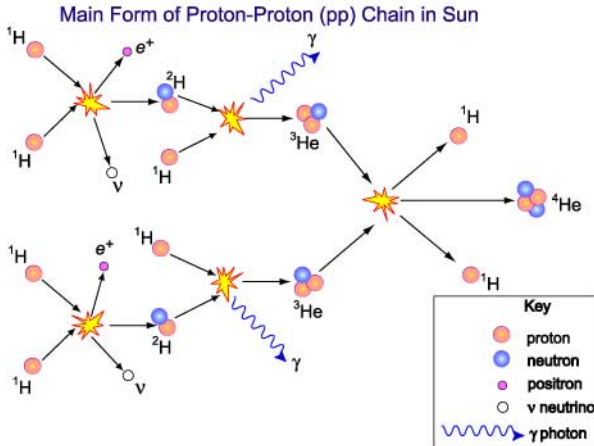
Vize: Jaderná elektrárna - slučovací/fúzní



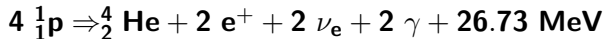
Praha (~ 1 GW): ročně \sim dodávka D-T směsi

Vyplat technologii

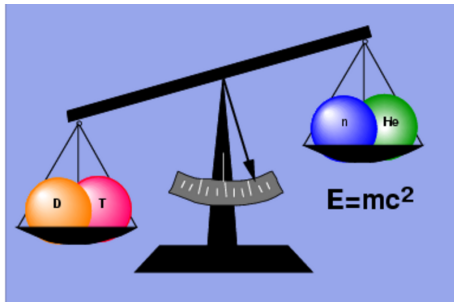
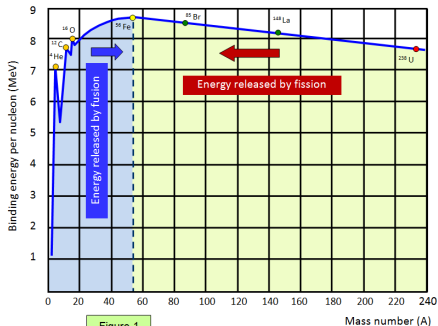
Inspirace: Slunce - protonový řetězec



credit:CSIRO

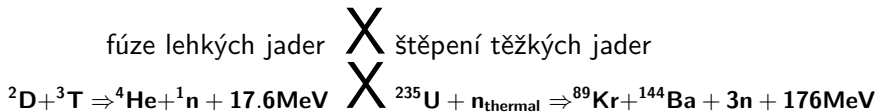
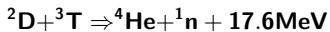


Uvolnění vazebné energie atomových jader

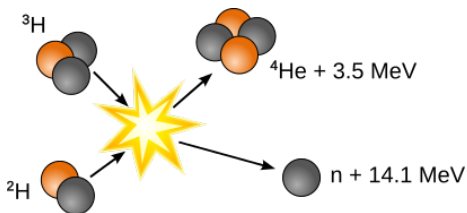


fúze lehkých jader

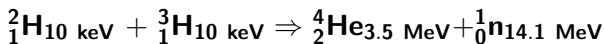
štěpení těžkých jader



Fúzní ${}^2_1\text{H}$ - ${}^3_1\text{H}$ (deuterium - tritium) reakce (nejvhodnější kandidát do pozemských podmínek)



credit:?



$$m_{2\text{H}} = 2.01355m_u, m_{3\text{H}} = 3.01550m_u, m_{\text{He}} = 4.00150m_u, m_{\text{n}} = 1.007332m_u$$

$$m_{(2\text{H}+3\text{H})} = 5.02905m_u, m_{(\text{He}+\text{n})} = 5.01017m_u,$$

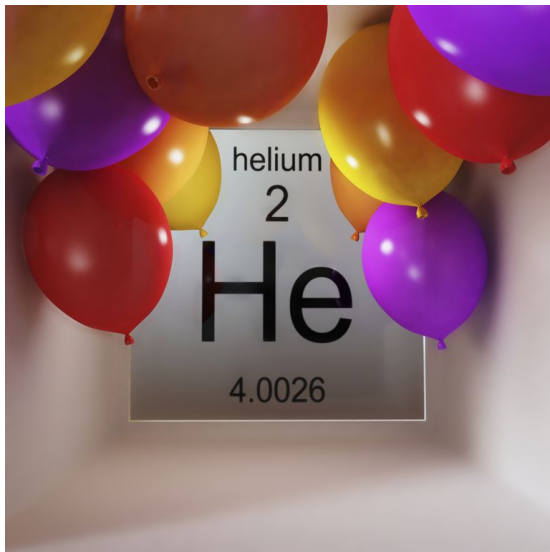
pak hmotnostní schodek $\Delta m = 0.01888m_u$.

$$E = \Delta m c^2: E = \Delta m \text{ krát } \frac{c^2 m_u}{e} = 17.6 \text{ MeV}$$

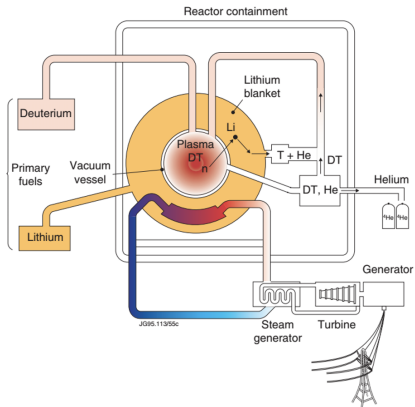
$$1\text{eV} \sim 11600^\circ\text{C} \approx {}^2_1\text{H}_{100 \text{ M}^\circ\text{C}} + {}^3_1\text{H}_{100 \text{ M}^\circ\text{C}} \Rightarrow {}^4_2\text{He}_{35 \text{ G}^\circ\text{C}} + {}^1_0\text{n}_{141 \text{ G}^\circ\text{C}}$$

Palivo: IAEA "Natural water"





Bezpečnost



* Nejde o řetězovou reakci.

* Tritium: slabý β zářič

$T_{1/2} = 12.5$ roku. Minimální nebezpečí.

* Minimalizovaný potenciál aktuálně přítomného D-T paliva.

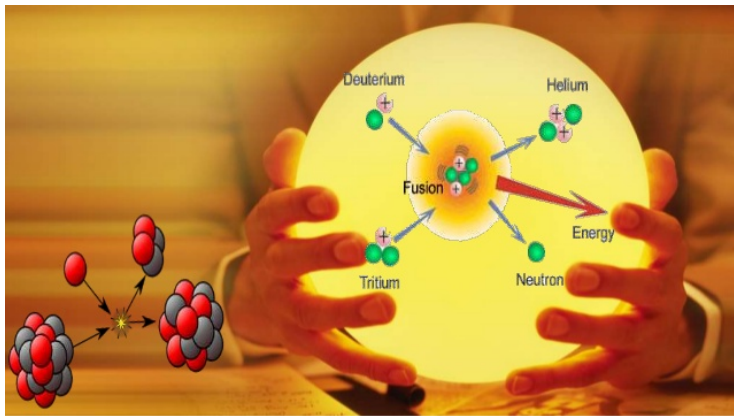
1952 "Operation Ivy - Mike" První test vodíkové bomby



credit:YouTube:Ivy Mike Countdown and detonation

Toto není vhodná technologie

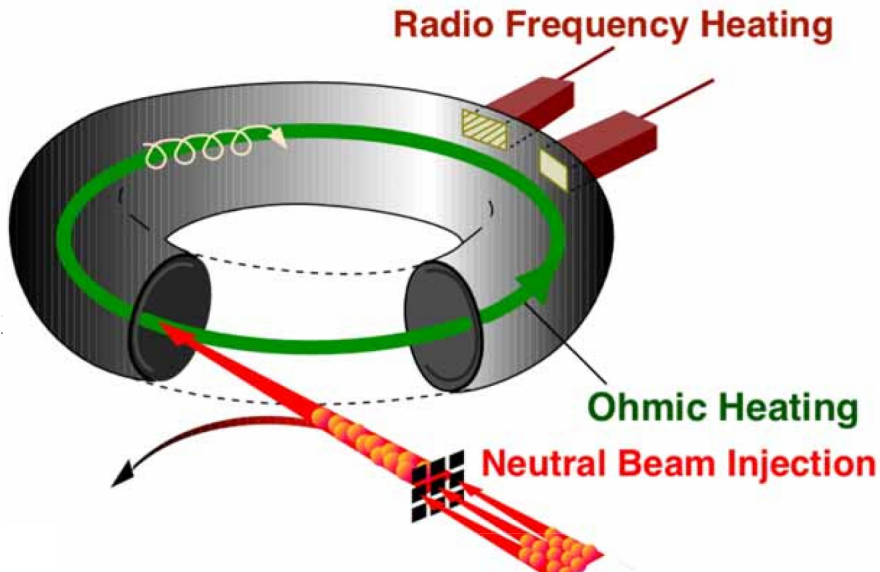
Hledá se vhodná fúzní technologie



Podmínky:

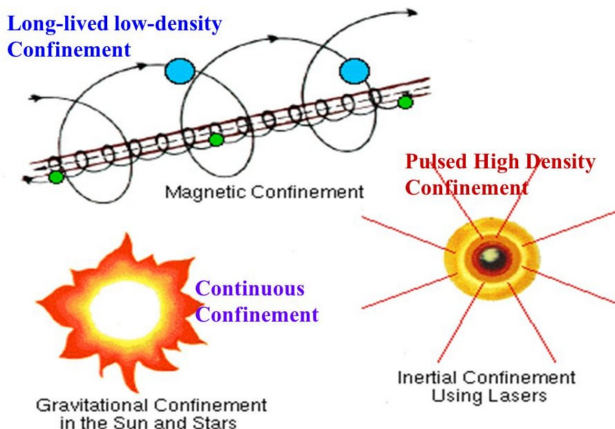
Zahřát na $\sim 100\,000\,000\text{ }^{\circ}\text{C}$ & **udržet** po dobu ~ 30 let

Ohřev plazmatu

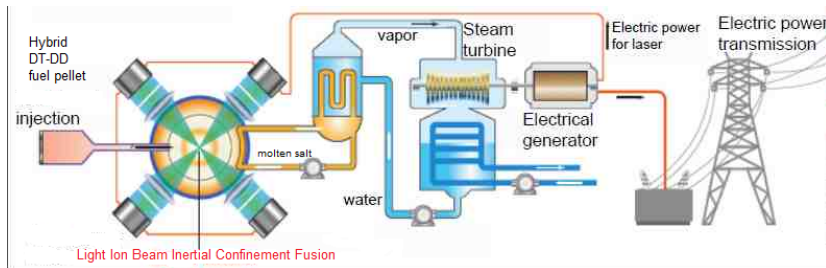


Tři možné cesty jak udržet plazma pro fúzi

Lawsonovo kritérium: $n\tau_E \geq 1.5 \cdot 10^{20} \frac{\text{s}}{\text{m}^3}$ ($2 \times 6 > 11$ || $6 \times 2 > 11$)



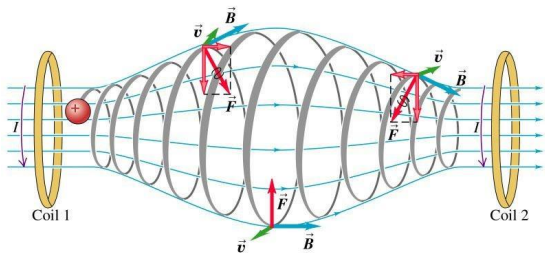
Inerciální fúze



credit:mext.jp

Velká výzva

Magnetické udržení: magnetická nádoba

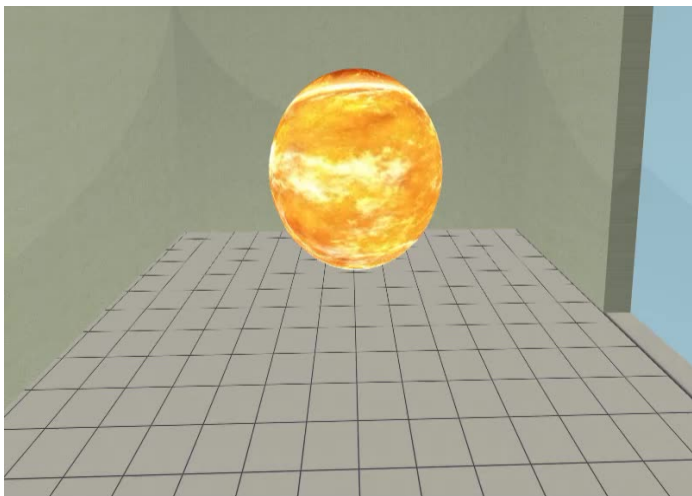


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Musíme ji ale svinout do kruhu (zbatvit se podstav)

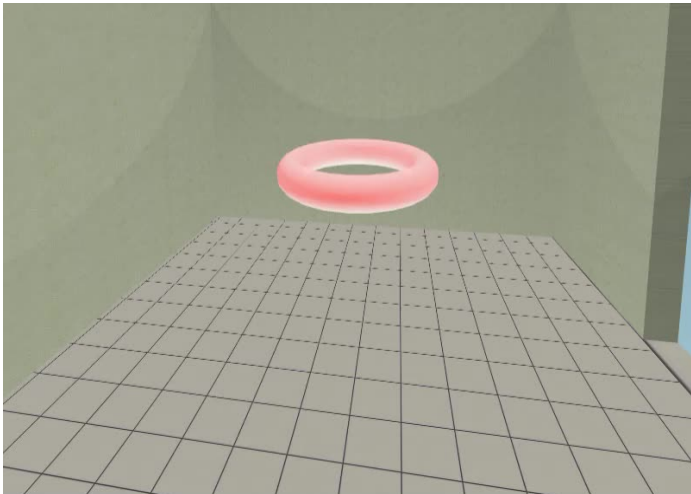
záchranný kruh/duše pneumatiky/donut

Náš cíl: vytvořit μ Slunce v pozemských podmínkách

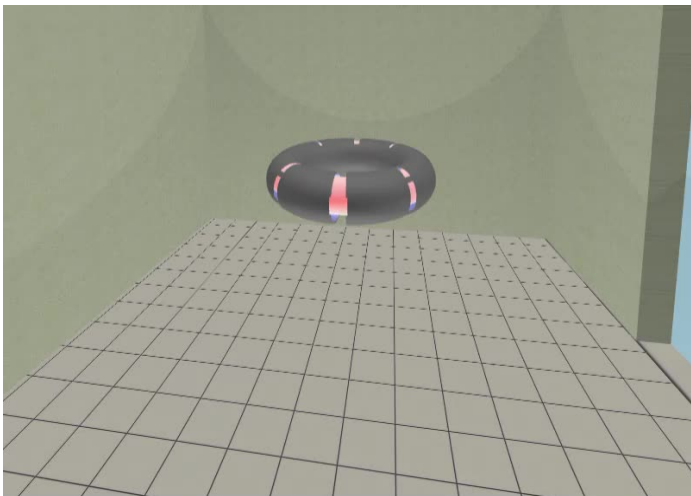


Magnetické udržení vyžaduje toroidální geometrii

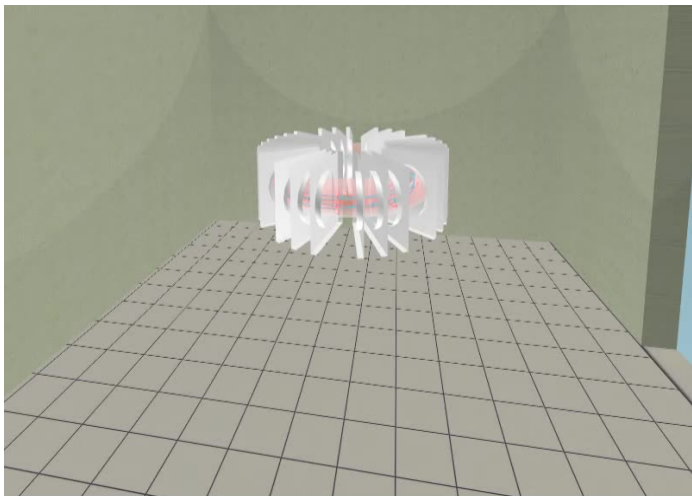
Svinutá magnetická nádoba



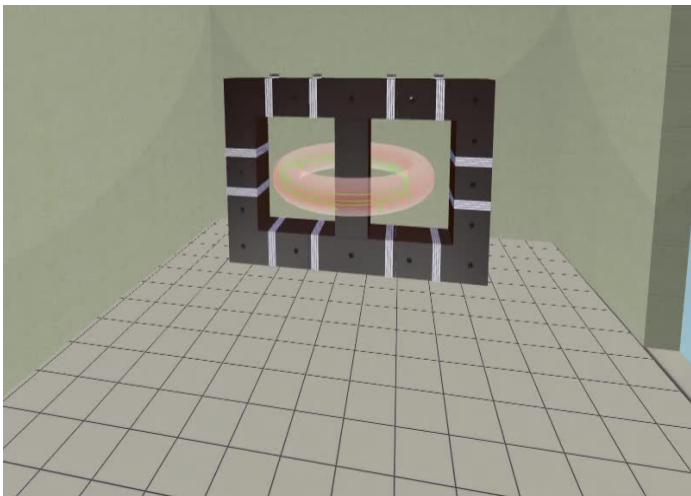
Musíme to celé umístit do reaktorové nádoby - komory



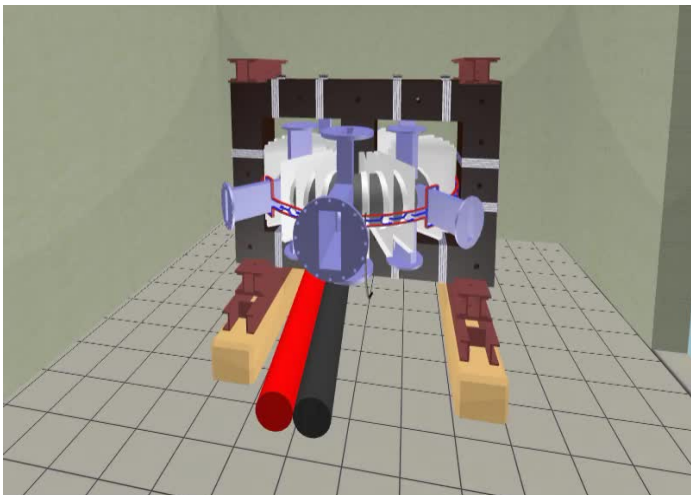
Toroidální magnetické pole udržuje plazma



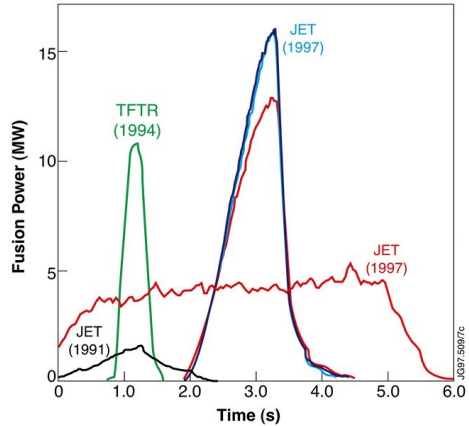
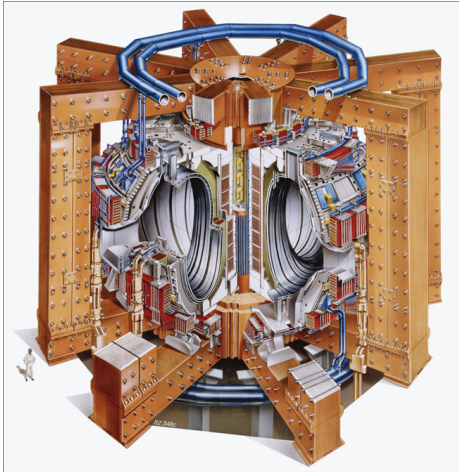
Transformátorová akce vytvoří a zahřeje plazma



Vše dohromady - voilà tokamak

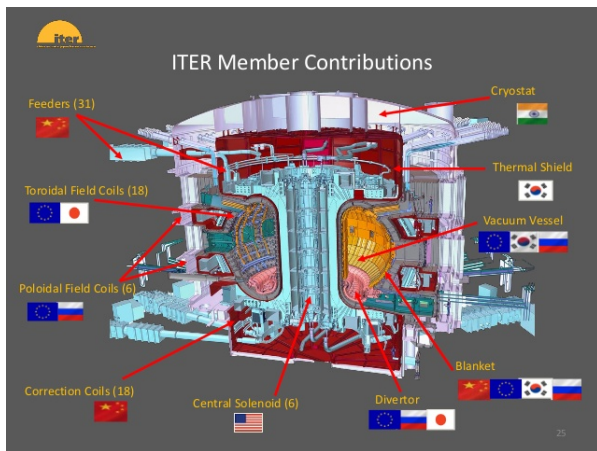


1997: Světový fúzní rekord @ JET (EU)



$P \approx 15$ MW, $Q \approx 0.65$, $\Delta T \approx 3$ s

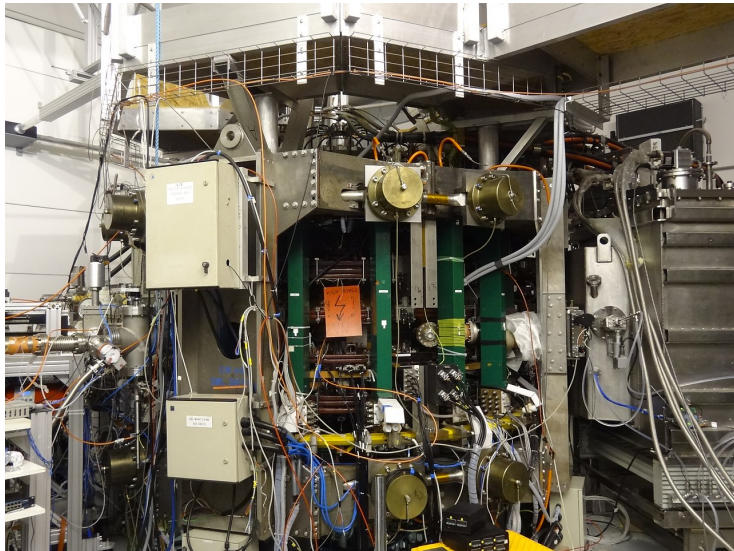
ITER (jižní Francie) \approx 18 miliard EUR



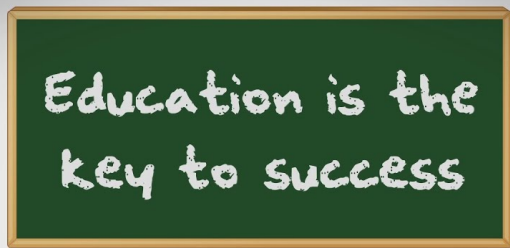
Mise:

$P \approx 500$ MW, $Q \approx 10$, $\Delta T \approx 10$ minut, konkurenceschopná cena elektřiny

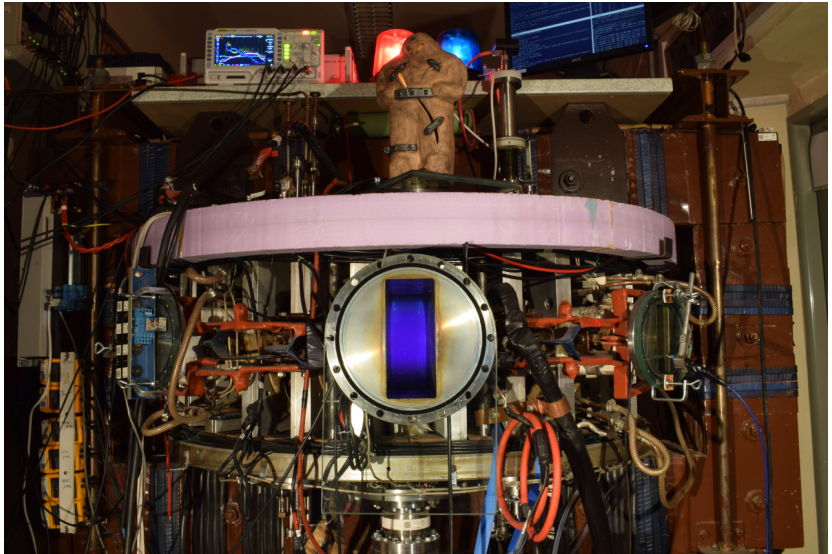
Příspěvek České republiky: tokamak COMPASS@IPP.CAS.CZ



Velké ambice



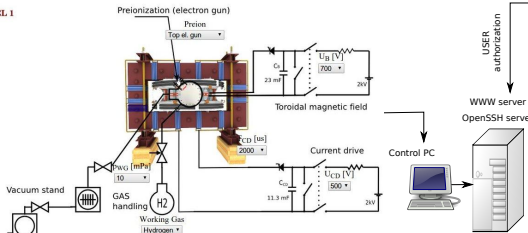
Tokamak GOLEM



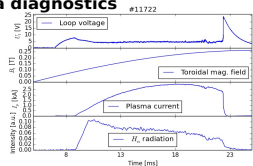
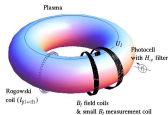
Tokamak GOLEM - experimentální schéma

LEVEL 1

Tokamak technology setup



Basic plasma diagnostics



internet

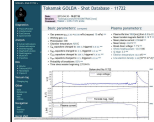
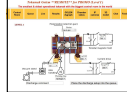
**Virtual control room
(remote participation)**

WWW control interface

Data presentation

HTML & PHP scripts

HTML (www pages)



SSH control interface

WINDOWS via putty

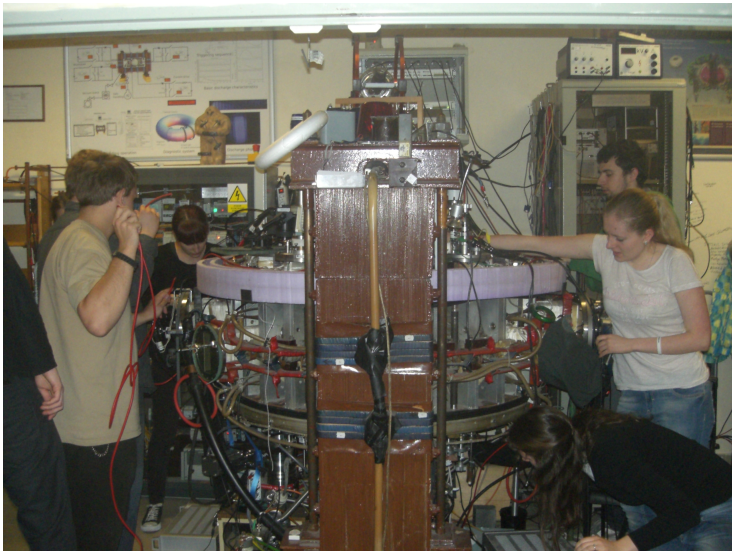
Data handling



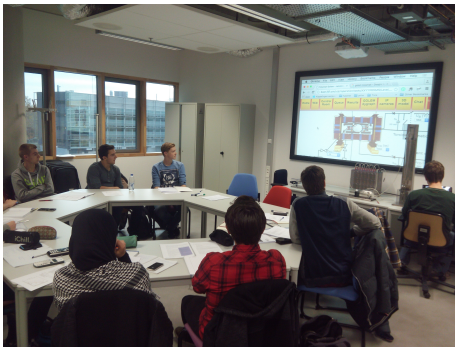
LINUX via ssh
or ssh+X tunnel
(advanced mode)

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

Hands on tokamak



Tokamak GOLEM - vzdálené řízení: 2009-2019 inventura



Studenti z TU Eindhoven, operující tokamak, 650 km vzdušnou čarou

- Demontrace: Ghent University 09; Bochum University 13; Garching 13; Lemvig High School 14; Instituto Tecnológico Costa Rica 10; Armidale University 17.
- Zimní a letní školy: French Training Course & EM 12-14,16-19; Bangkok 16-19; TU Eindhoven 11,15-19; TU Kobehaven 14,15,18; Grenoble TU 15, University of Belgrade 15-18; BUTE Budapest 10,12-18; University of Padova 14,16,18; TU Torino 16-18, St. Peterburg University 18-19. Kharkov University 19

Poplatek: pohlednice z místa vzdáleného řízení

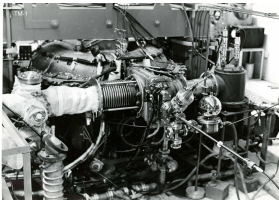


GOLEM



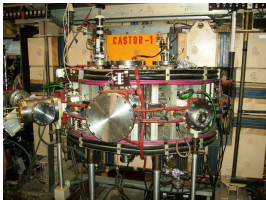
Děkuji za pozornost

Tokamak TM1
@Kurchatov Institute near Moscow
~1960-1977



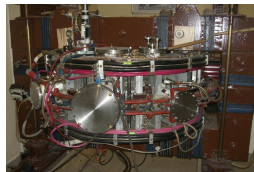
SCIENCE

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 earliest & oldest operational tokamak with the biggest control room in the world

Home WB1 Control Room Queue Live Results GOLEM diagram Chamber status IP camera 3D model Chat Feedback Logout

LEVEL 1

Preionization (electron gun)
Preion. Press: 1

Toroidal magnetic field
T0 [V] 0.000

Current drive
C0 [A] 0.000
30.00A

GAS handling
GAS handling
Waking Gas 0.000

Vacuum stand
Vacuum stand

Discharge comment

Place the discharge setup into the queue

Tokamak GOLEM @ Wikipedia ..

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home Kalendaršif Produkce Forecast Slovnik Rano

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The Free Encyclopedia

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Featured content
Current events

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 cusp. 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]

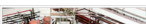
Currently in operation [edit]

(in chronological order of start of operations)

- 1960s: TM1-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



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 Čěrovský, Bořek Leitl, Martin Himmel. Petr Švihra, Petr Mácha, Vojtěch Fišer, Filip Papoušek, Sergei Kulkov, Martin Imříšek.