

Spoutání energie hvězd v pozemských podmínkách

Vojtěch Svoboda
Colours of Ostrava 2019

July 17, 2019

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



Hlavní budova FJFI v Praze - Břehová



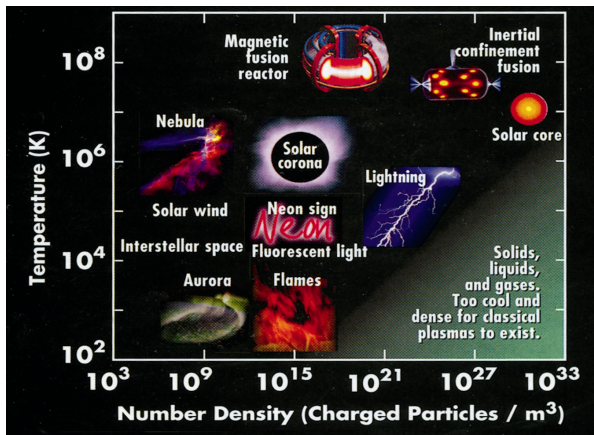
insignie FJFI



Betlémská kaple - slavnostní síň ČVUT

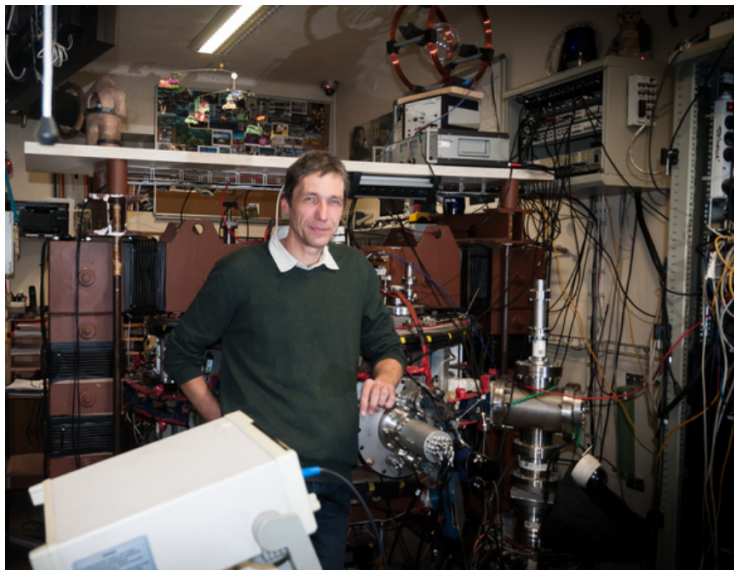
- ČVUT založena roku 1707 císařem Josefem I.
- ČVUT má přibližně 2700 zaměstnanců, 16500 vysokoškolských studentů, 1700 doktorandů. (\approx 2500 zahraničních studentů).
- FJFI byla založena v roce 1955 s posláním vyškolit nové odborníky na vznikající československý jaderný program.
- FJFI je v současné 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 interface for the term "energy". At the top, the Google logo is on the left, and the search bar contains the word "energy". To the right of the search bar are icons for search, voice search, and image search. Below the search bar, there are navigation tabs for "All", "Images", "News", "Maps", "Videos", and "More". To the right of these tabs are "Settings" and "Tools".

Below the navigation tabs is a horizontal row of circular icons representing different energy-related topics: power, body, light, saving, work, science, wave, healing, solar, renewable, electrical, conservation, wind, nuclear, and physics. A right-pointing arrow is at the end of this row.

The main content area displays a grid of image search results. Each result consists of a thumbnail image and a caption with a URL. The thumbnails include:

- A globe with energy lines.
- A world map with energy lines.
- A glowing lightbulb.
- A lightning bolt striking a circuit board.
- Wind turbines and solar panels.
- A glowing blue sphere with radiating lines.
- A glowing lightbulb on a circuit board.
- A hand holding a glowing green orb.
- Abstract energy waves in red and yellow.
- The word "ENERGY" in blue, glowing letters.
- Abstract energy waves in blue.
- Wind turbines in a field.
- A pie chart showing energy sources.
- Abstract energy waves in pink and purple.
- A glowing orange and yellow abstract shape.
- A glowing lightbulb with colorful energy lines.
- A glowing lightbulb with a network of nodes.
- A pie chart showing energy sources.
- Wind turbines in a field.
- The word "ENERGY" in blue, glowing letters.
- A cityscape with energy lines.

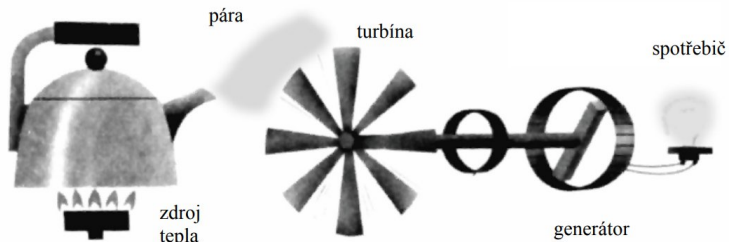
Below the grid of image results is a "Related searches" section with a list of search terms and arrows pointing to the right:

- body energy
- science energy
- energy human

At the bottom of the page, there are more image results, including:

- A globe with energy lines.
- A green energy source.
- A lightning bolt striking a circuit board.
- A glowing green energy source.
- A glowing green energy source.
- A glowing blue energy source.

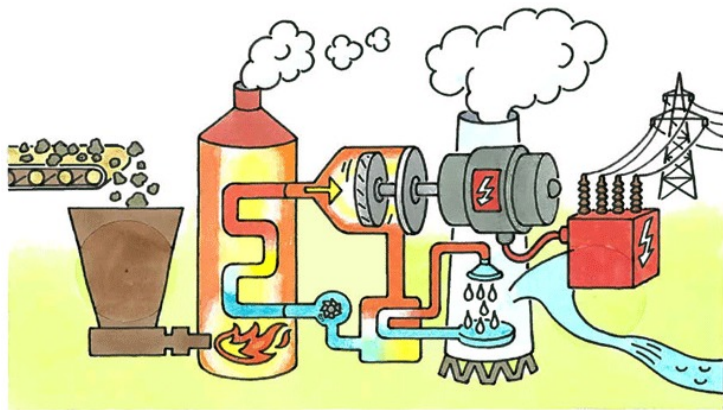
Základní princip tepelné elektrárny



Základní otázka zní:

?? Čím topit ??

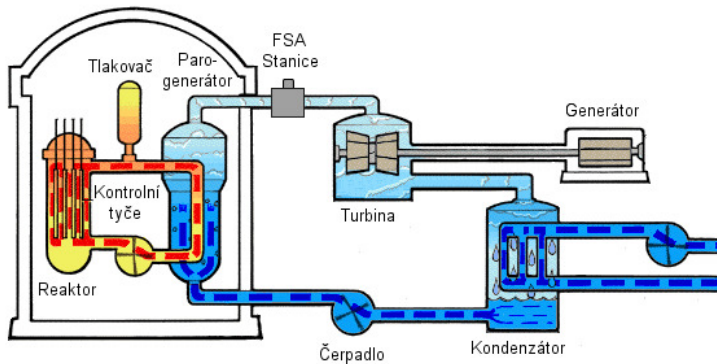
Uhelná elektrárna



Praha (~ 1 GW): denně ~ vlak uhlí

Emise

Jaderná elektrárna - štěpná



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

Dotáhnout technologii: Suroviny, Odpad, Bezpečnost

Google: Energy Crisis

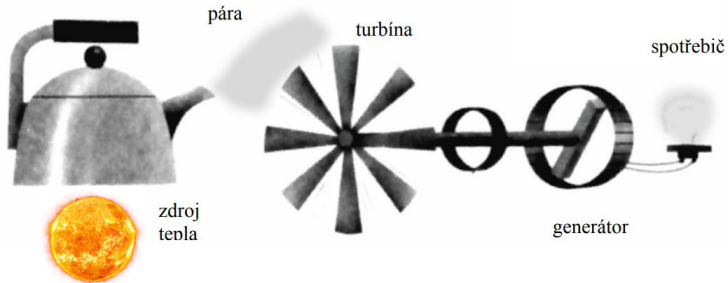
About 501,000,000 results (0.51 seconds)

The image shows a Google search interface for the query "energy crisis". At the top, the Google logo is on the left, and the search bar contains "energy crisis" with a magnifying glass icon. Below the search bar are navigation tabs for "All", "Images", "News", "Videos", "Books", and "More", along with "Settings" and "Tools". A horizontal row of filters includes "1970s", "oil", "India", "worldwide", "pakistan", "global", "future", "electricity", "climate change", "conclusion", "history", "solution", "economic", and "diagram".

The search results are displayed in a grid of 12 columns and 3 rows. Each result includes a thumbnail image and a text-based title with a URL. The thumbnails include: a globe with "THE ENERGY CRISIS"; a sign that reads "FUEL SHORTAGE IS GOING TO GET THE WORLD BACK ON ITS FEET"; a line graph titled "Global Energy Supply"; a word cloud titled "ENERGY CRISIS"; a word cloud titled "ENERGY CRISIS"; a photograph of a gas station with a sign that says "PUMPS CLOSED"; a bar chart titled "World per Capita Energy Consumption"; a photograph of an oil pumpjack; a photograph of a power plant; a word cloud titled "Energy Crisis"; a photograph of a power plant; a bar chart titled "Energy Crisis - Wikipedia"; a photograph of an oil pumpjack; a photograph of a globe with arrows; a photograph of a globe; a bar chart titled "The Caring Energy Crisis?"; a diagram titled "Energy Crisis"; a photograph of a power plant; a pie chart titled "Recent progress in renewable energy..."; a photograph of a globe; a photograph of a globe; a photograph of a globe; a diagram titled "Related searches"; a word cloud titled "ENERGY CRISIS"; a photograph of a power plant; a bar chart titled "AUSTRALIA'S ENERGY CRISIS April 2018..."; a photograph of a fuel gauge; and a photograph of an oil pumpjack.

Below the grid, there are several more thumbnails, including a photograph of a power plant, a photograph of a power plant, a photograph of a power plant, a photograph of a power plant, a photograph of a power plant, and a photograph of a power plant.

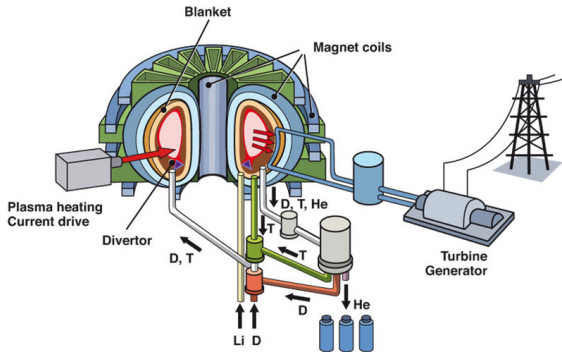
Topit malým Sluncem/hvězdou ??





Můžeme se zmocnit energie
která pohání Slunce/hvězdy?

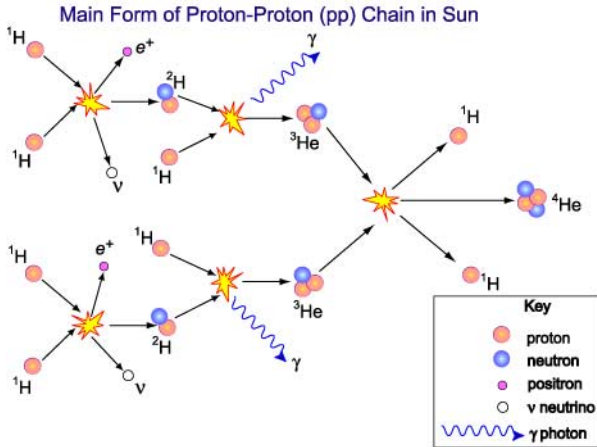
Vize: Jaderná elektrárna - slučovací/fúzní



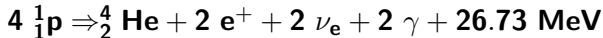
Praha (~ 1 GW): ročně \sim dodávka D-T směsi

Vyplát technologii

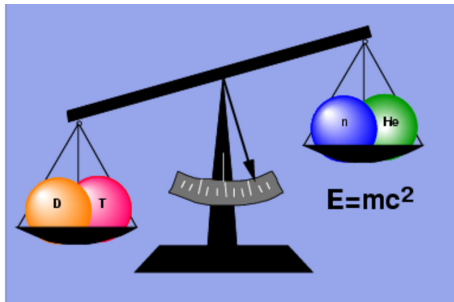
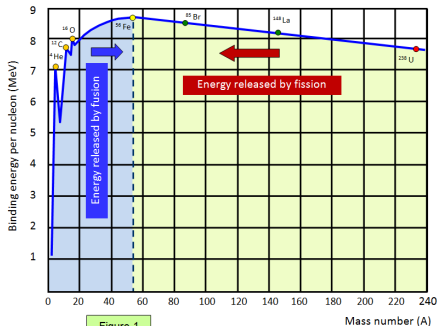
Inspirace: Slunce - protonový řetězec



credit:CSIRO

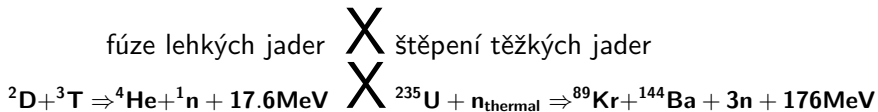
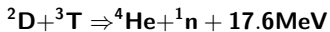


Uvolnění vazebné energie atomových jader

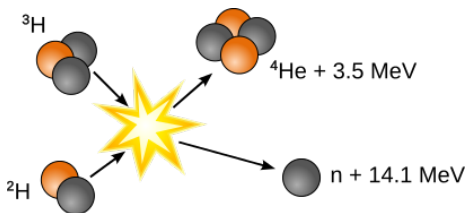


fúze lehkých jader

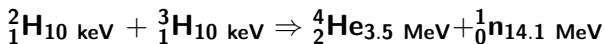
štěpení těžkých jader



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



credit:?



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

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

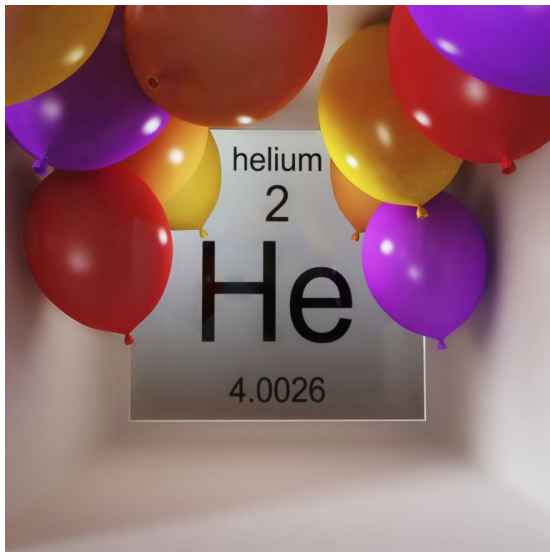
pak hmotnostní schodek $\Delta m = 0.01888m_u$.

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

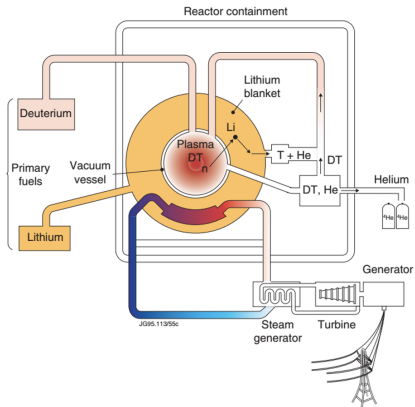
$$1\text{eV} \sim 11600^\circ\text{C} \approx {}^2_1\text{H}_{100 \text{ M}^\circ\text{C}} + {}^3_1\text{H}_{100 \text{ M}^\circ\text{C}} \Rightarrow {}^4_2\text{He}_{35 \text{ G}^\circ\text{C}} + {}^1_0\text{n}_{141 \text{ G}^\circ\text{C}}$$

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.

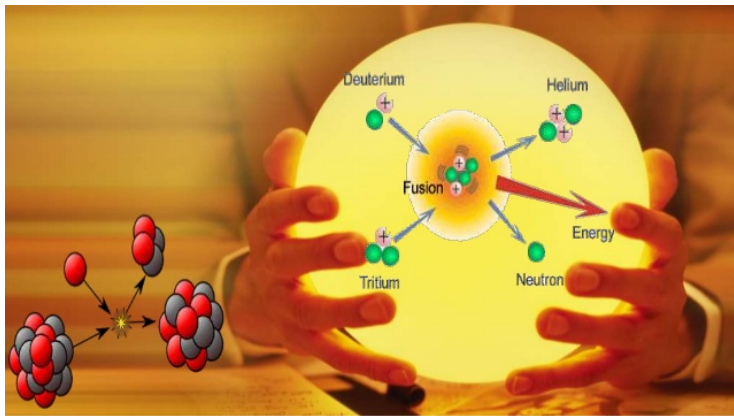
1952 "Operation Ivy - Mike" První test vodíkové bomby



credit:YouTube:Ivy Mike Countdown and detonation

Toto není vhodná technologie

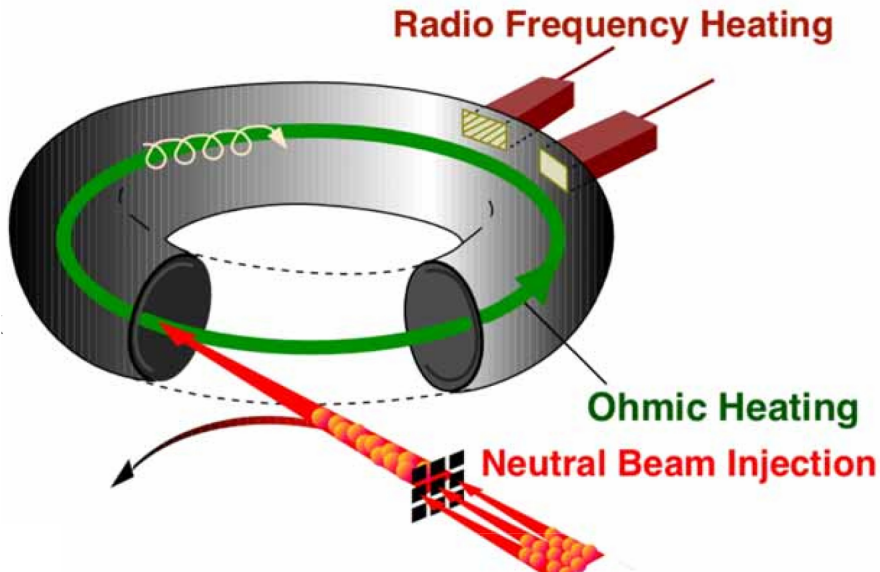
Hledá se vhodná fúzní technologie



Podmínky:

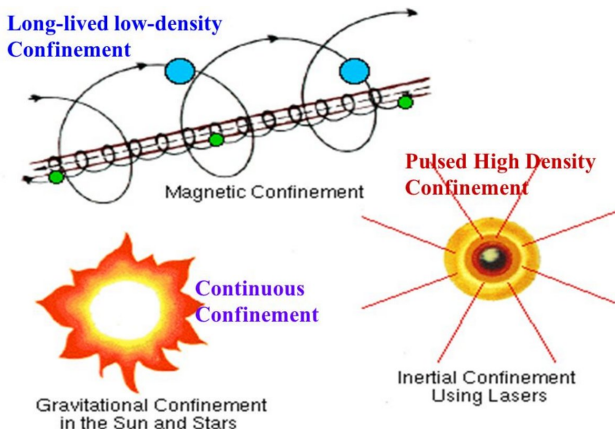
Zahřát na $\sim 100\,000\,000\text{ }^{\circ}\text{C}$ & **udržet** po dobu ~ 30 let

Ohřev plazmatu

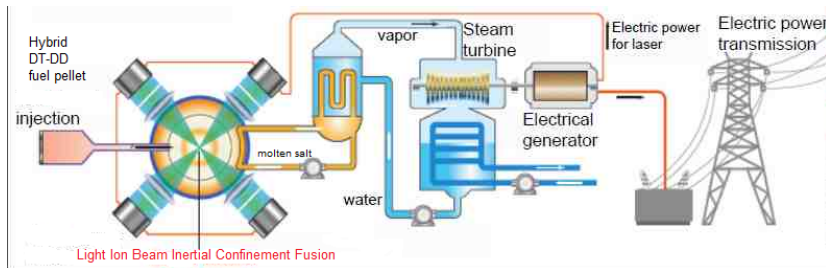


Tři možné cesty jak udržet plazma pro fúzi

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



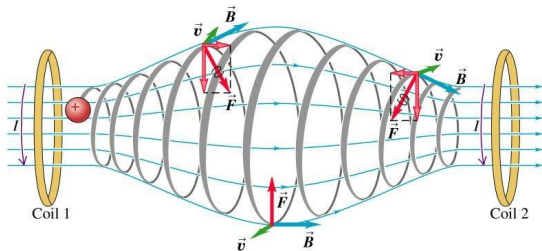
Inerciální fúze



credit:mext.jp

Velká výzva

Magnetické udržení: magnetická nádoba

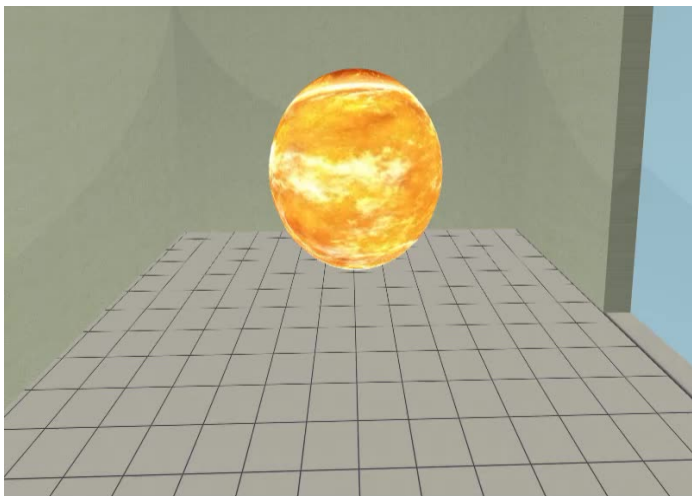


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Musíme ji ale svinout do kruhu

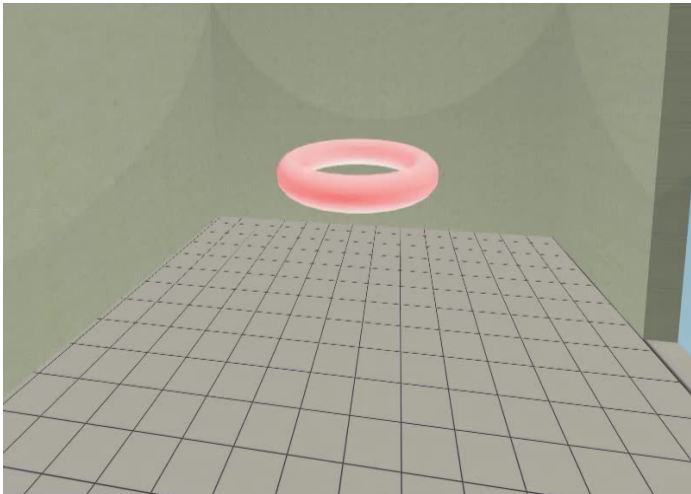
záchranný kruh/duše pneumatiky/kobliha - donut

Náš cíl: vytvořit μ Slunce v pozemských podmínkách

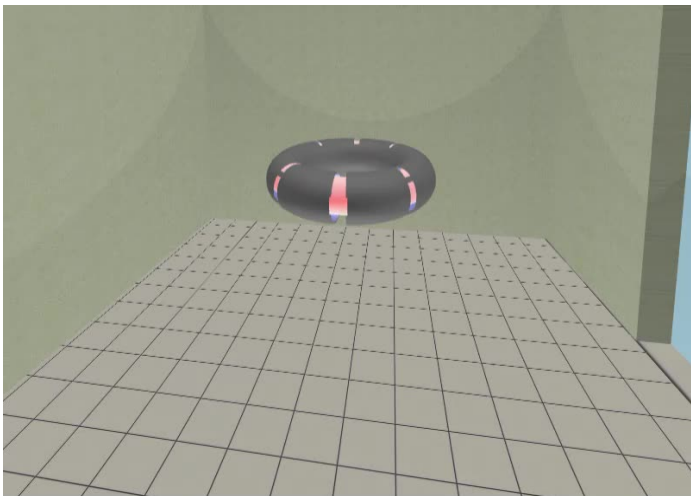


Magnetické udržení vyžaduje toroidální geometrii

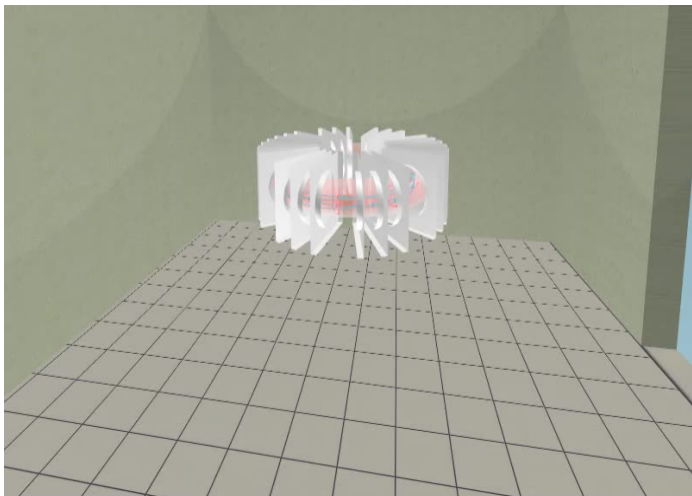
Svinutá magnetická nádoba



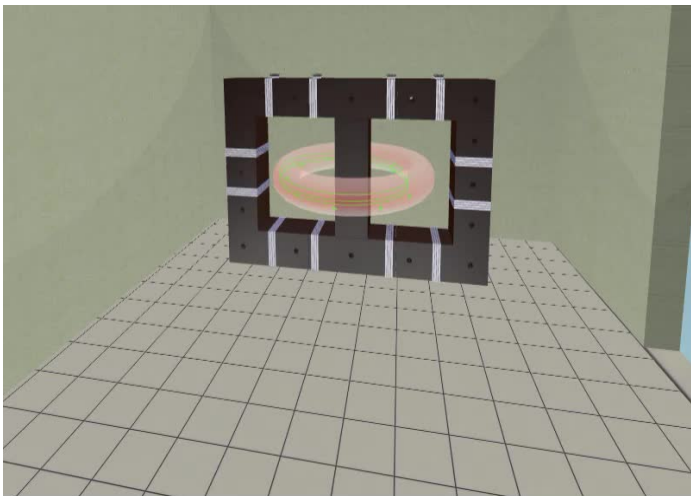
Musíme to celé umístit do reaktorové nádoby - komory



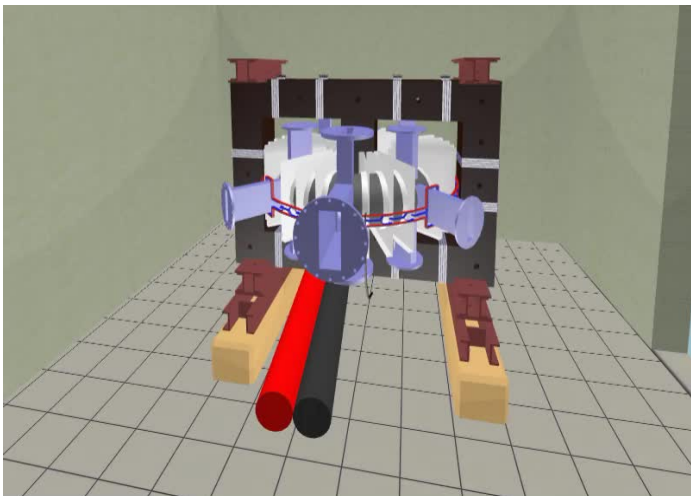
Toroidální magnetické pole udržuje plazma



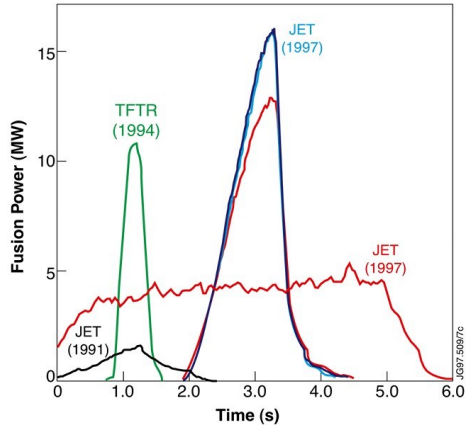
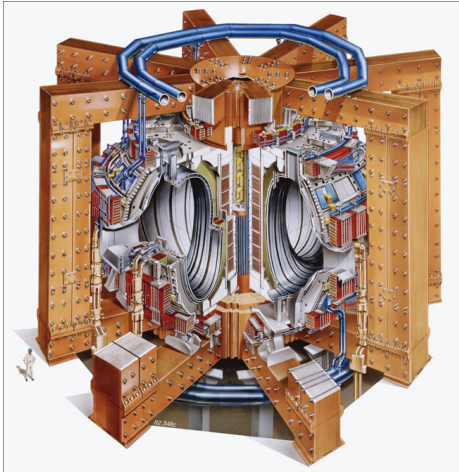
Transformátorová akce vytvoří a zahřeje plazma



Vše dohromady - voilà tokamak

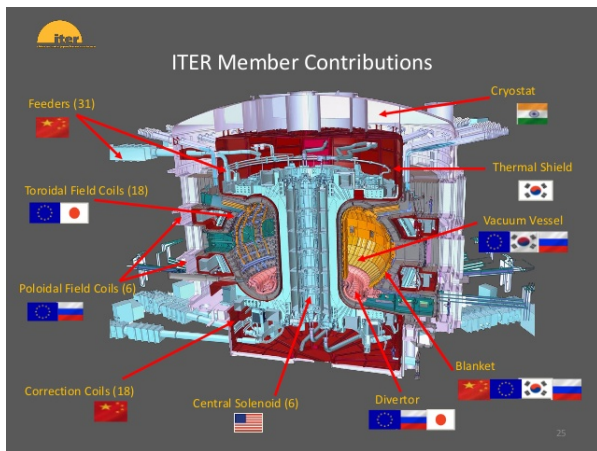


1997: Světový fúzní rekord @ JET (EU)



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

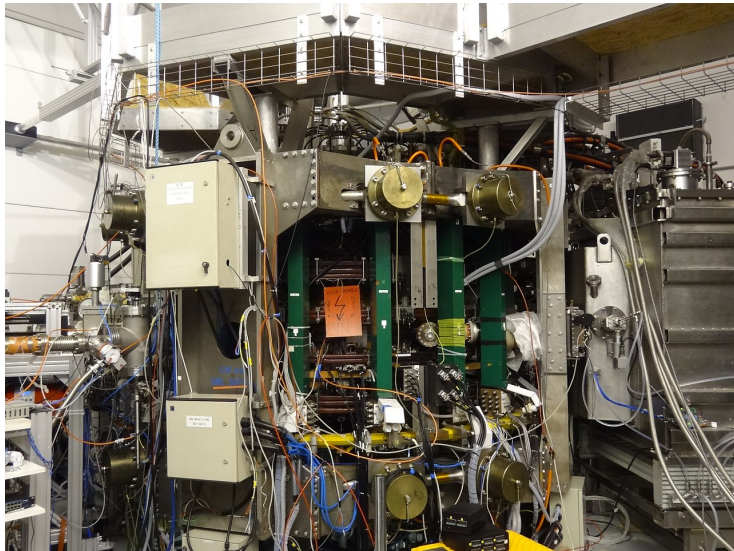
ITER (jižní Francie) \approx 18 miliard EUR



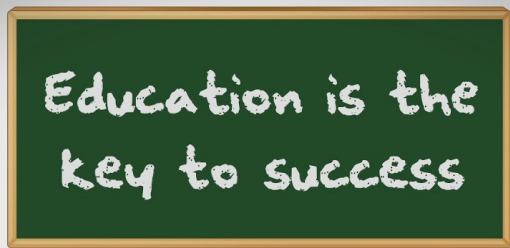
Mise:

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

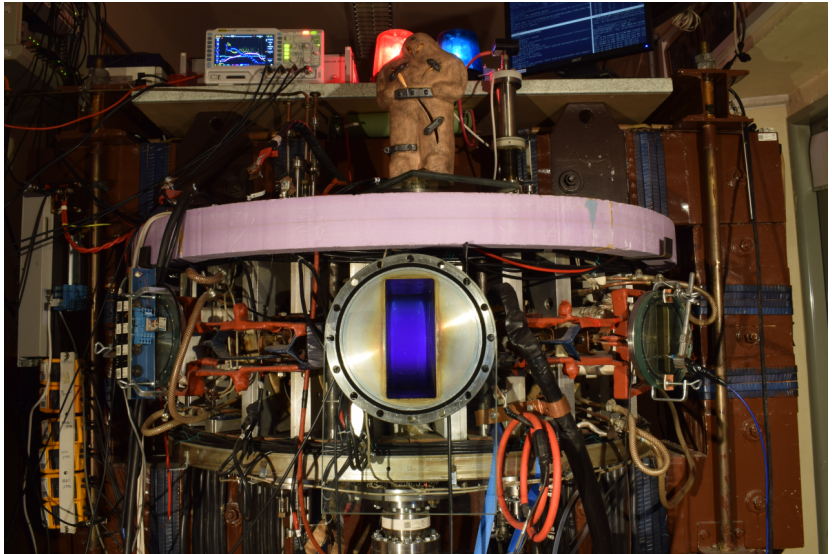
Příspěvek České republiky: tokamak COMPASS@IPP.CAS.CZ



Velké ambice



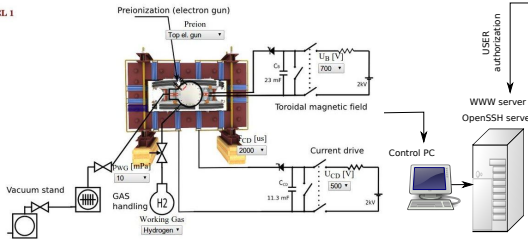
Tokamak GOLEM



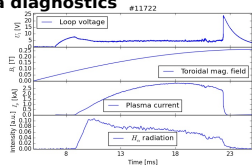
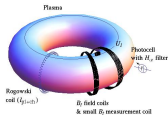
Tokamak GOLEM - experimentální schéma

LEVEL 1

Tokamak technology setup



Basic plasma diagnostics



internet

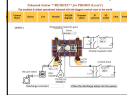
**Virtual control room
(remote participation)**

WWW control interface

Data presentation

HTML & PHP scripts

HTML (www pages)



SSH control interface

WINDOWS via putty

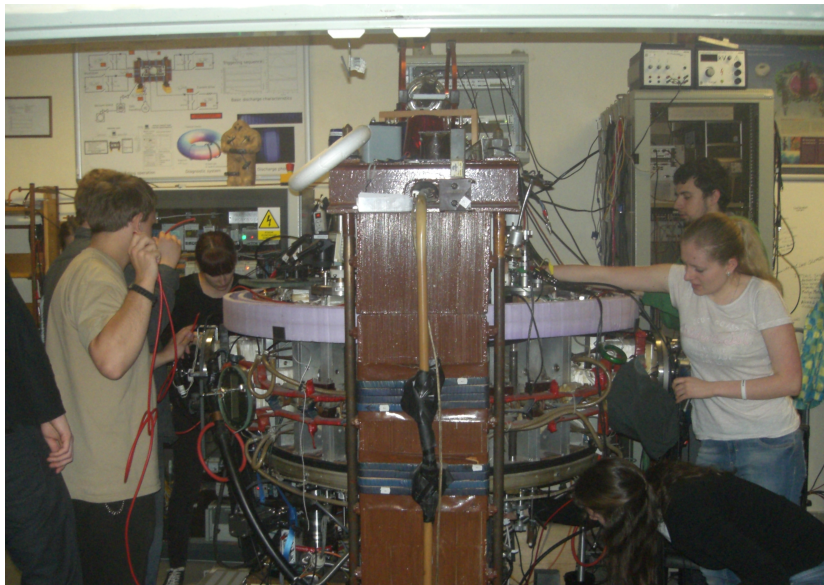
Data handling



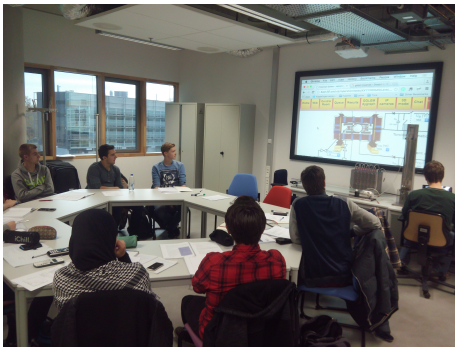
LINUX via ssh
or ssh+X tunnel
(advanced mode)

- *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



Pozvánka na workshop

Big Bang stage dnes 20:00, zítra 14:00

Go to <http://golem.fjfi.cvut.cz/CoO>

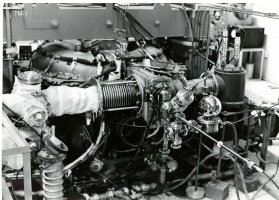
... a odpalte si svůj vlastní tokamakovy výboj ..
z jakéhokoli zařízení s internetem (klidně z mobilního telefonu)

GOLEM



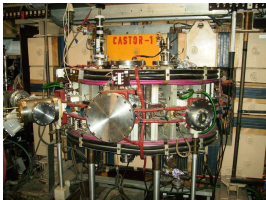
Děkuji za pozornost

Tokamak TM1
@Kurchatov Institute near Moscow
~1960-1977



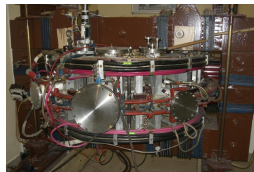
SCIENCE

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

LEVEL 1

Preionization (electron gun)
Preion:

Toroidal magnetic field

Current drive

Discharge comment:

Place the discharge setup into the queue

Tokamak GOLEM @ Wikipedia ..

File Edit View Go Bookmarks Tools Settings Window Help

home | Kalendář | Produkce | Forecast | Slovnik | Rano

Not logged in | Talk | Contributions | Create account | Log in

Article | **Talk** | Read | Edit | View history | Search

WIKIPEDIA

The Free Encyclopedia

Main page
Contents
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 ISTOK,^[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:

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Students, teachers, technicians (random order):

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