Spoutání energie hvězd v pozemských podmínkách

Vojtěch Svoboda

Základní popularizační přednáška 2019

November 1, 2019

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

Hlavní budova FJFI v Praze - Břehová

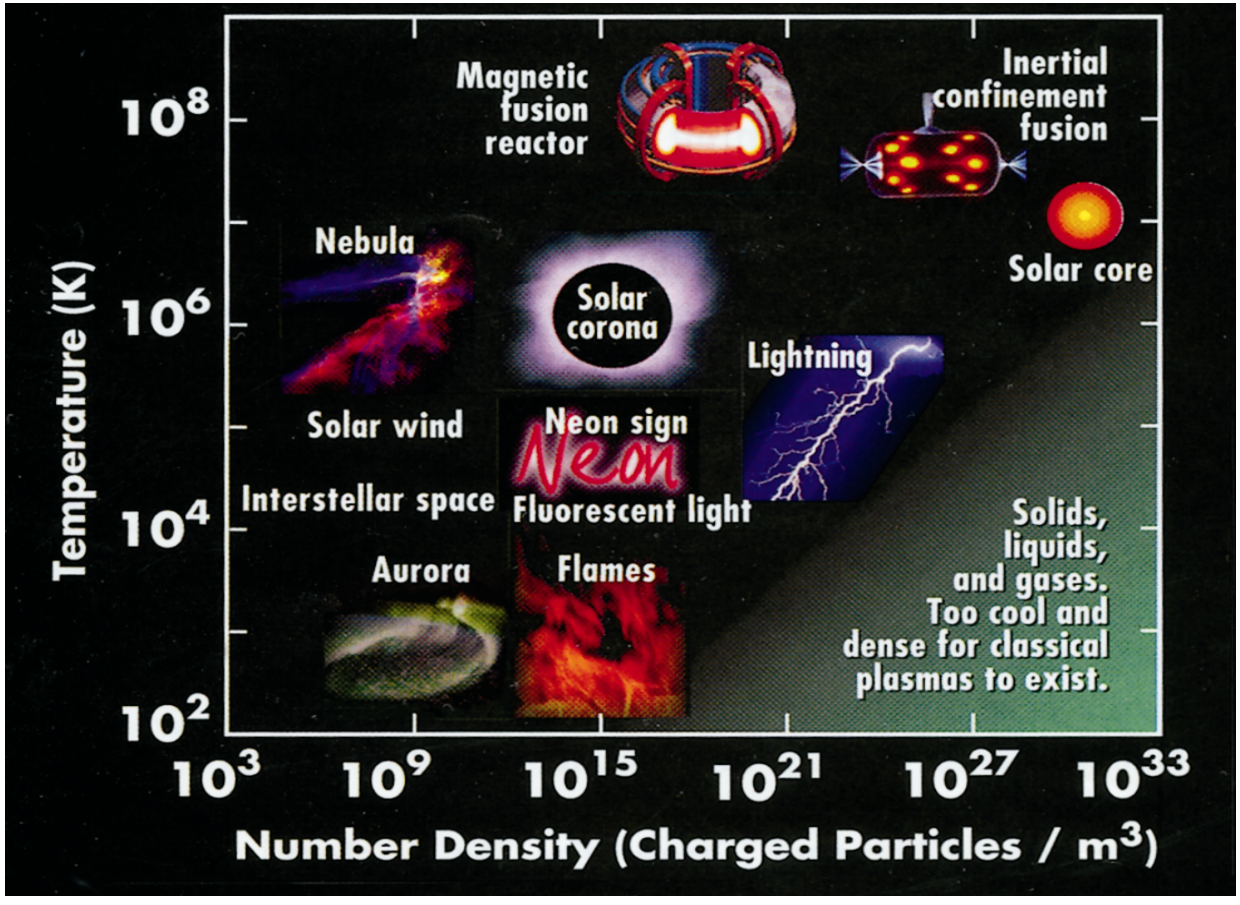
insignie FJFI

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.

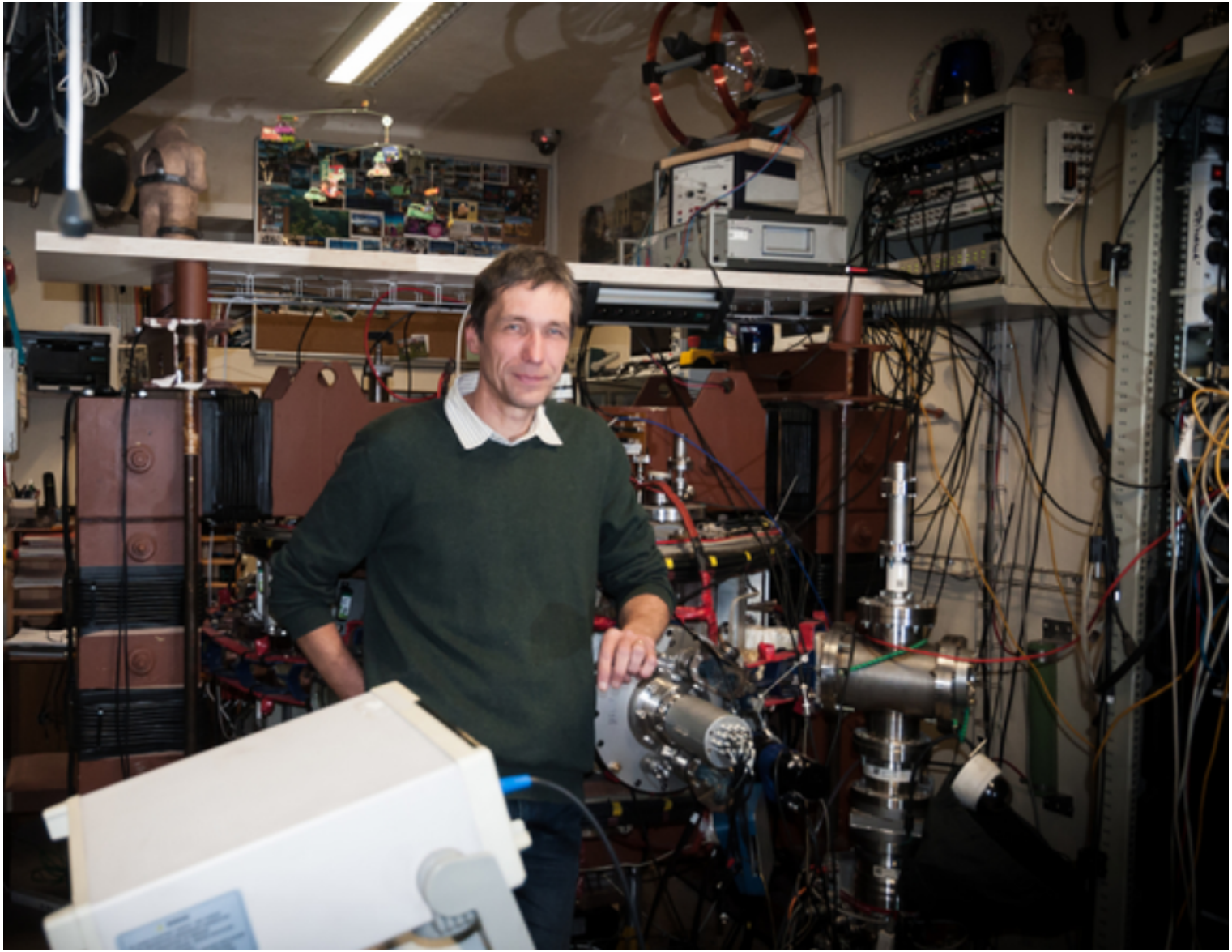
Badatelská skupina / studijní specializace

Fyzika plazmatu a termojaderné fúze



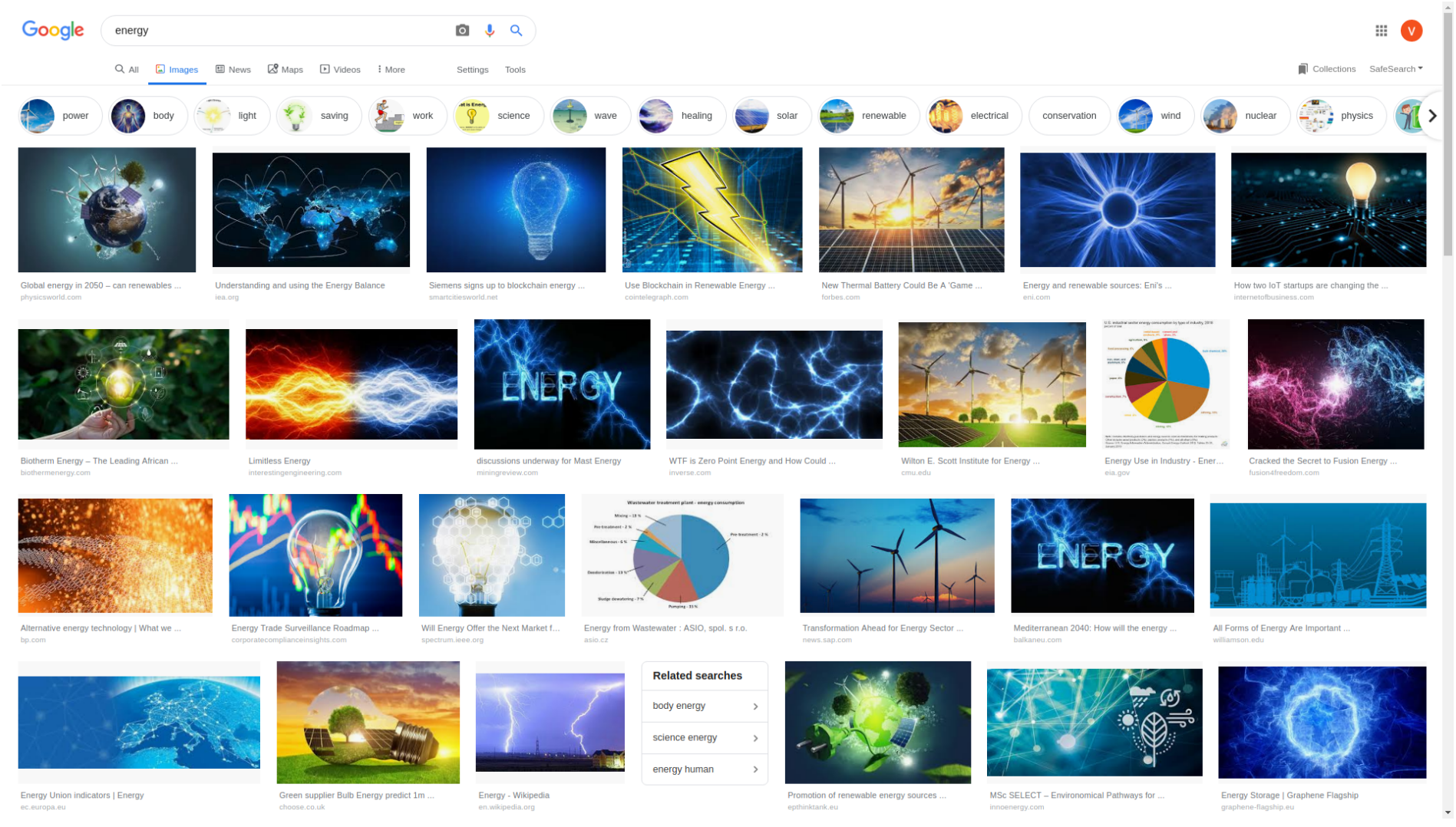
99.999 % Vesmíru je v plazmatickém stavu

Tokamak GOLEM & Vojtěch Svoboda

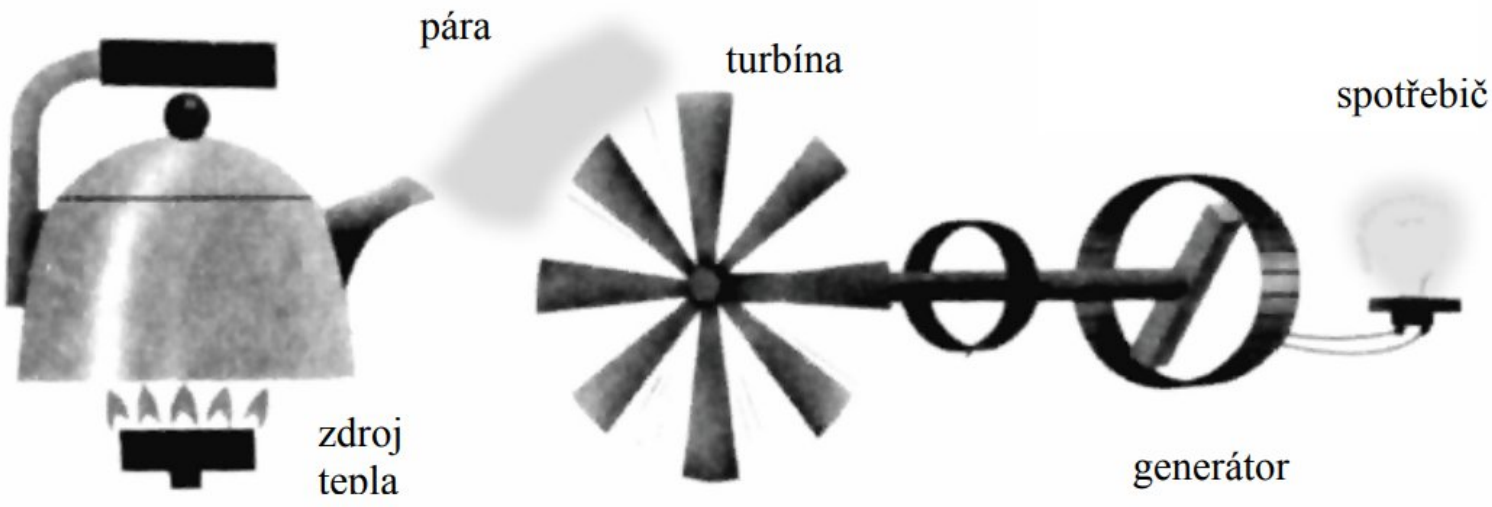


Google: Energy

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



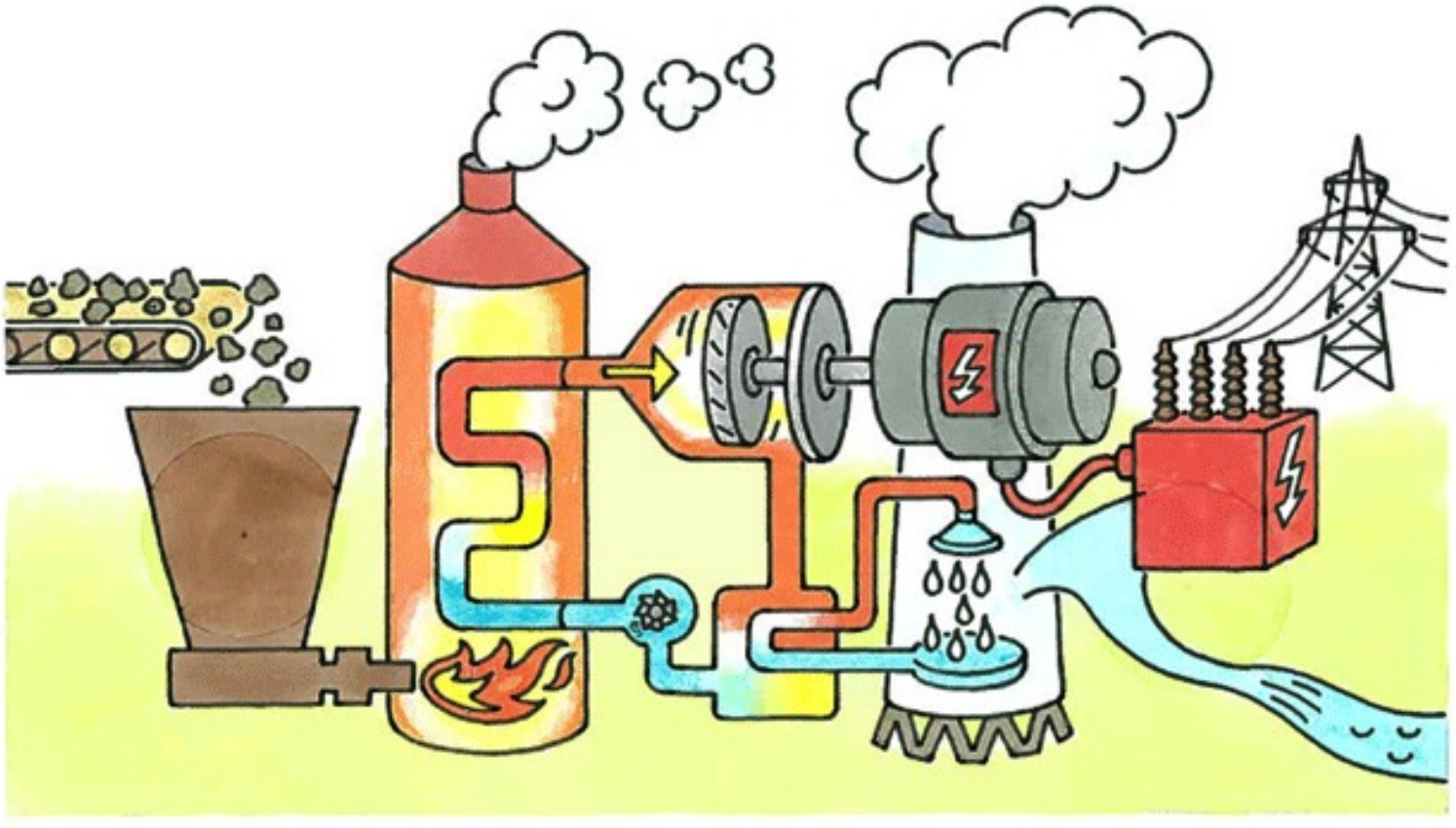
Základní princip tepelné elektrárny



Základní otázka zní:

?? Čím topit ??

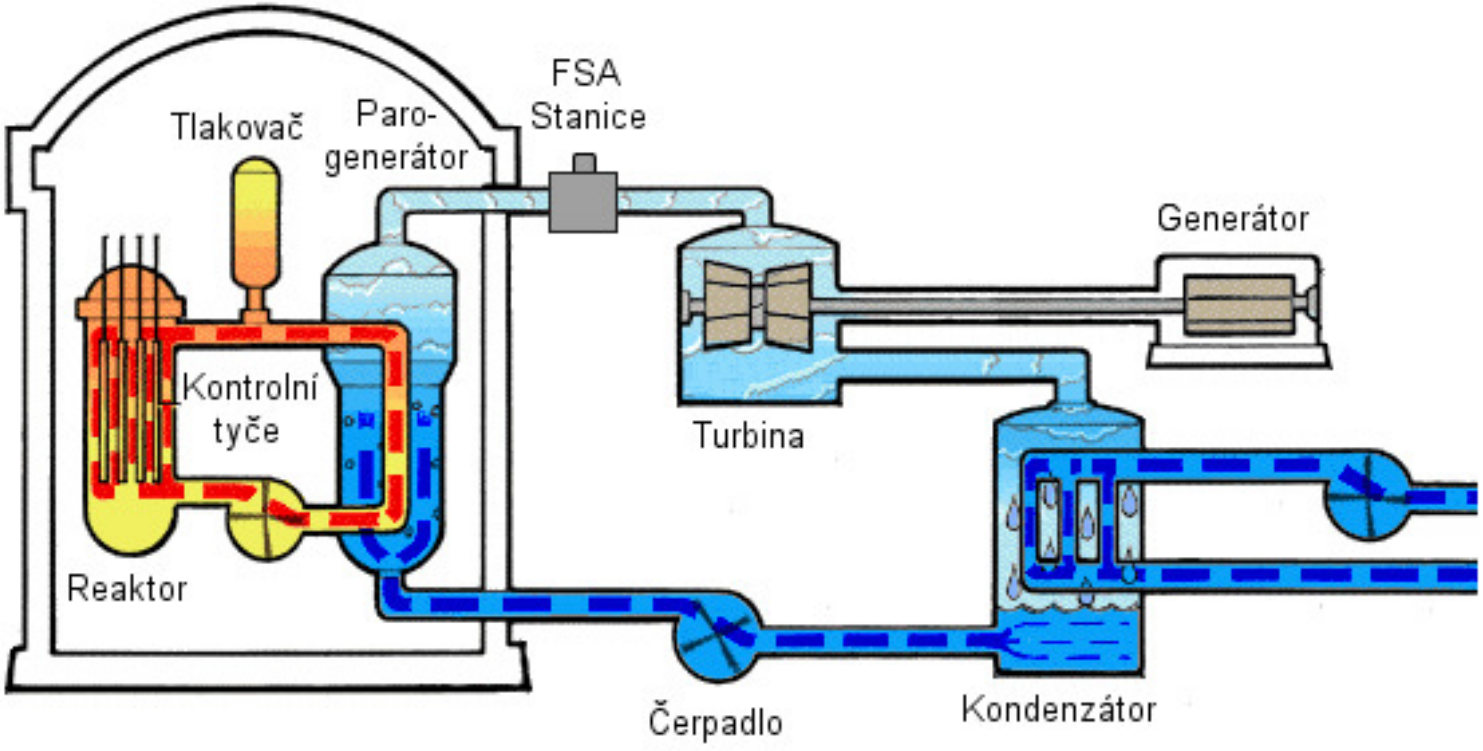
Uhelná elektrárna



Praha ($\sim$ 1 GW): denně $\sim$ vlak uhlí

Emise

Jaderná elektrárna - štěpná

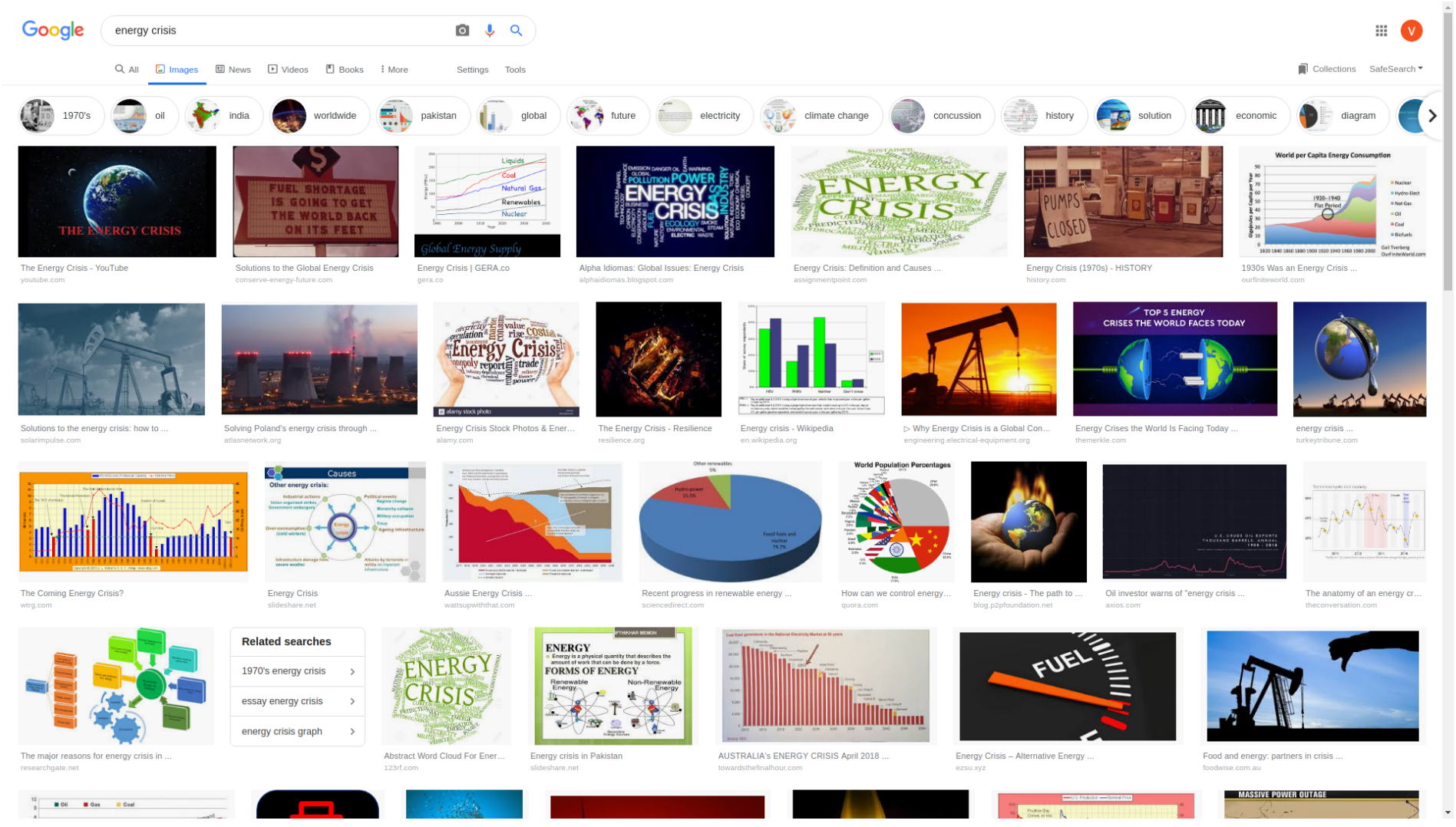


Praha ($\sim$ 1 GW): ročně $\sim$ vagón jaderného paliva

Dotáhnout technologii: Suroviny, Odpad, Bezpečnost

Google: Energy Crisis

About 501,000,000 results (0.51 seconds)



The Energy Crisis - YouTube
youtube.com

Solutions to the Global Energy Crisis
conserve-energy-future.com

Energy Crisis | GERA.co
gera.co

Alpha Idiomas: Global Issues: Energy Crisis
alphaidiomas.blogspot.com

Energy Crisis: Definition and Causes ...
assignmentpoint.com

Energy Crisis (1970s) - HISTORY
history.com

1930s Was an Energy Crisis ...
ourfiniteworld.com

Solutions to the energy crisis: how to ...
solarimpulse.com

Solving Poland's energy crisis through ...
atlasnetwork.org

Energy Crisis Stock Photos & Ener...
alamy.com

The Energy Crisis - Resilience
resilience.org

Energy crisis - Wikipedia
en.wikipedia.org

▷ Why Energy Crisis is a Global Con...
engineering.electrical-equipment.org

Energy Crises the World Is Facing Today ...
themerkle.com

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turkeytribune.com

The Coming Energy Crisis?
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Energy crisis - The path to ...
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Oil investor warns of "energy crisis ...
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The major reasons for energy crisis in ...
researchgate.net

Abstract Word Cloud For Ener...
123rf.com

Energy crisis in Pakistan
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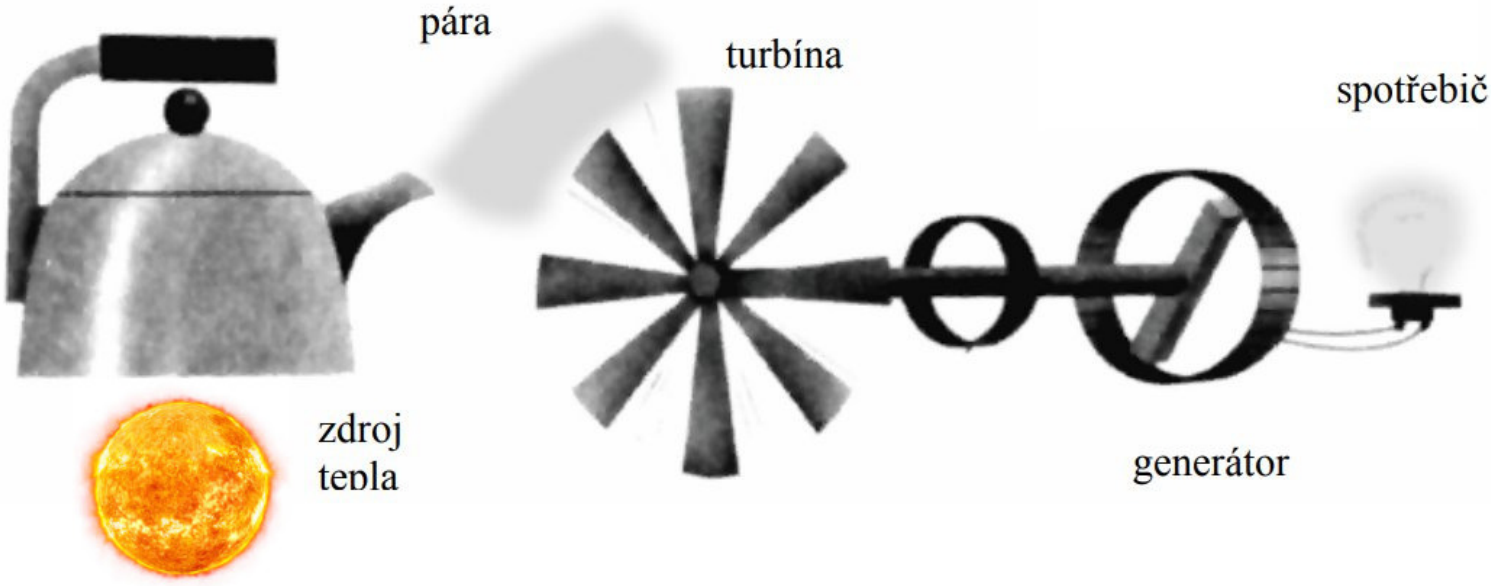
AUSTRALIA's ENERGY CRISIS April 2018 ...
towardsthefinalhour.com

Energy Crisis – Alternative Energy ...
ezsu.xyz

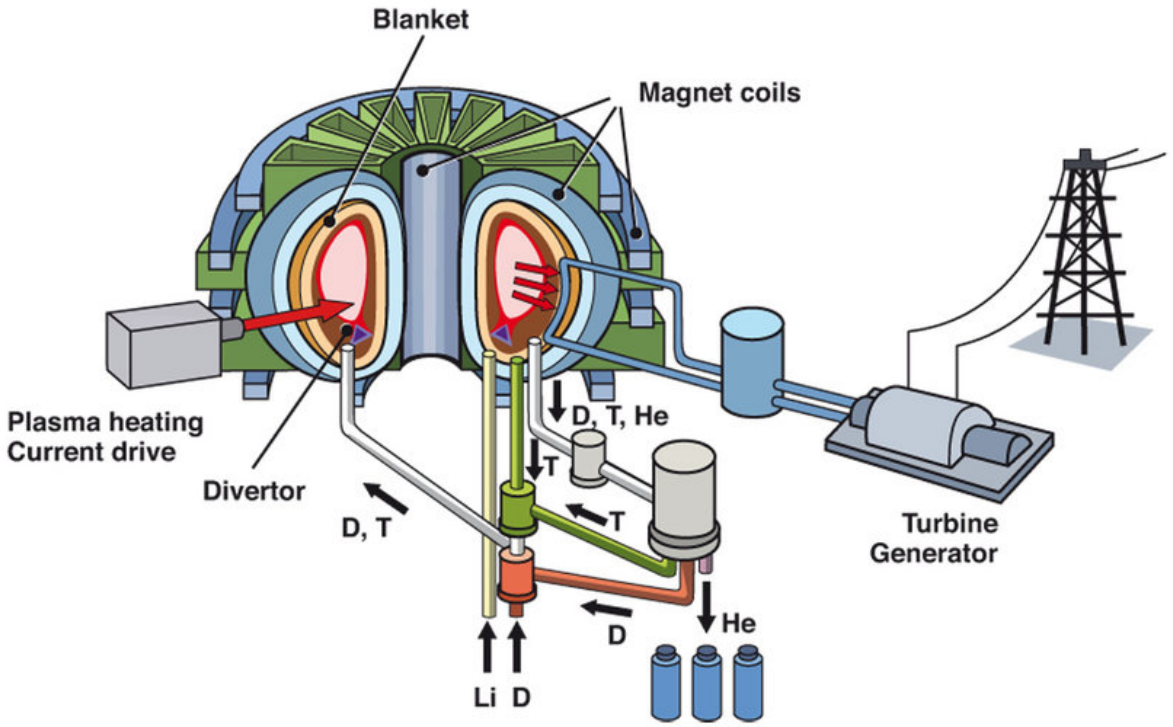
Food and energy: partners in crisis ...
foodwise.com.au

Topit malým Sluncem/hvězdou ??



Výzva

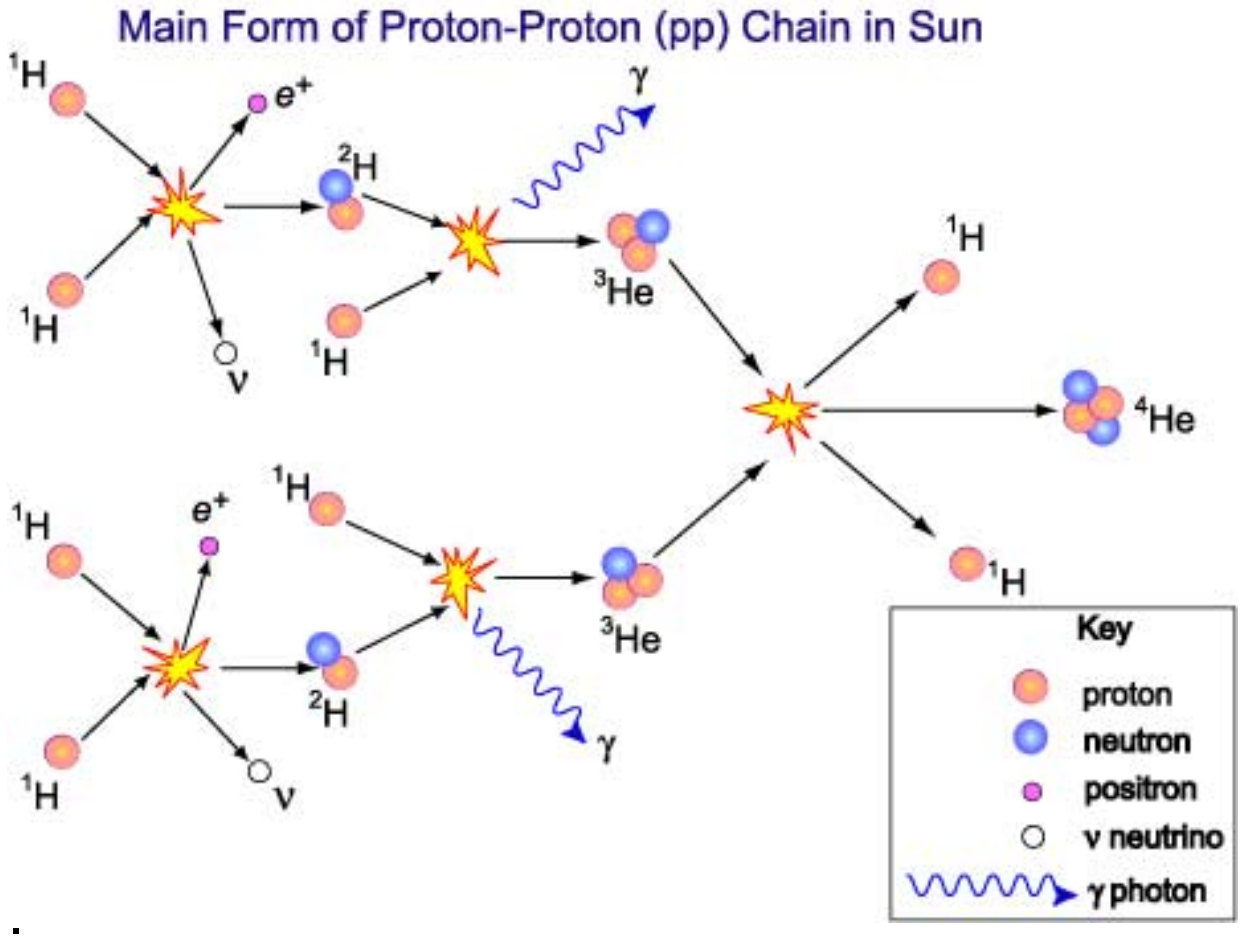
Vize: Jaderná elektrárna - slučovací/fúzní



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

Vypiplat technologii

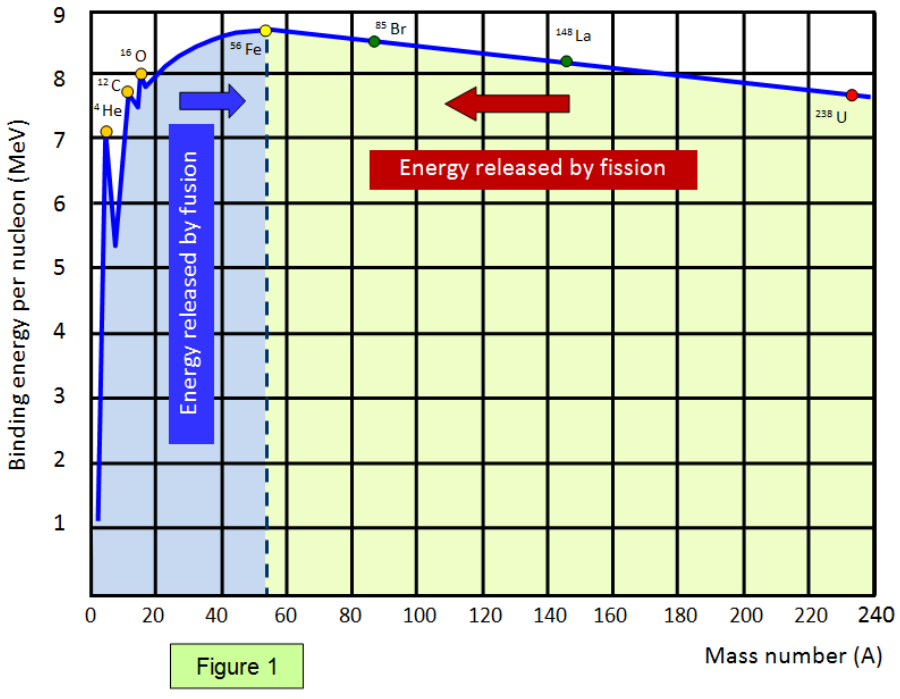
Inspirace: Slunce - protonový řetězec

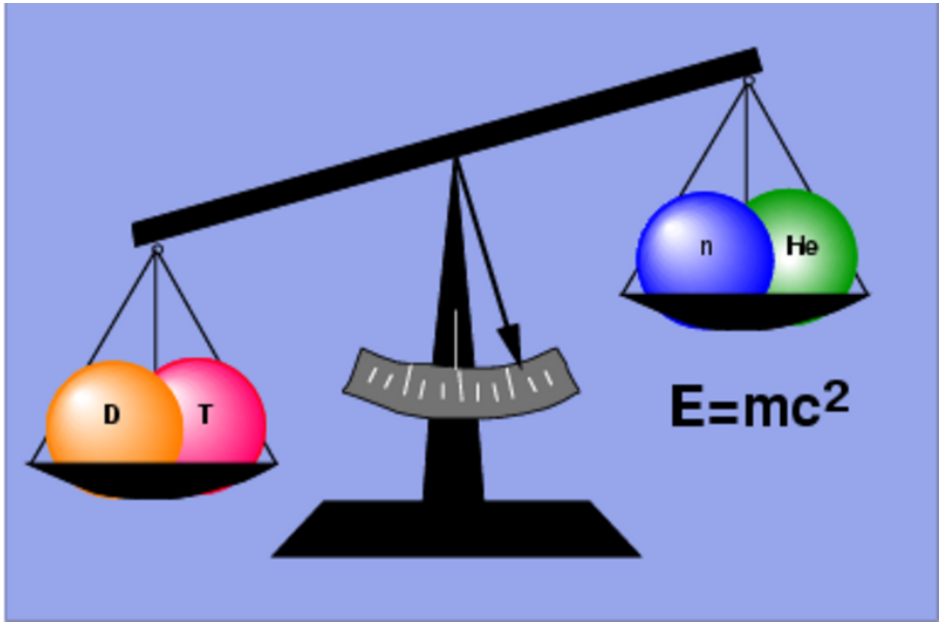


credit:CSIRO

$$4\ {}^{1}_{1}\mathbf{p} \Rightarrow {}^{4}_{2}\mathbf{He} + 2\ \mathbf{e}^{+} + 2\ \nu_{\mathbf{e}} + 2\ \gamma + \mathbf{26.73\ MeV}$$

Uvolnění vazebné energie atomových jader

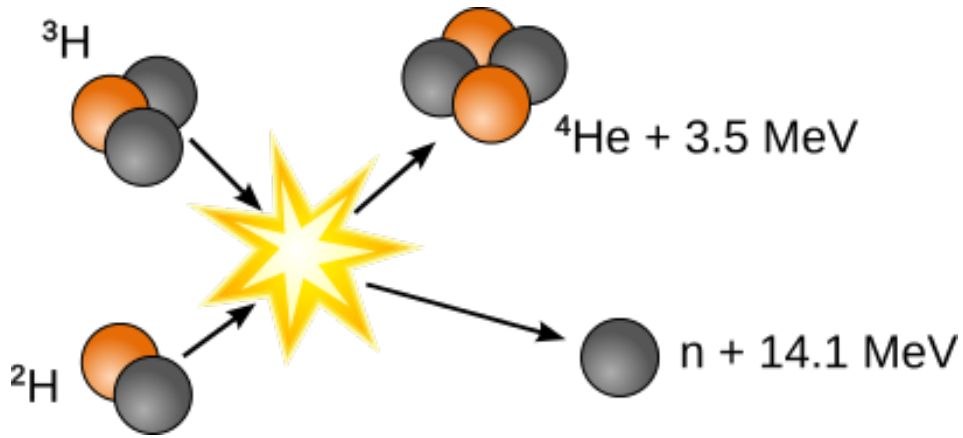




fúze lehkých jader X štěpení těžkých jader

$^{2}\mathbf{D}+^{3}\mathbf{T} \Rightarrow ^{4}\mathbf{He}+^{1}\mathbf{n}+\mathbf{17.6MeV}$ X $^{235}\mathbf{U}+\mathbf{n_{thermal}} \Rightarrow ^{89}\mathbf{Kr}+^{144}\mathbf{Ba}+\mathbf{3n}+\mathbf{176MeV}$

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



credit:[?]

$$\mathbf{^2_1H_{10\ keV} + {}^3_1H_{10\ keV} \Rightarrow {}^4_2He_{3.5\ MeV} + {}^1_0n_{14.1\ MeV}}$$

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

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

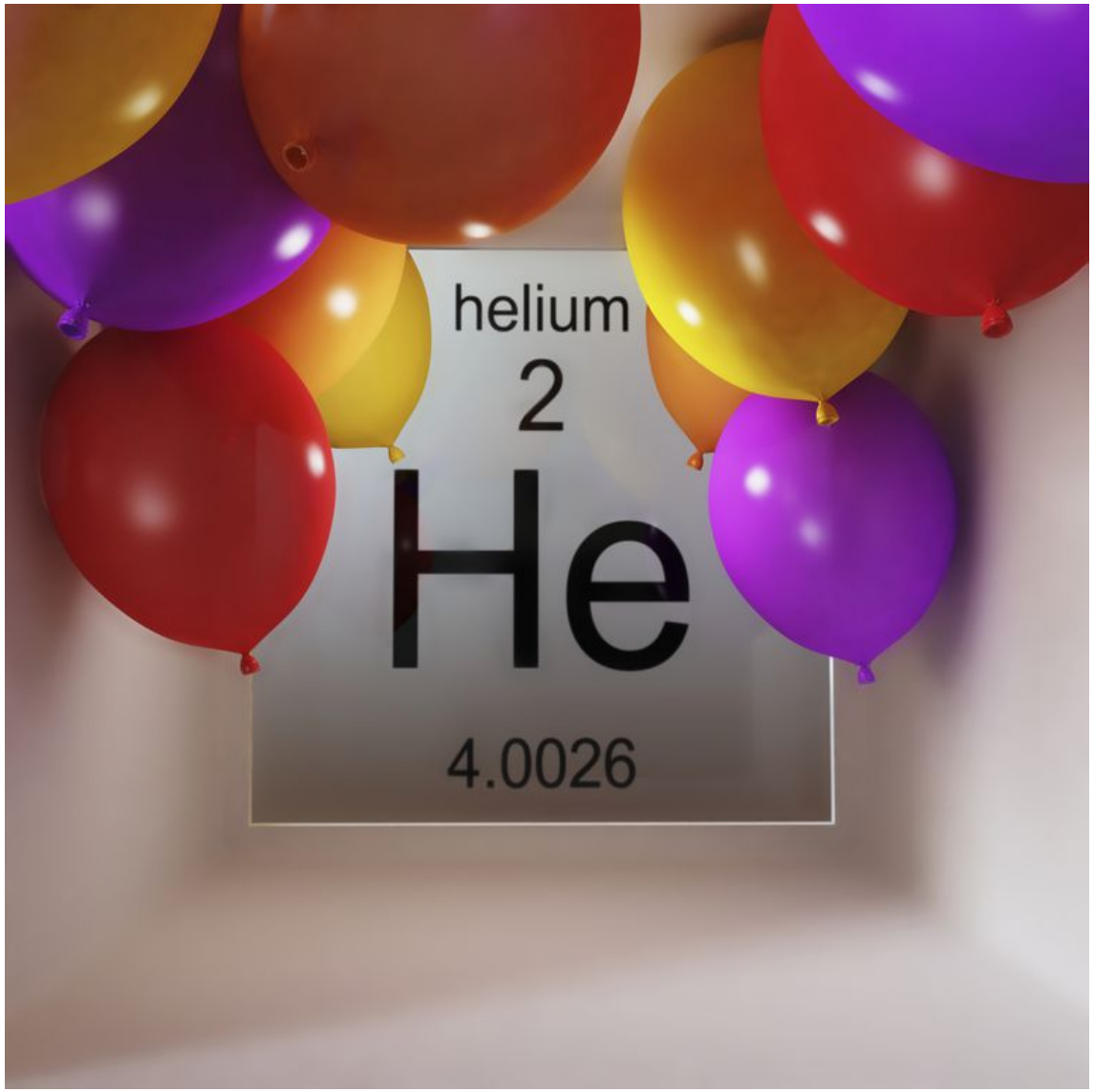
pak hmotnostní schodek $\Delta m = 0.01888 m_u$.

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

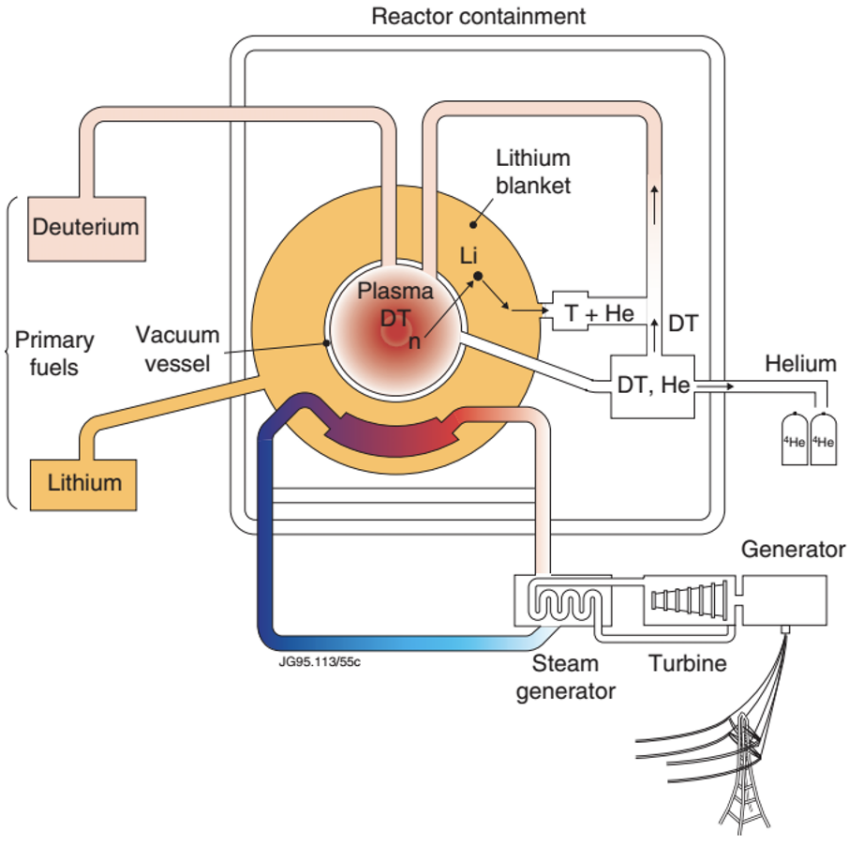
$$1\mathrm{eV} \sim 11600^\circ\mathrm{C} \approx \quad \mathbf{^2_1H_{100\ M\circ C} + {}^3_1H_{100\ M\circ C} \Rightarrow {}^4_2He_{35\ G\circ C} + {}^1_0n_{141\ G\circ C}}$$

Palivo: IAEA "Natural water"

Odpad



Bezpečnost



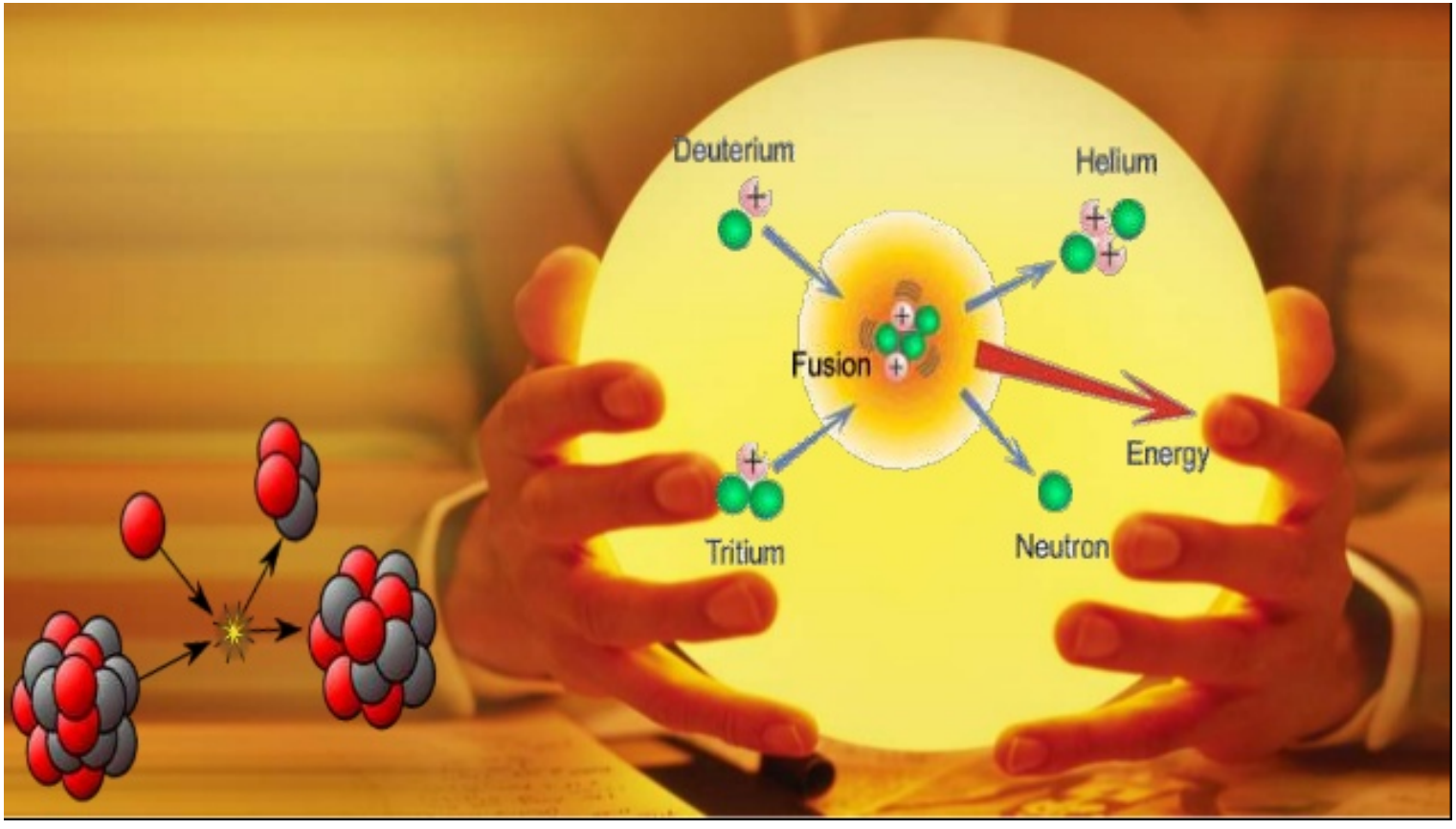
* Nejde o řetězovou reakci.
* Tritium: slabý β zářič $T_{1/2} = 12.5\ \mathrm{roku}$. Minimální nebezpečí.
* Minimalizovaný potenciál aktuálně přítomného D-T paliva.

1952 "Operation Ivy - Mike" První test vodíkové bomby

credit:YouTube:Ivy Mike Countdown and detonation

Toto není vhodná technologie

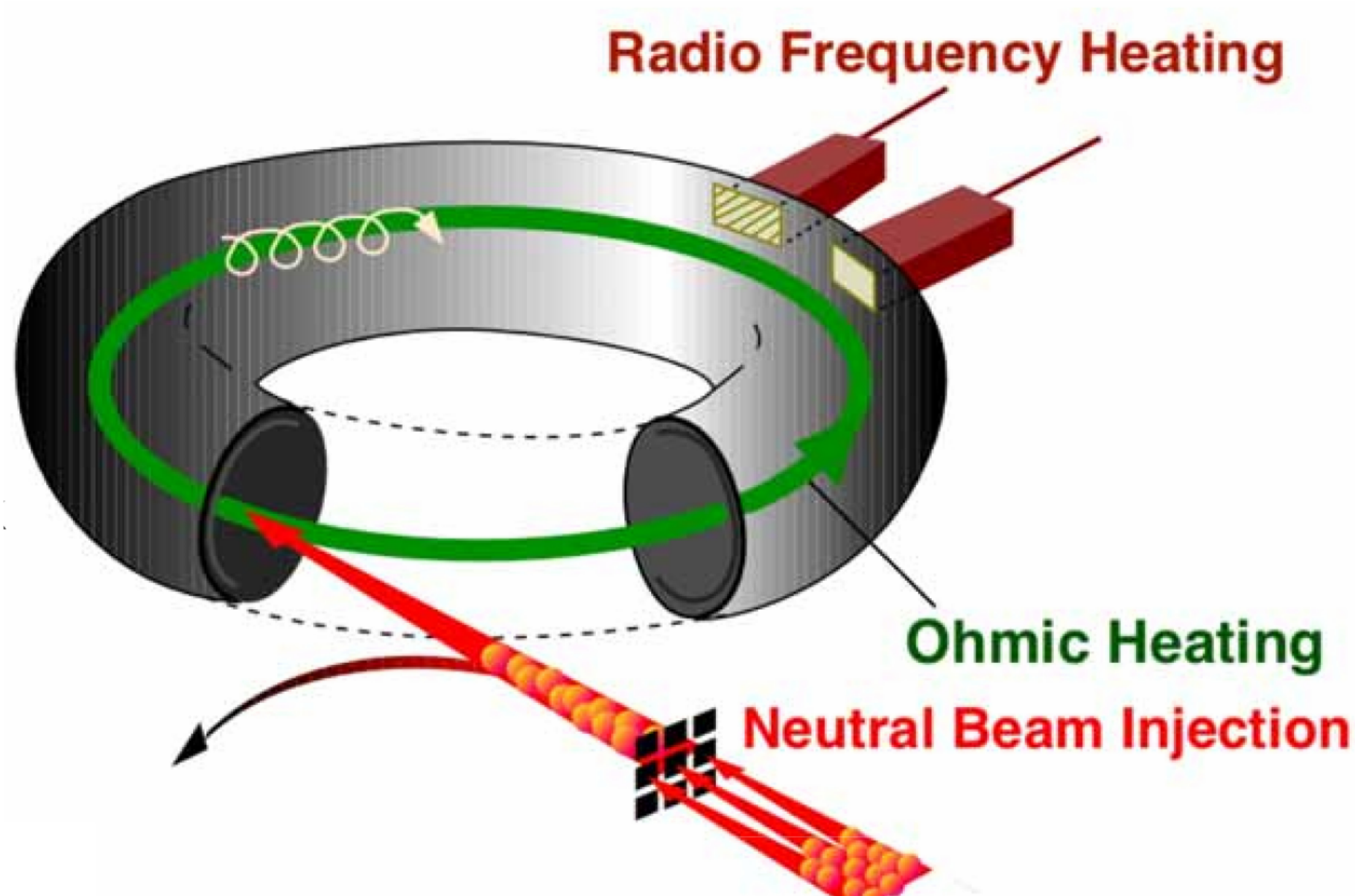
Hledá se vhodná fúzní technologie



Podmínky:

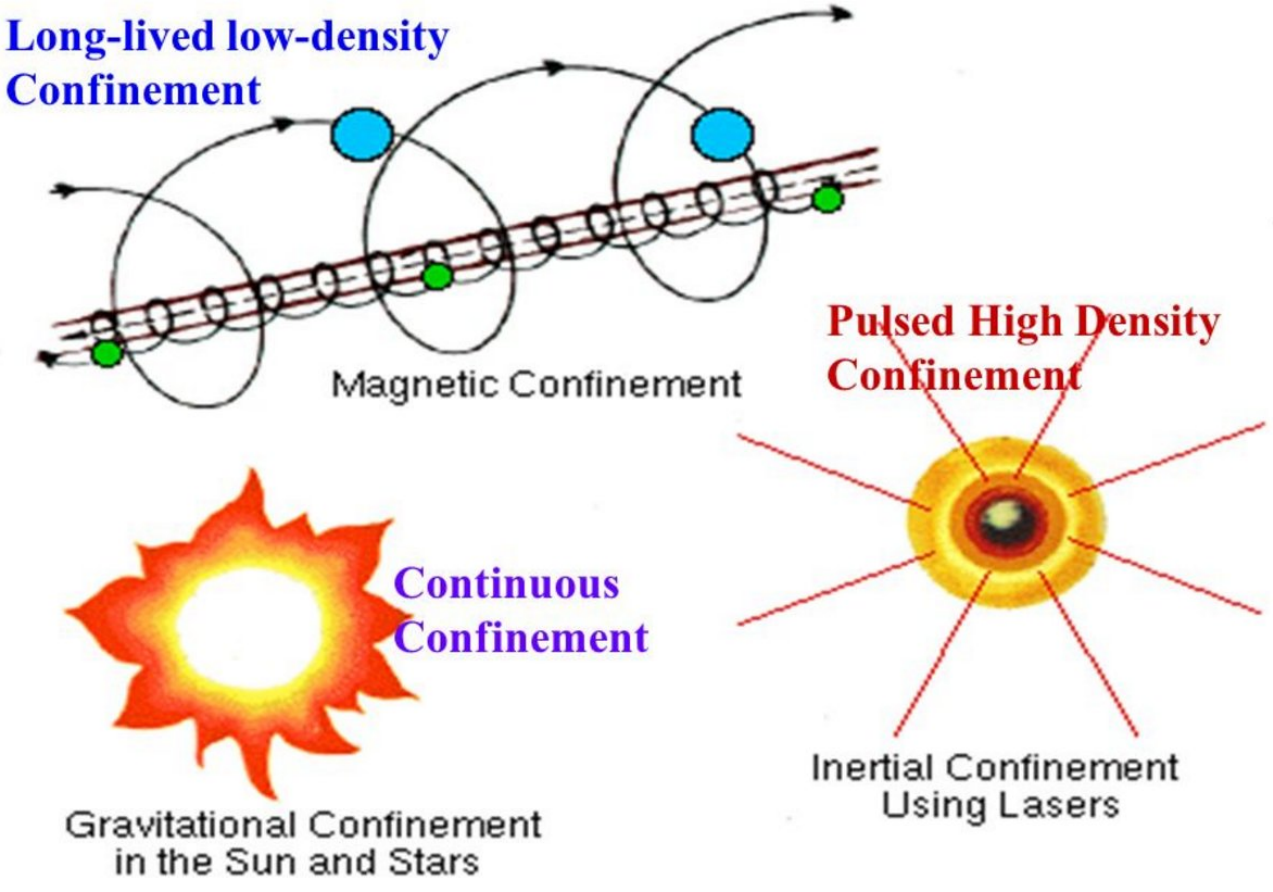
Zahřát na $\sim$ 100 000 000 °C & **udržet** po dobu $\sim$ 30 let

Ohřev plazmatu

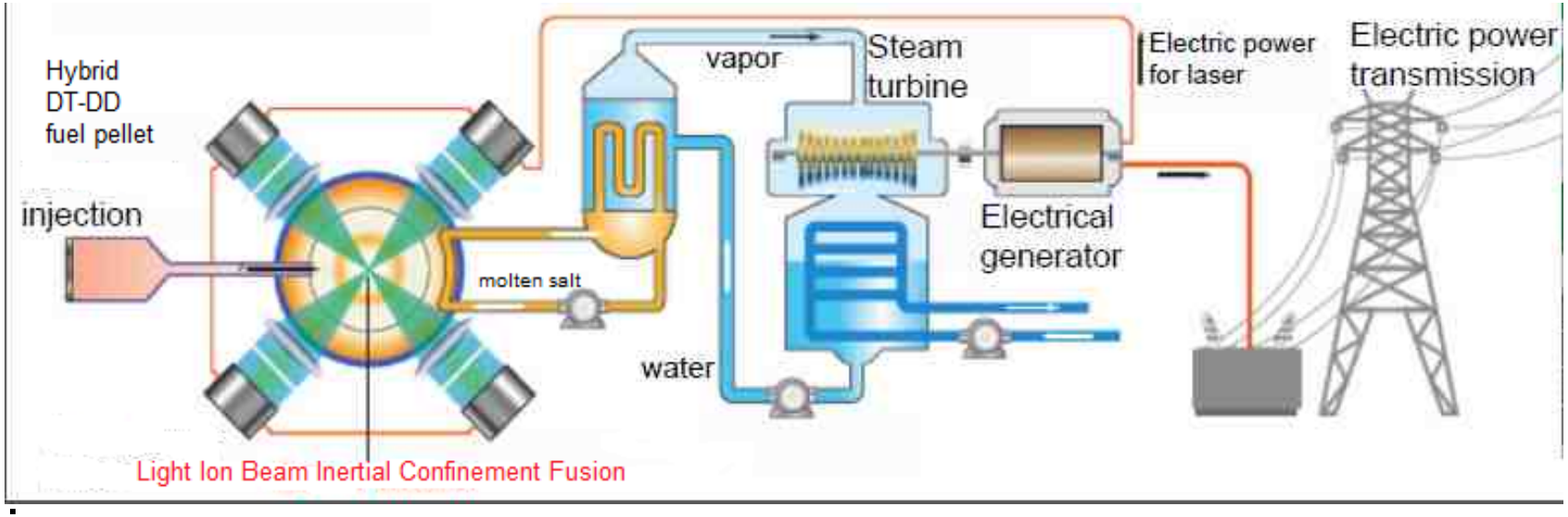


Tři možné cesty jak udržet plazma pro fúzi

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



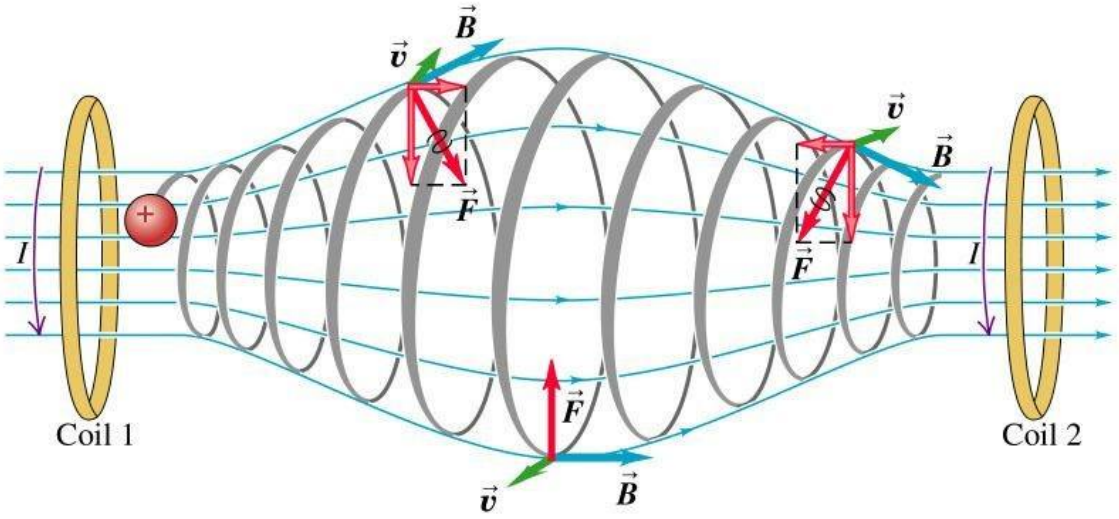
Inerciální fúze



credit:mext.jp

Velká výzva

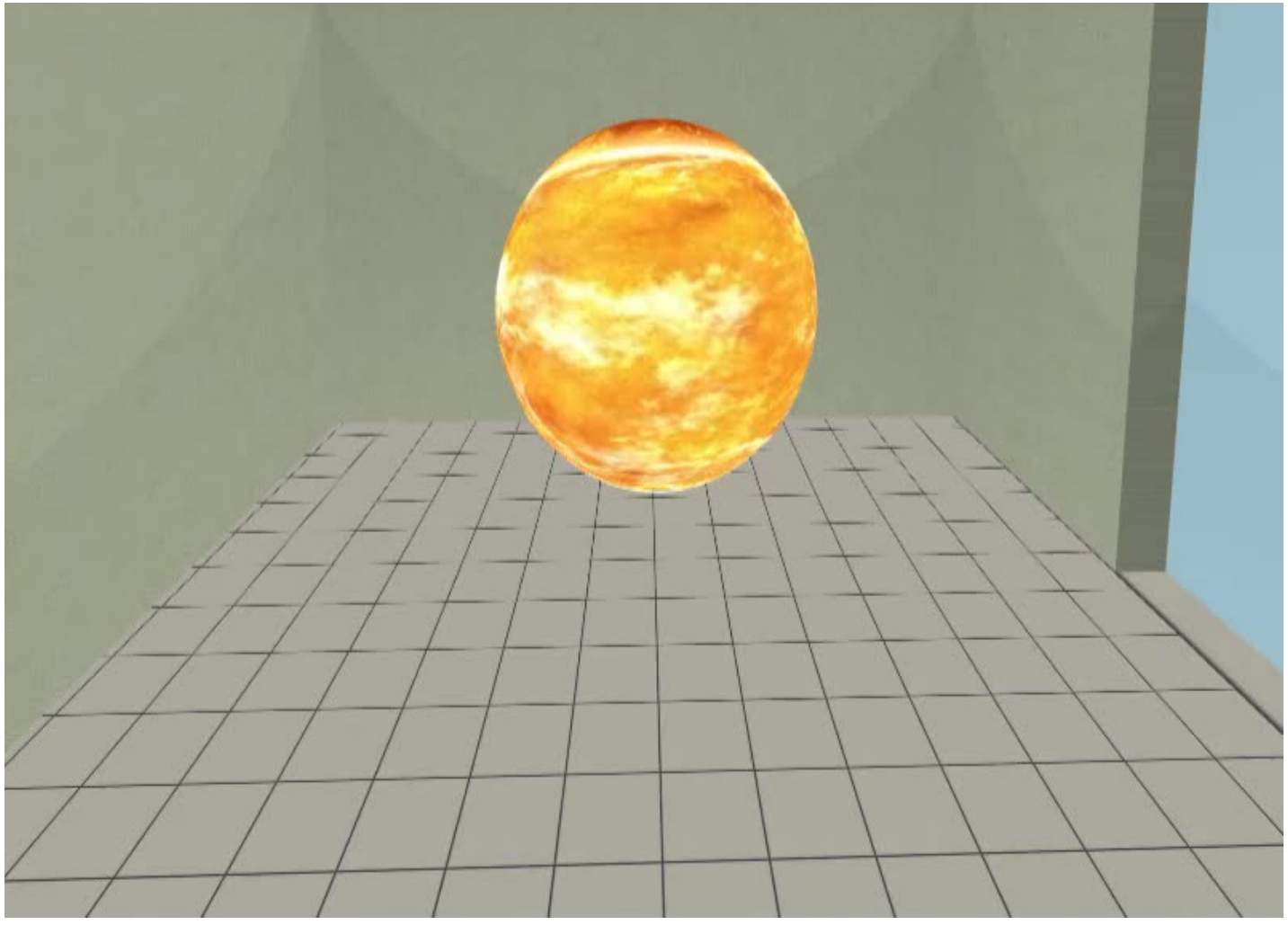
Magnetické udržení: magnetická nádoba



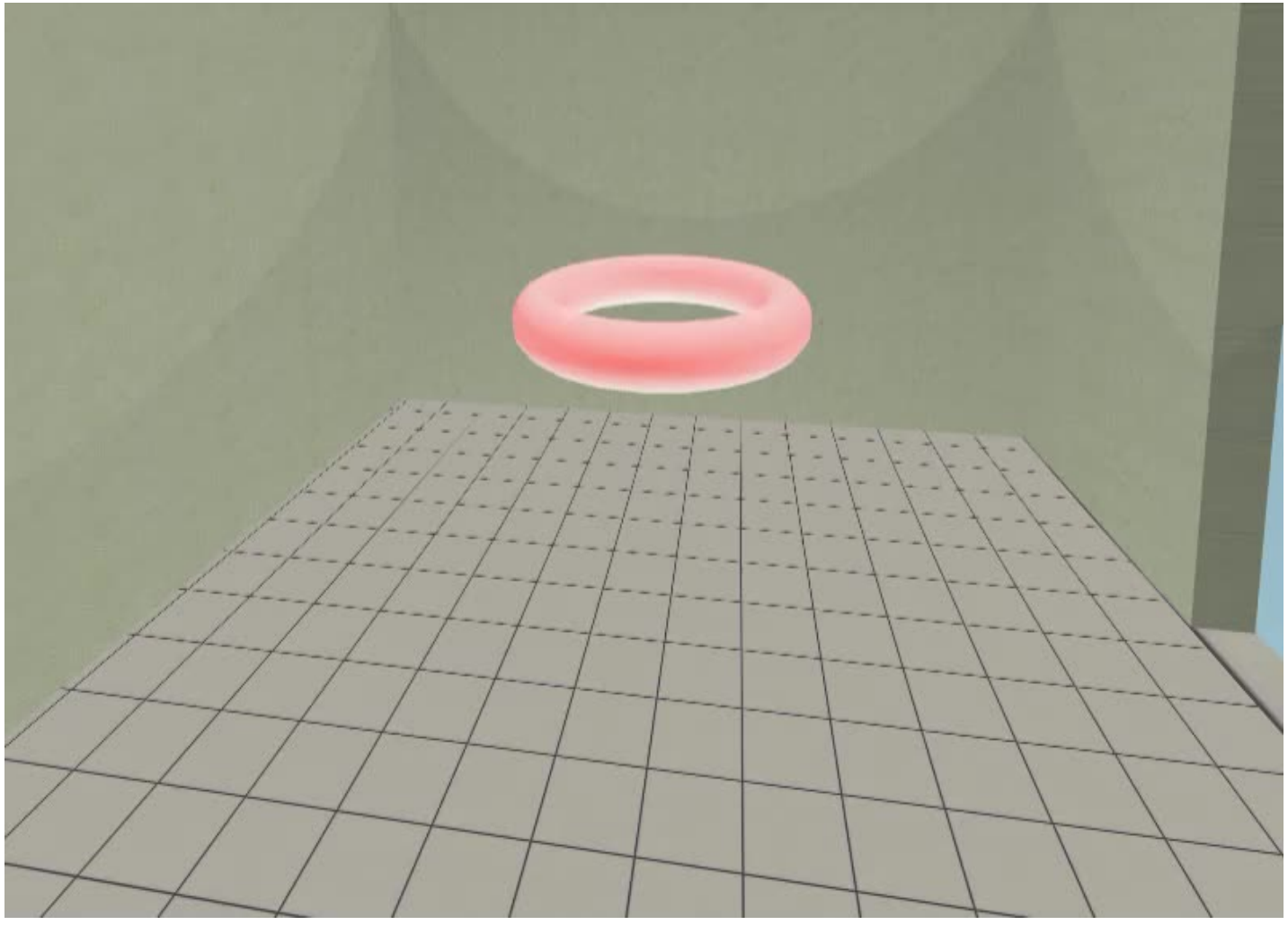
Musíme ji ale svinout do kruhu (zbavit se podstav)

záchranný kruh/duše pneumatiky/kobliha - donut

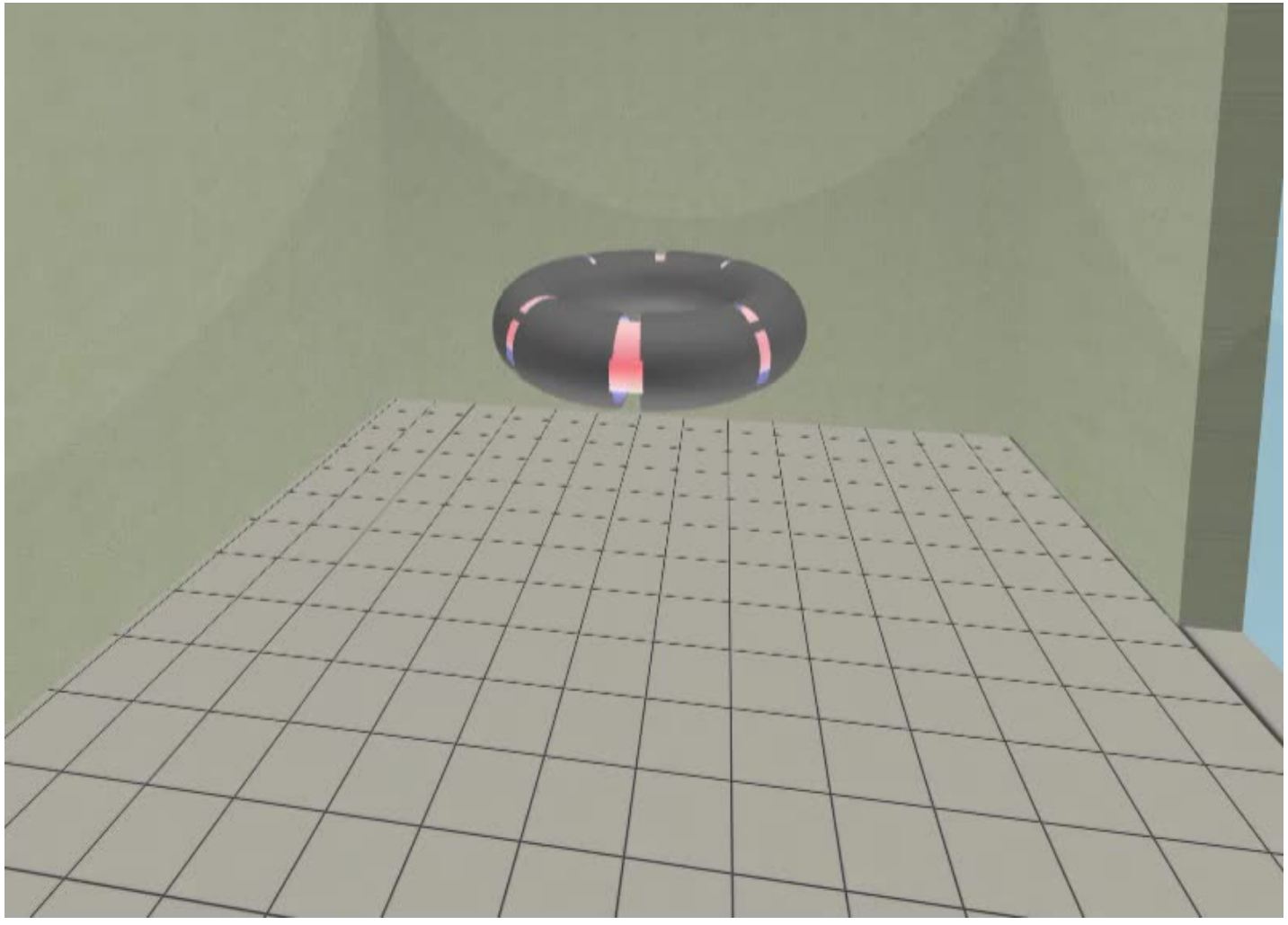
Náš cíl: vytvořit μSlunce v pozemských podmínkách



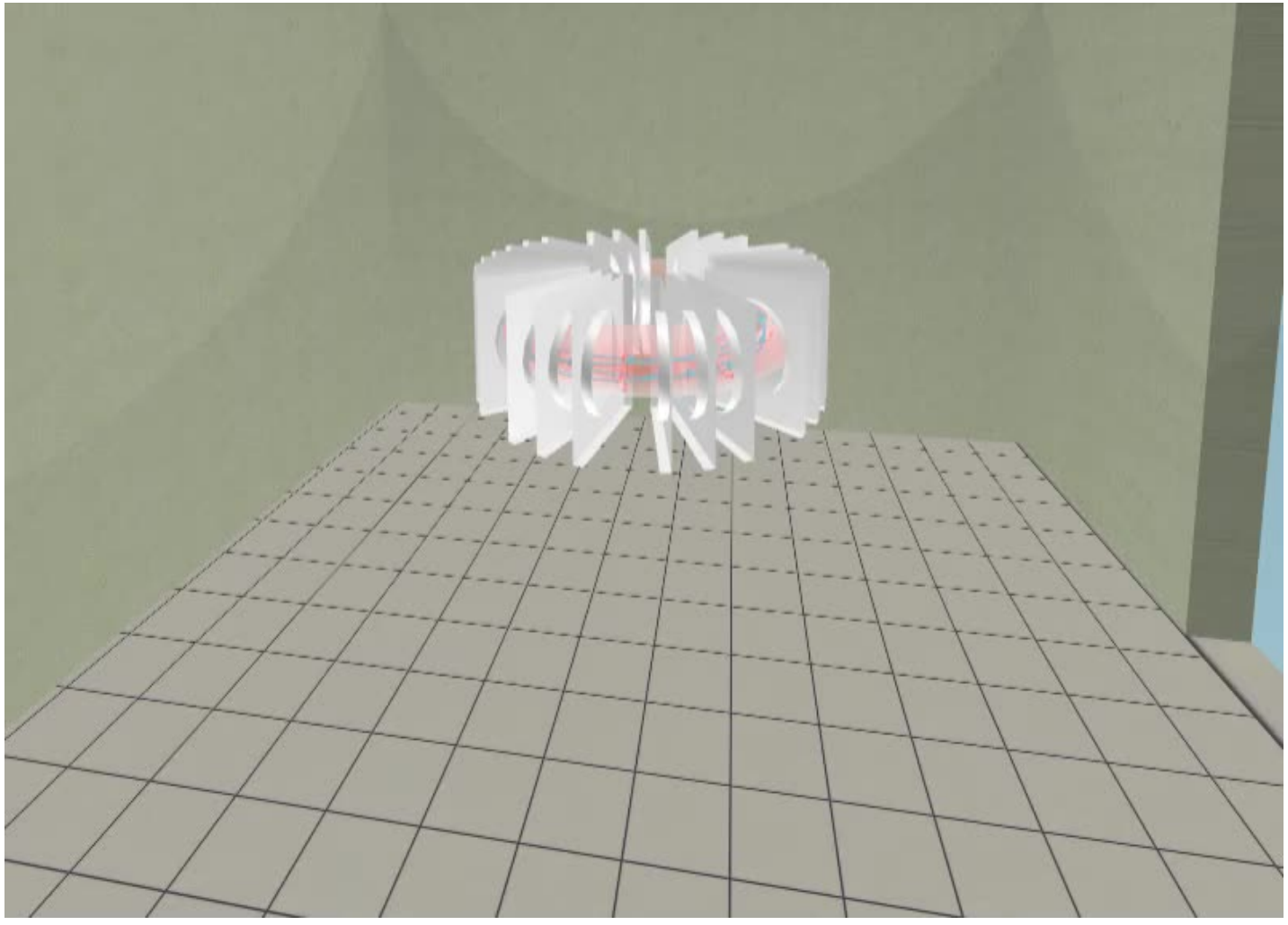
Magnetické udržení vyžaduje toroidální geometrii
Svinutá magnetická nádoba



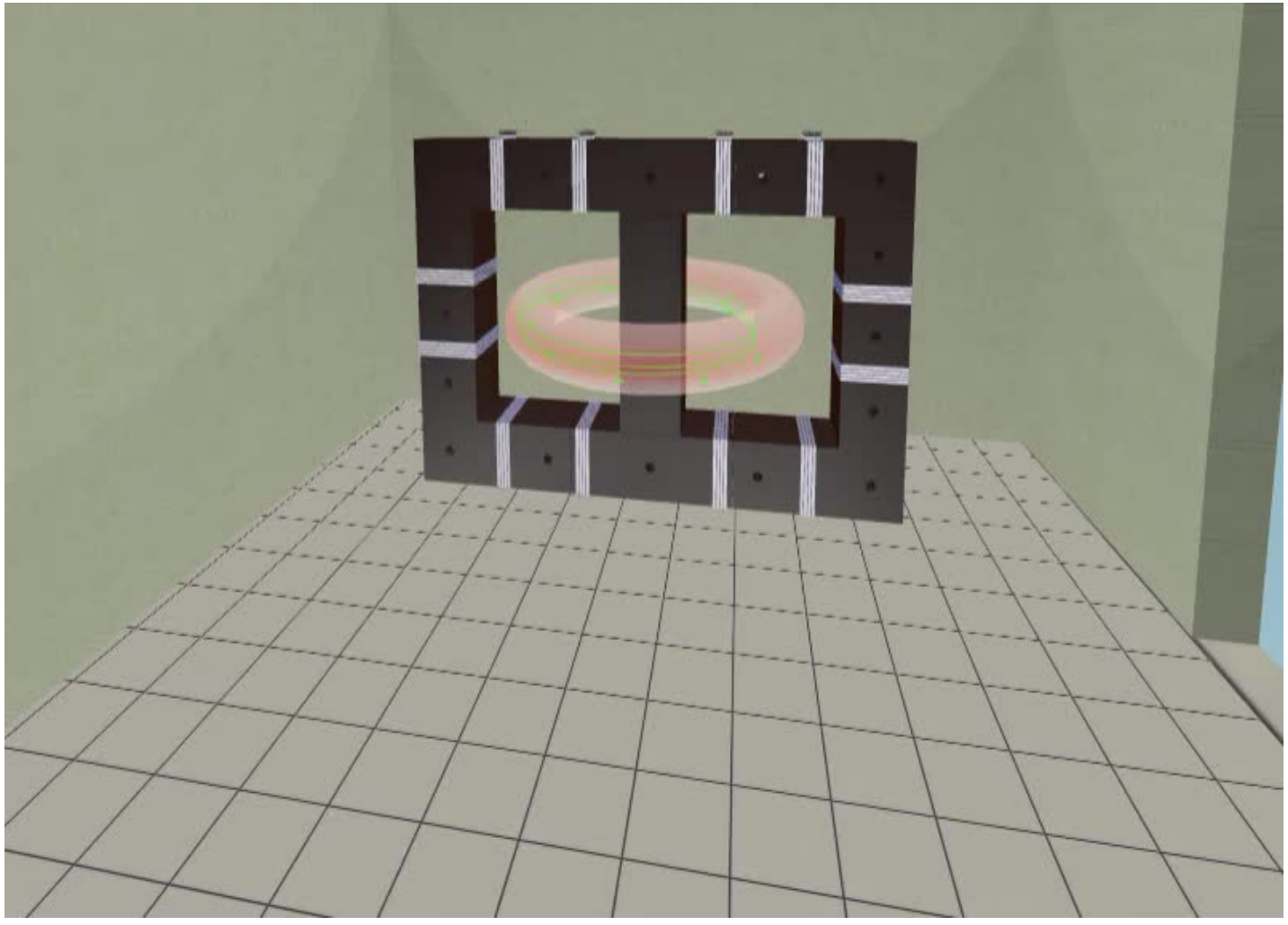
Musíme to celé umístit do reaktorové nádoby - komory



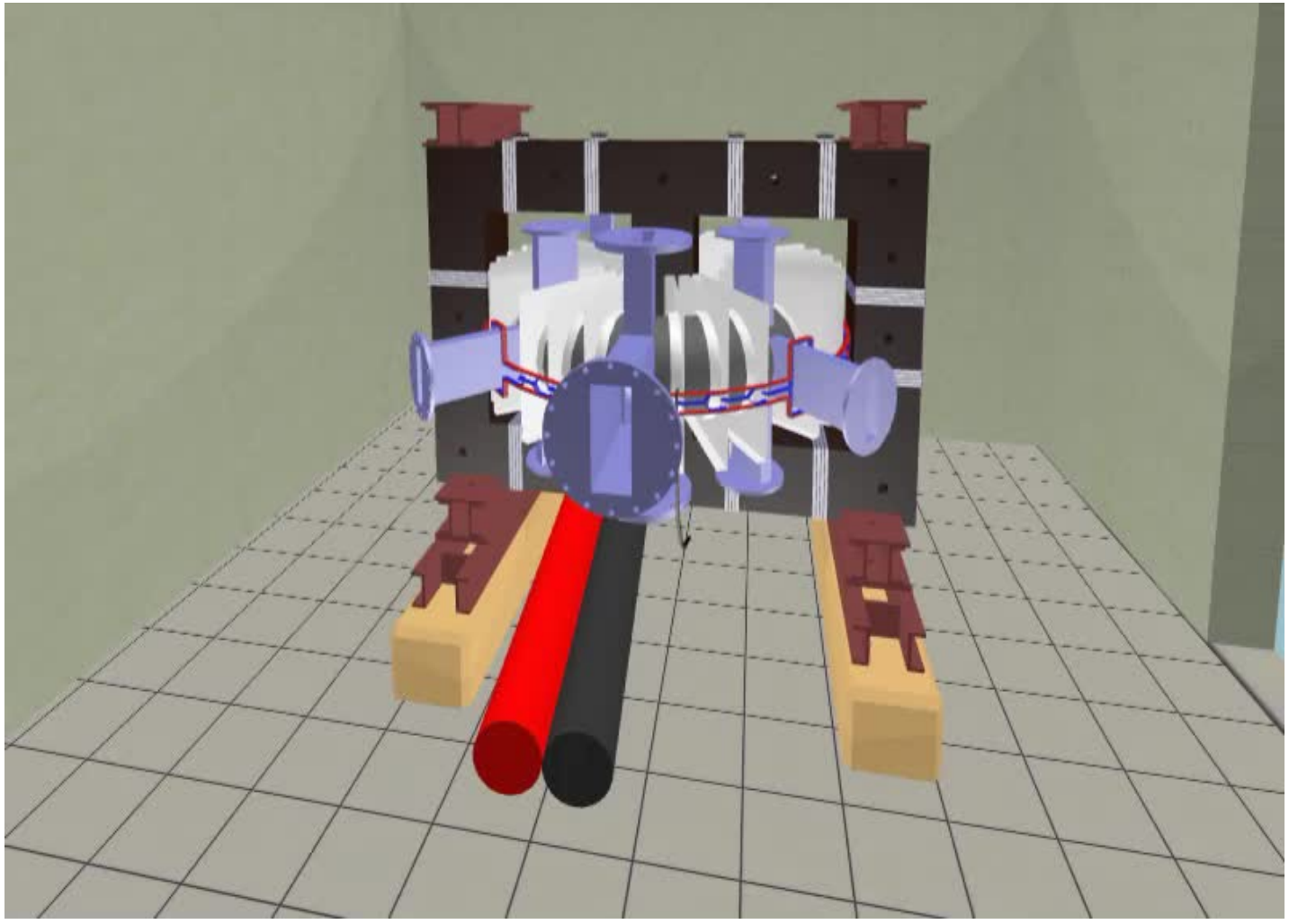
Toroidální magnetické pole udržuje plazma



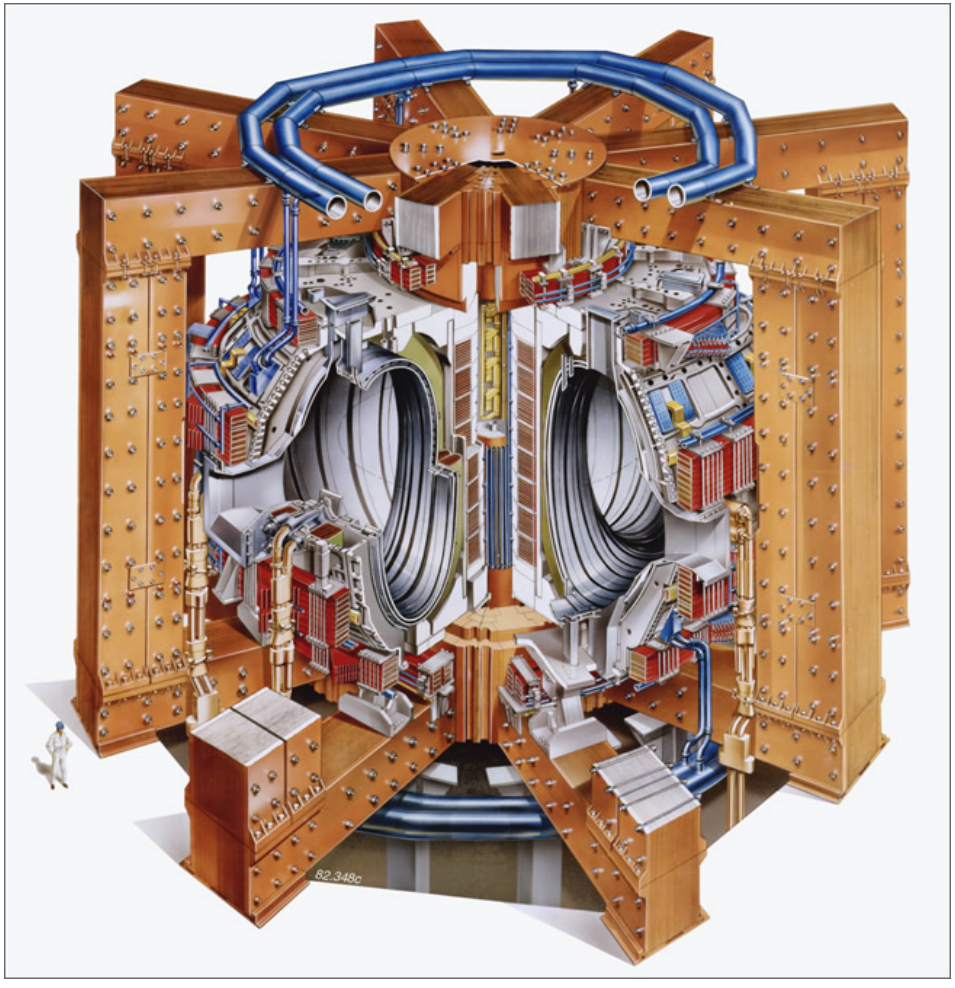
Transformátorová akce vytvoří a zahřeje plazma

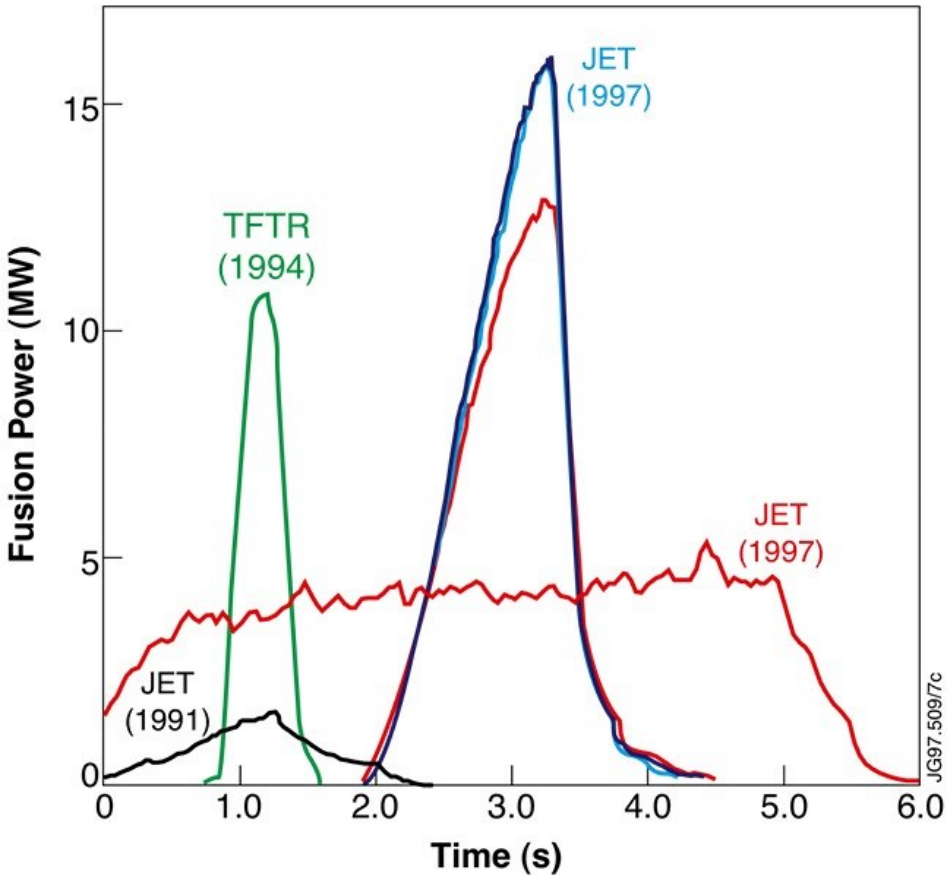


Vše dohromady - voilà tokamak



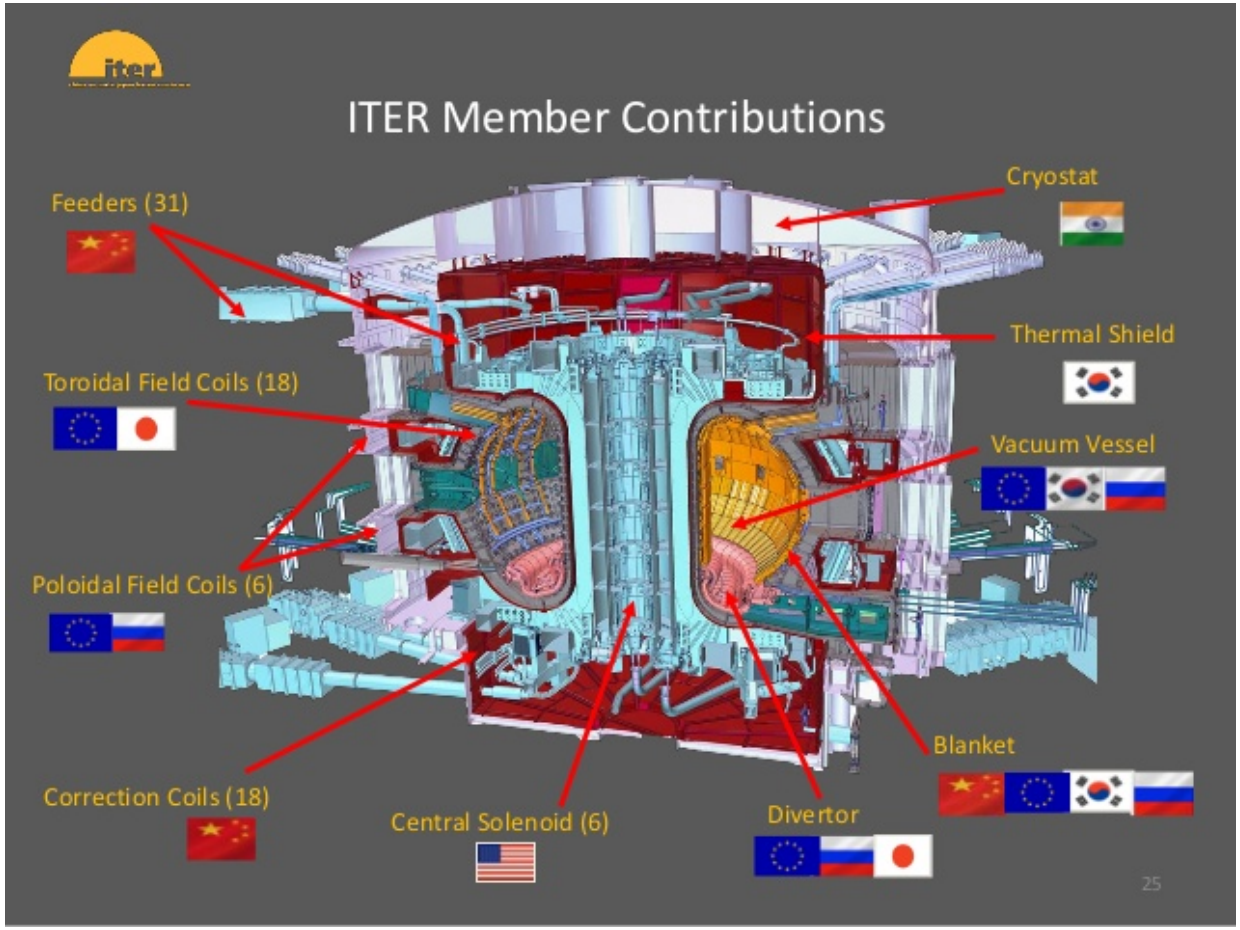
1997: Světový fúzní rekord @ JET (EU)





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

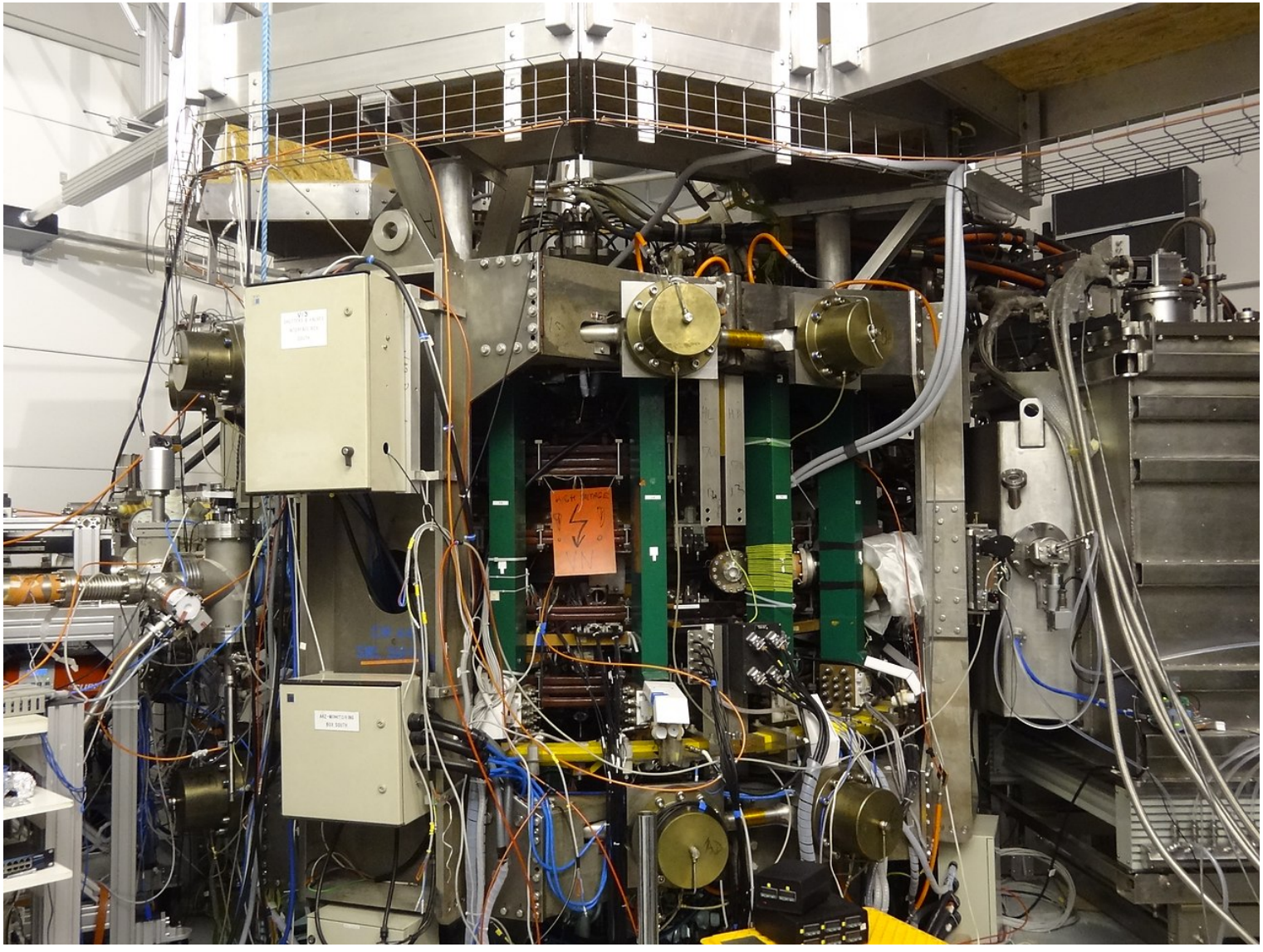
ITER (jižní Francie) $\approx$ 18 miliard EUR



Mise:

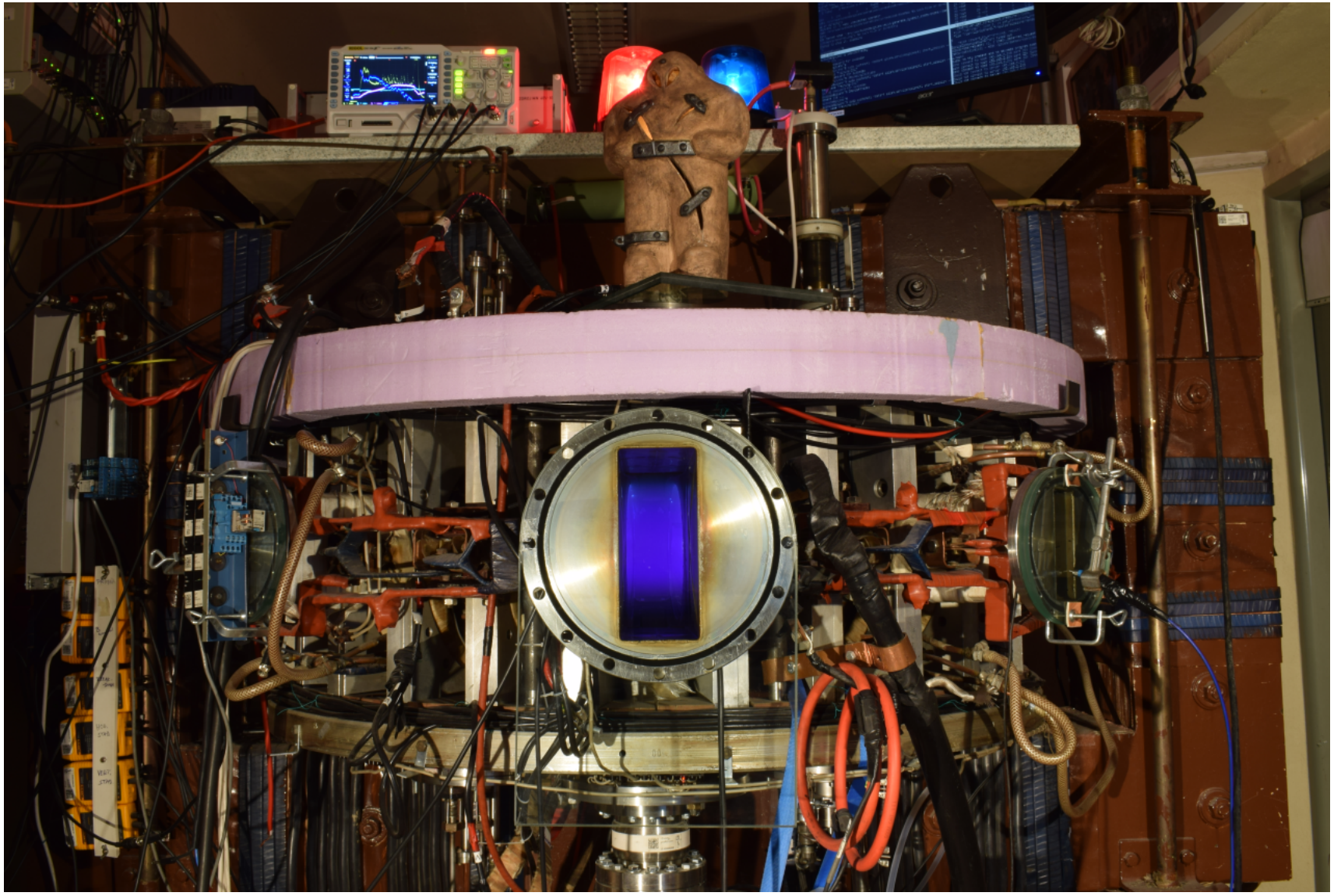
$P \approx 500$ MW, $Q \approx 10$, $\Delta T \approx 10$ minut, konkurenceschopná cena elektřiny

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



Velké ambice ....

Tokamak GOLEM



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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]

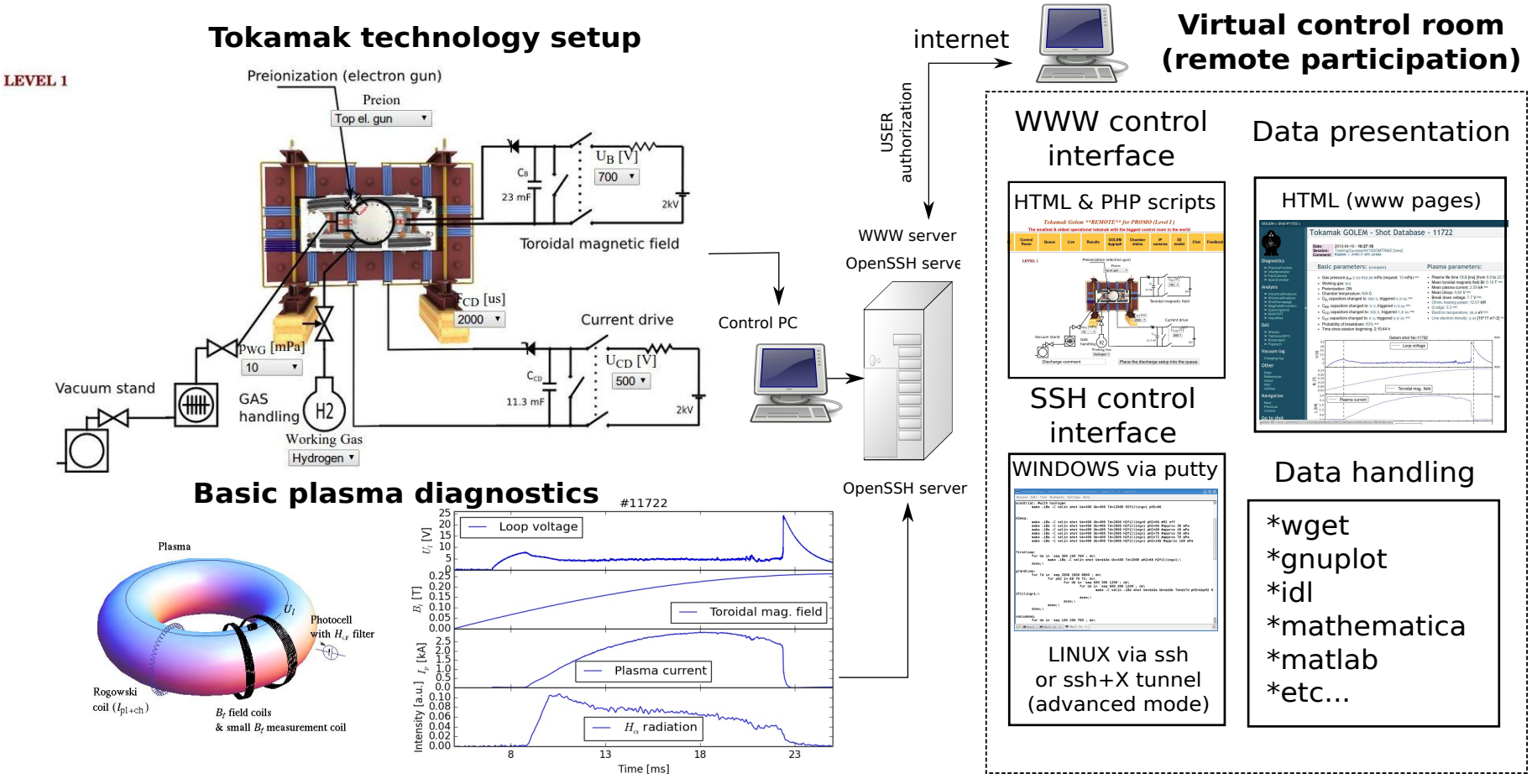
Currently in operation [edit]

(in chronological order of start of operations)

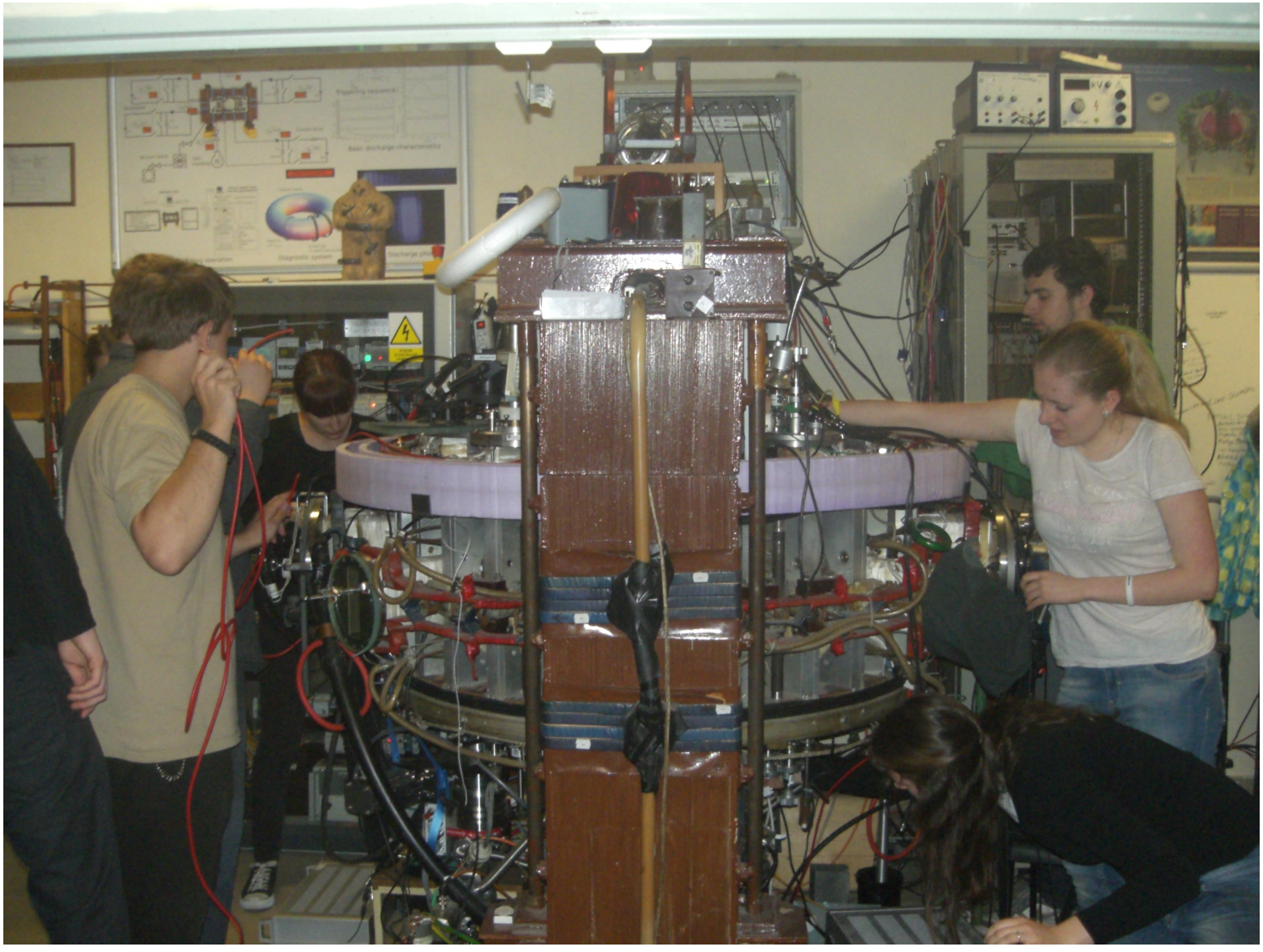

Alcator C-Mod

- 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

Tokamak GOLEM - experimentální schéma



Hands on tokamak



Tokamak GOLEM - vzdálené řízení: 2009-2019 inventura

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

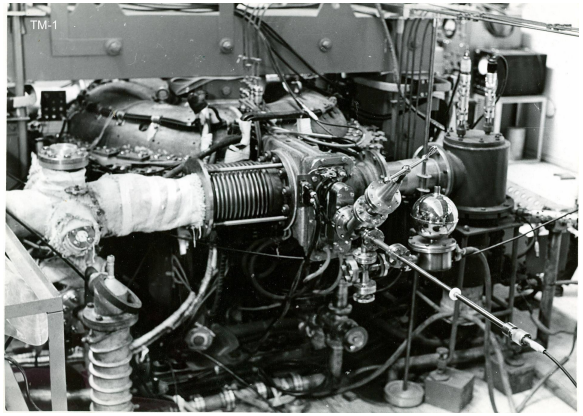
- Demonstrace: Ghent University 09; Bochum University 13; Garching 13; Lemvig High School 14; Instituto Tecnologico Costa Rica 10; Armidale University 17.
- Zimní a letní školy: French Training Course & EM 12-14,16-19; Bangkok 16-19; TU Eindhoven 11,15-19;TU Kobehaven 14,15,18;Grenoble TU 15, University 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

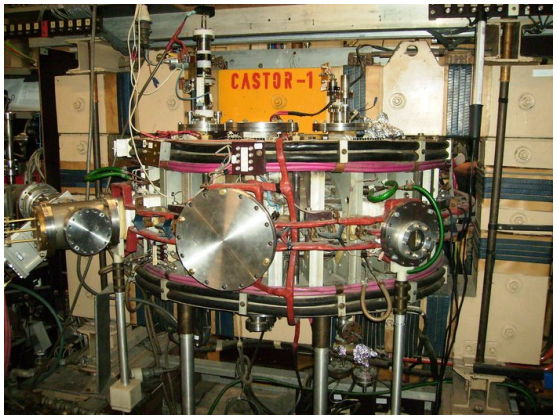
Děkuji za pozornost

Tokamak TM1
@Kurchatov Institute near Moscow
~1960-1977



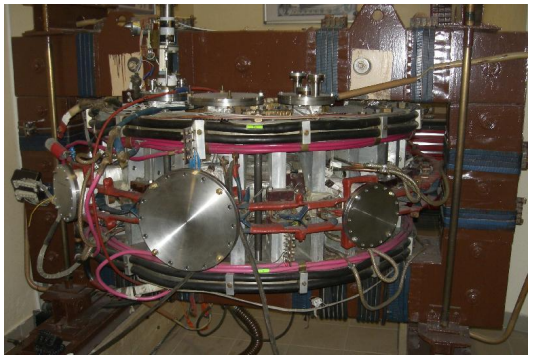
SCIENCE

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



SCIENCE
& education

Tokamak GOLEM
@Czech Technical University, Prague
2007-



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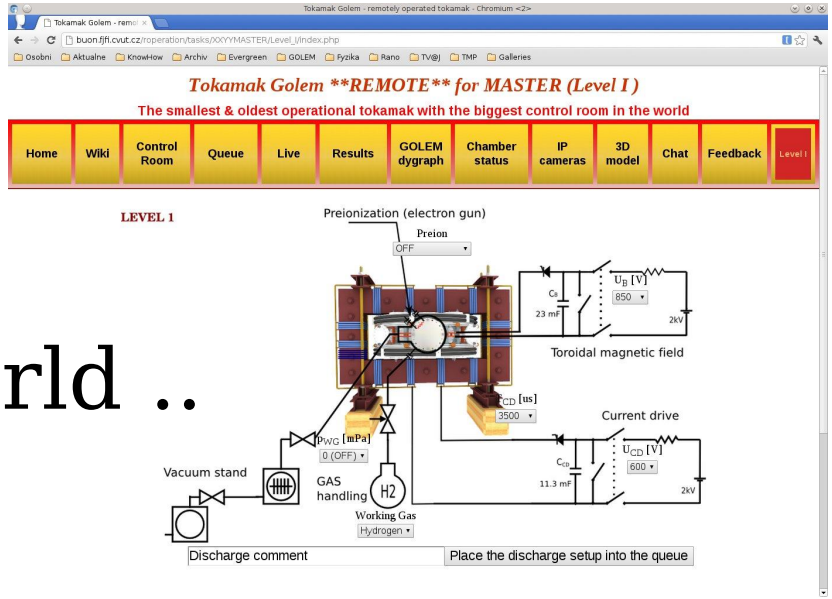
control room
in the world ..



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