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

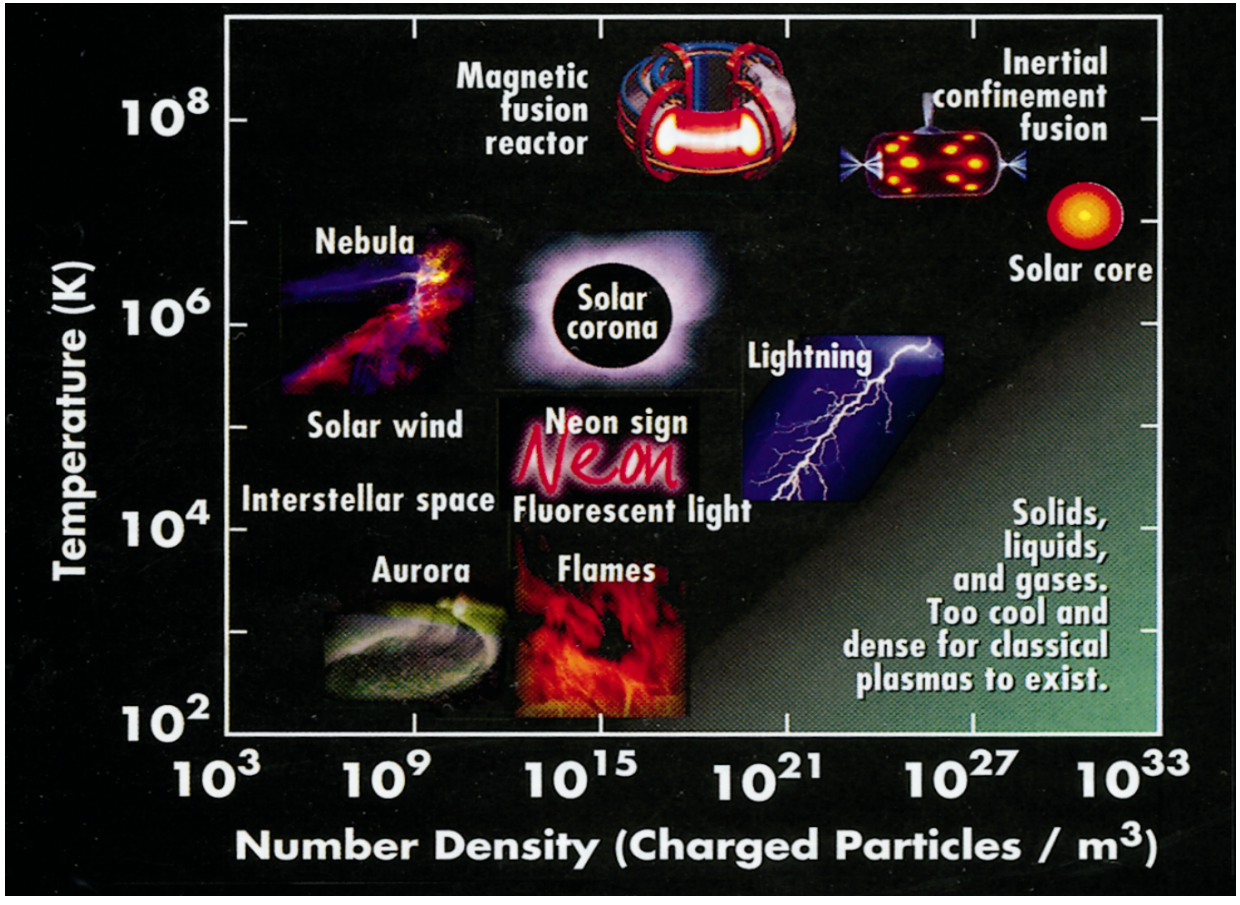
insignie FJFI

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.

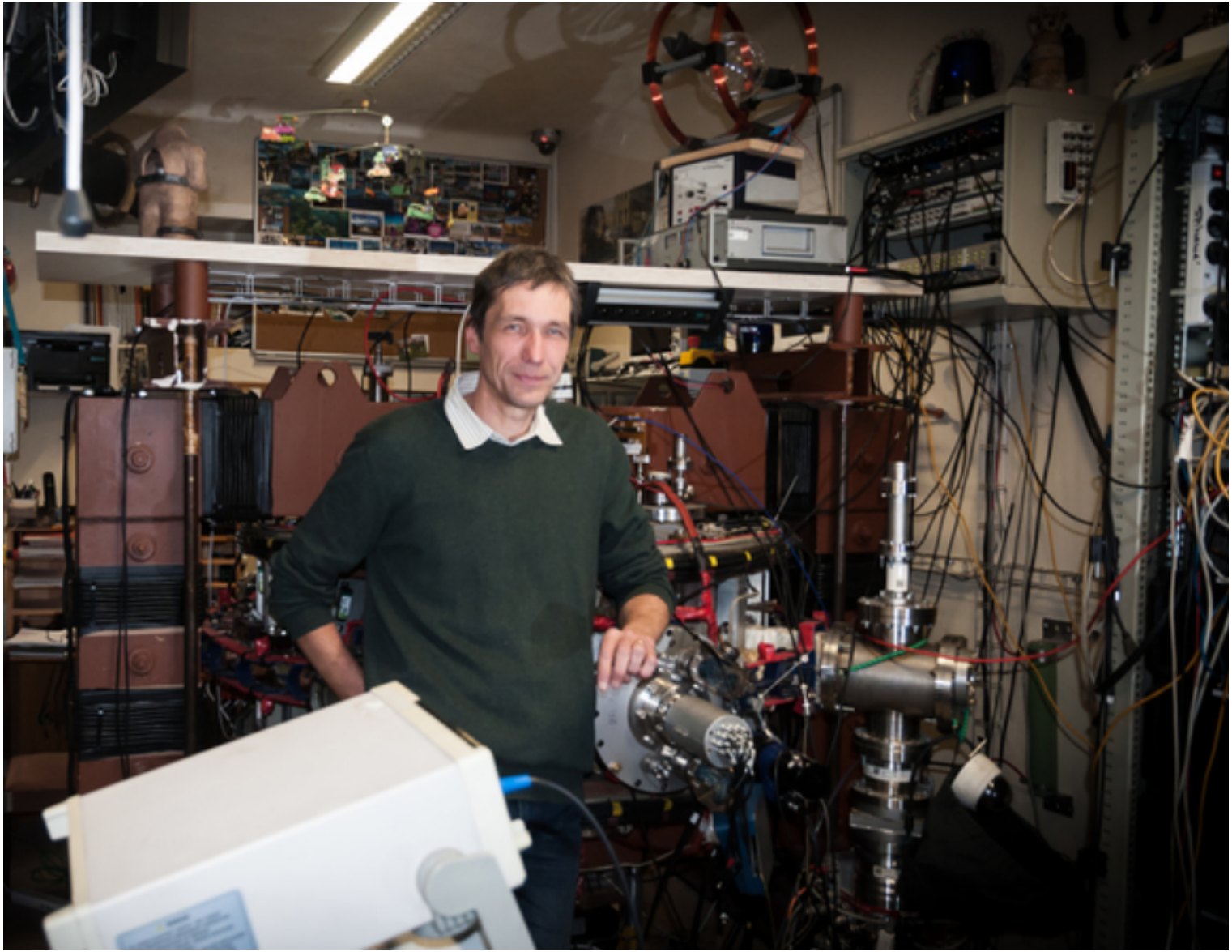
Badatelská skupina / studijní specializace

Fyzika plazmatu a termojaderné fúze



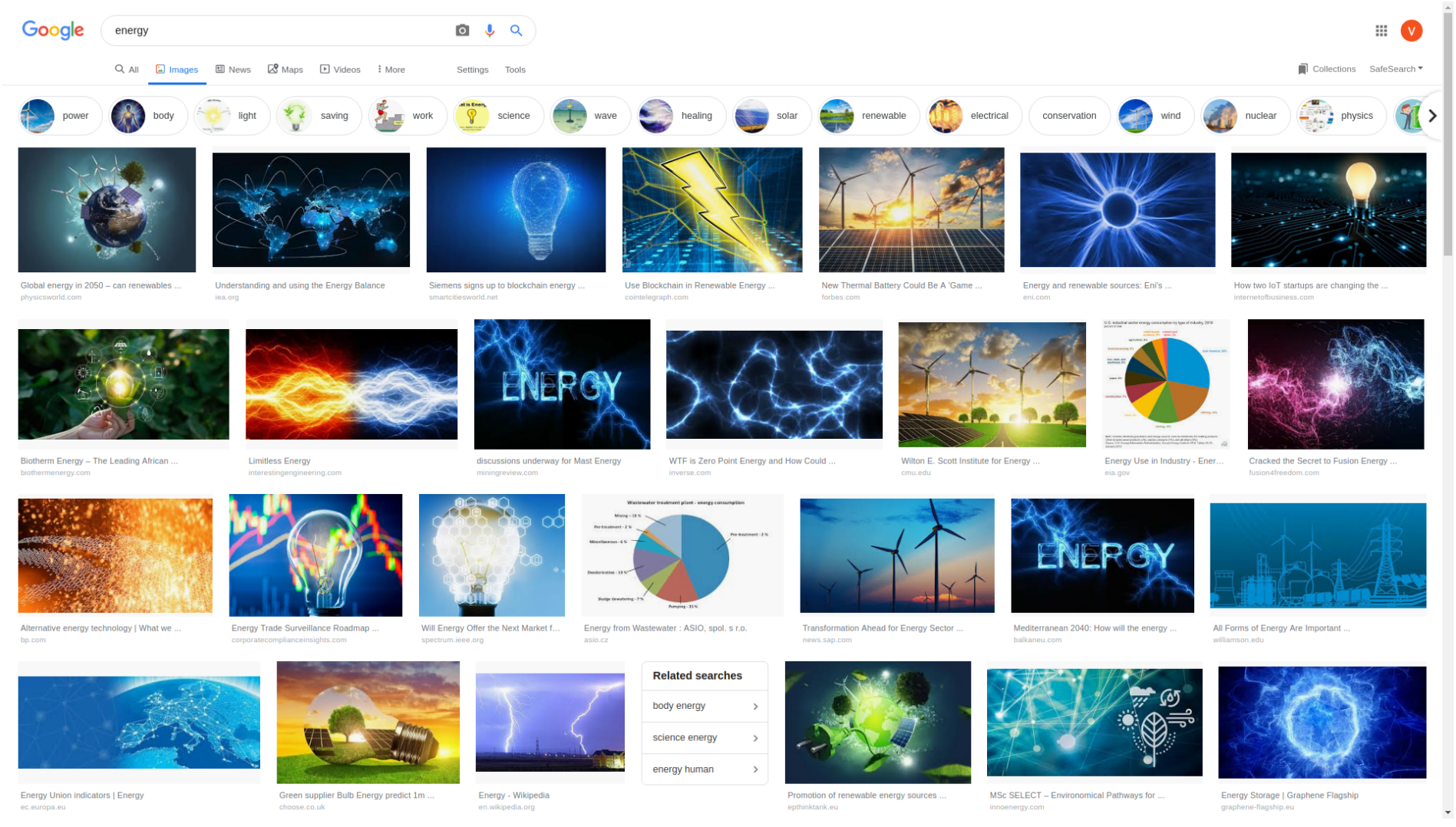
99.999 % Vesmíru je v plazmatickém stavu

Tokamak GOLEM & Vojtěch Svoboda

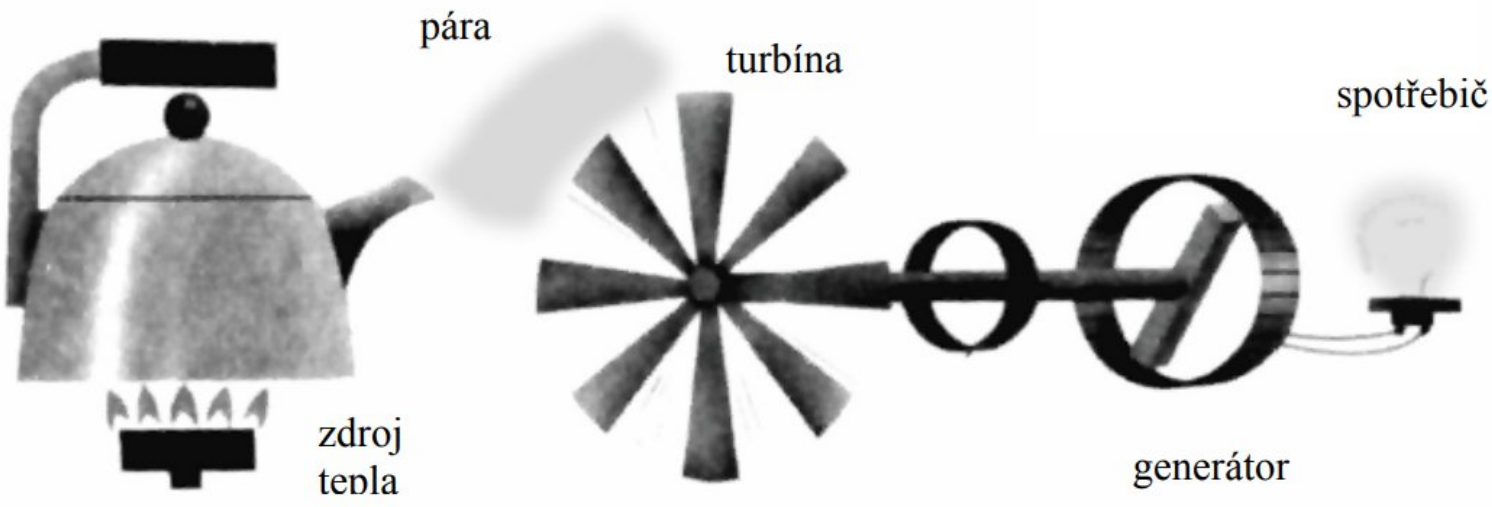


Google: Energy

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



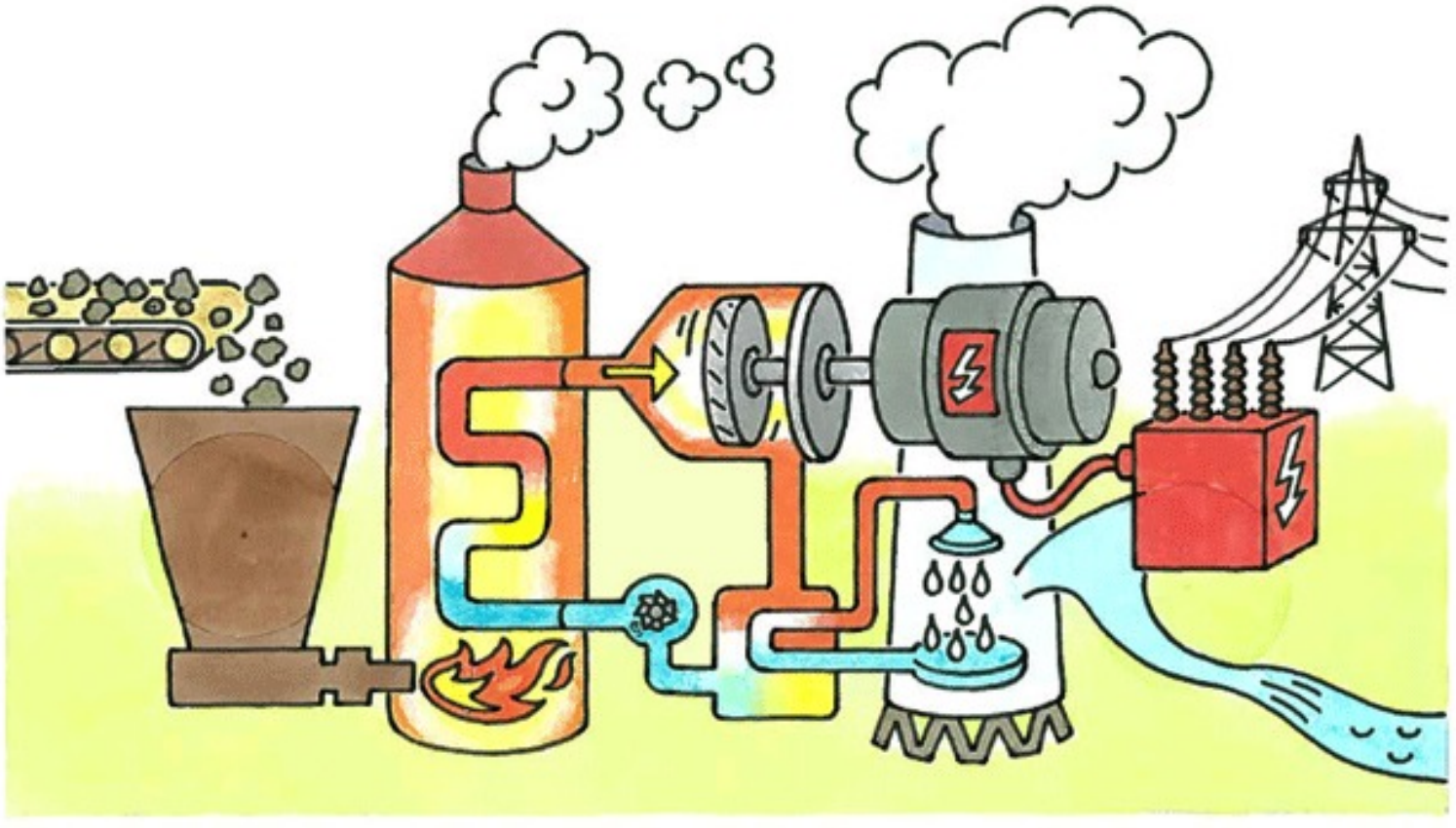
Základní princip tepelné elektrárny



Základní otázka zní:

?? Čím topit ??

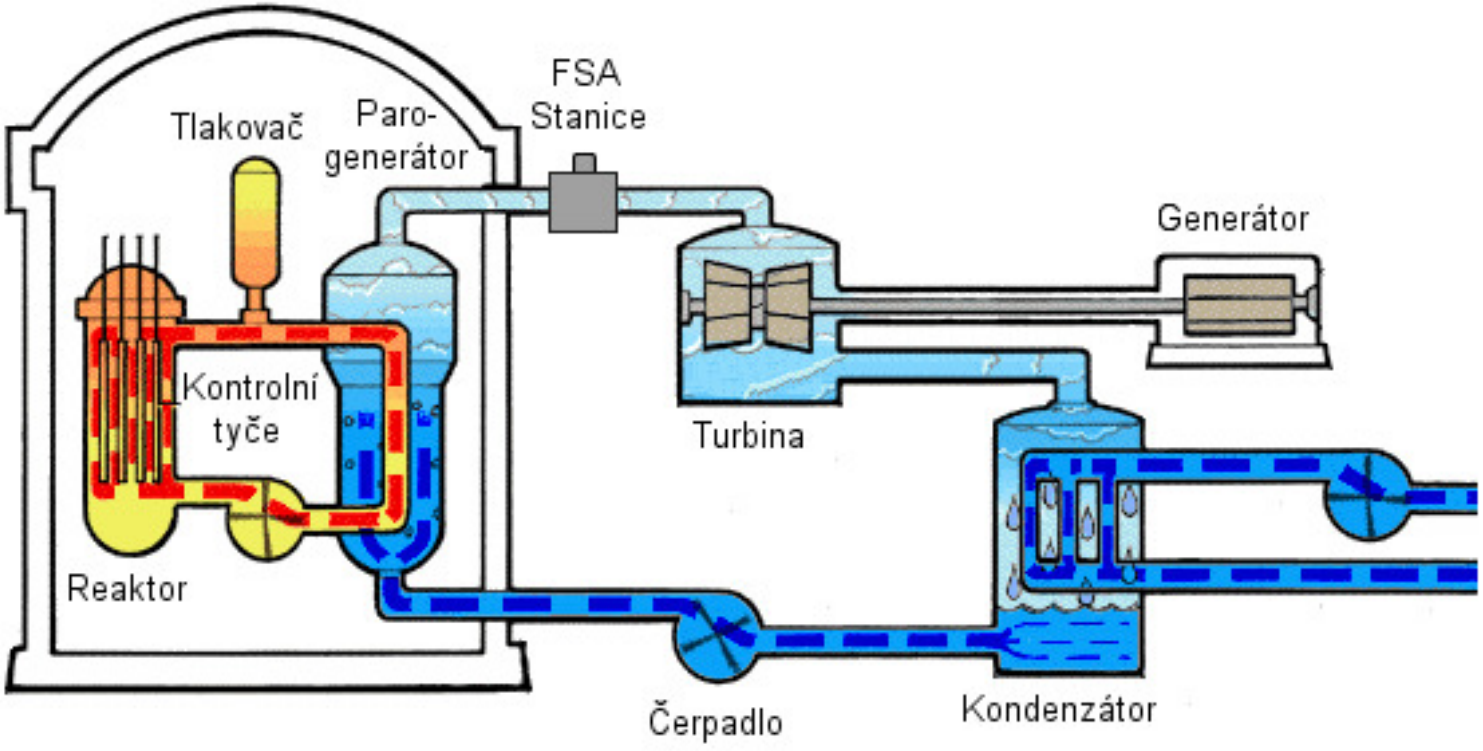
Uhelná elektrárna



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

Emise

Jaderná elektrárna - štěpná

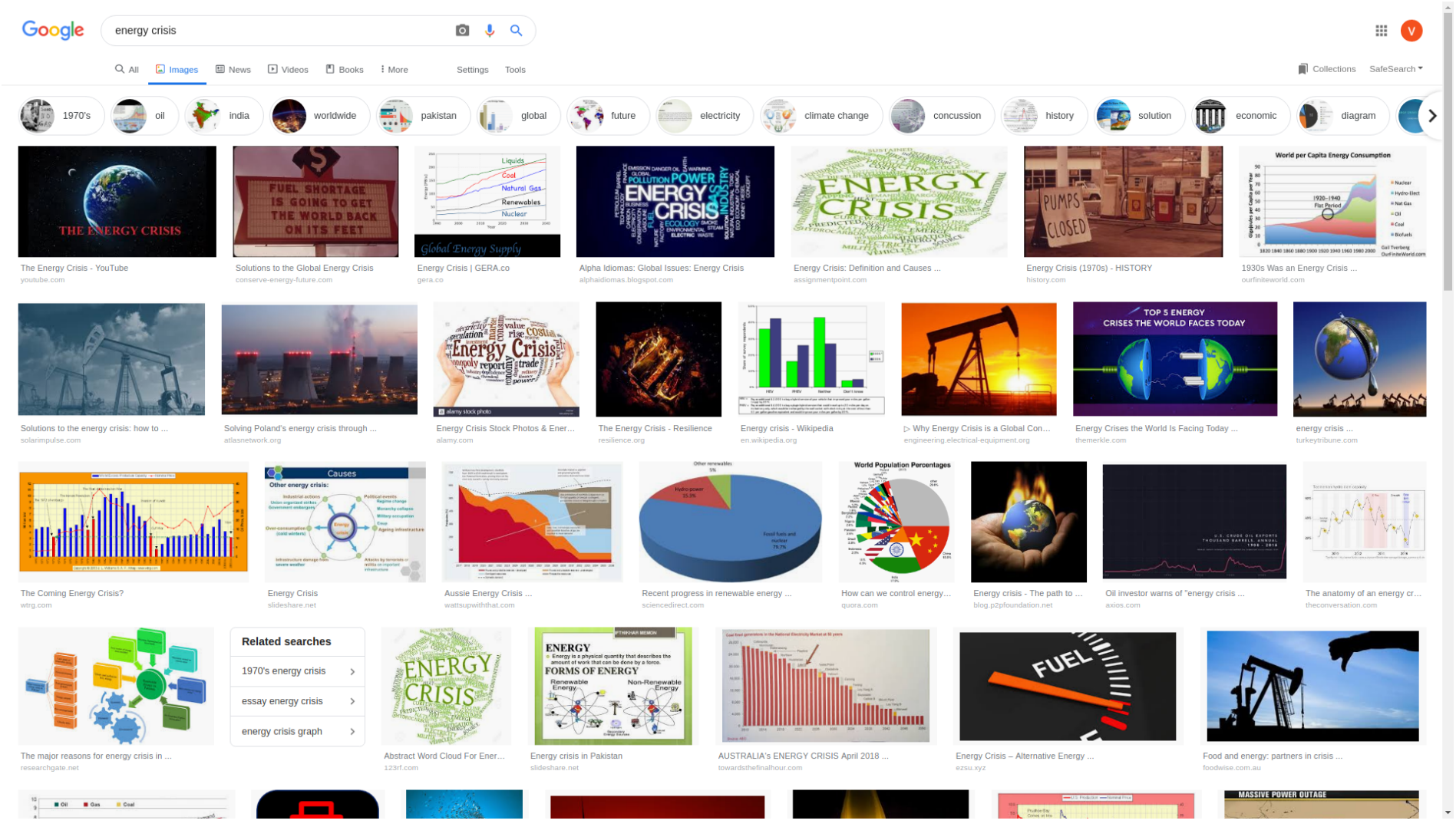


Praha ($\sim$ 1 GW): ročně $\sim$ vagón jaderného paliva

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

energy crisis ...
turkeytribune.com

The Coming Energy Crisis?
wtrg.com

Energy Crisis
slideshare.net

Aussie Energy Crisis ...
wattsupwiththat.com

Recent progress in renewable energy ...
sciencedirect.com

How can we control energy...
quora.com

Energy crisis - The path to ...
blog.p2pfoundation.net

Oil investor warns of "energy crisis ...
axios.com

The anatomy of an energy cr...
theconversation.com

The major reasons for energy crisis in ...
researchgate.net

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

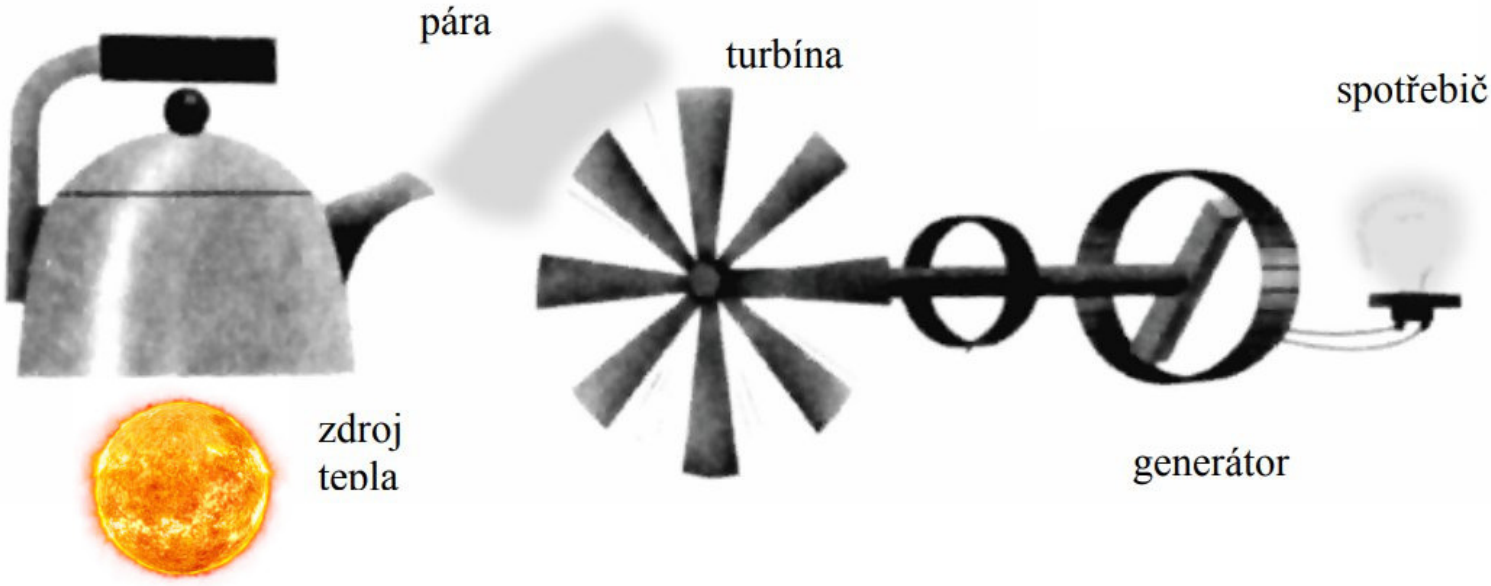
Energy crisis in Pakistan
slideshare.net

AUSTRALIA's ENERGY CRISIS April 2018 ...
towardsthefinalhour.com

Energy Crisis – Alternative Energy ...
ezsu.xyz

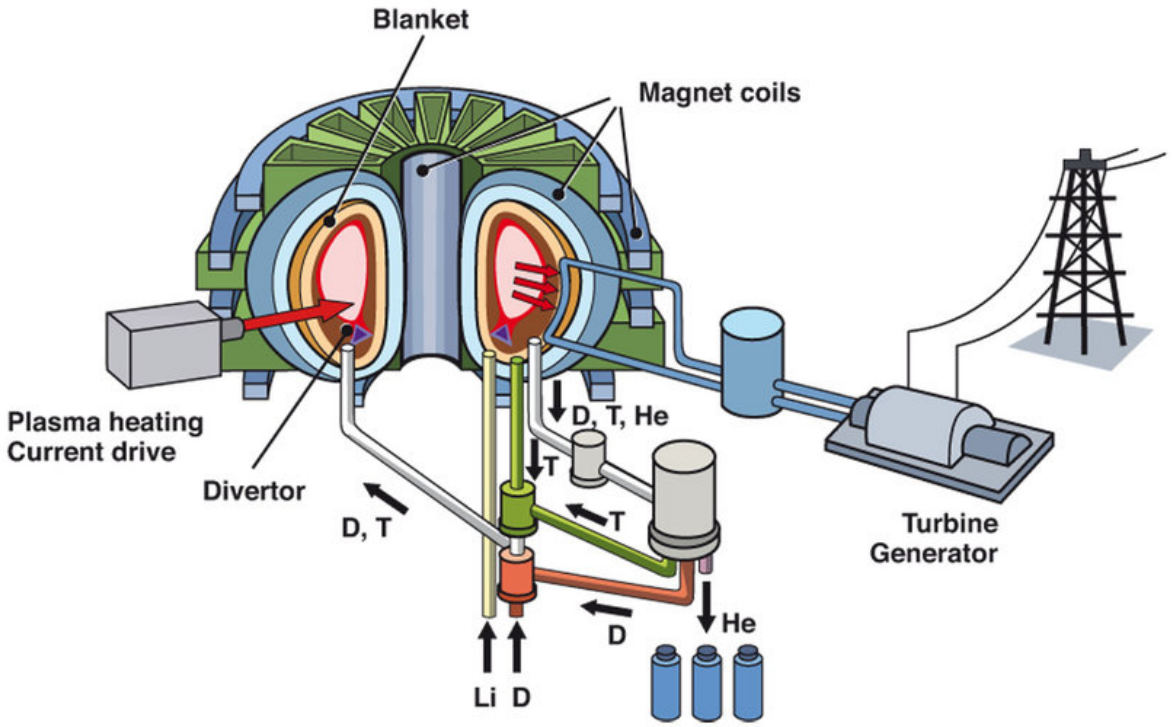
Food and energy: partners in crisis ...
foodwise.com.au

Topit malým Sluncem/hvězdou ??



Výzva

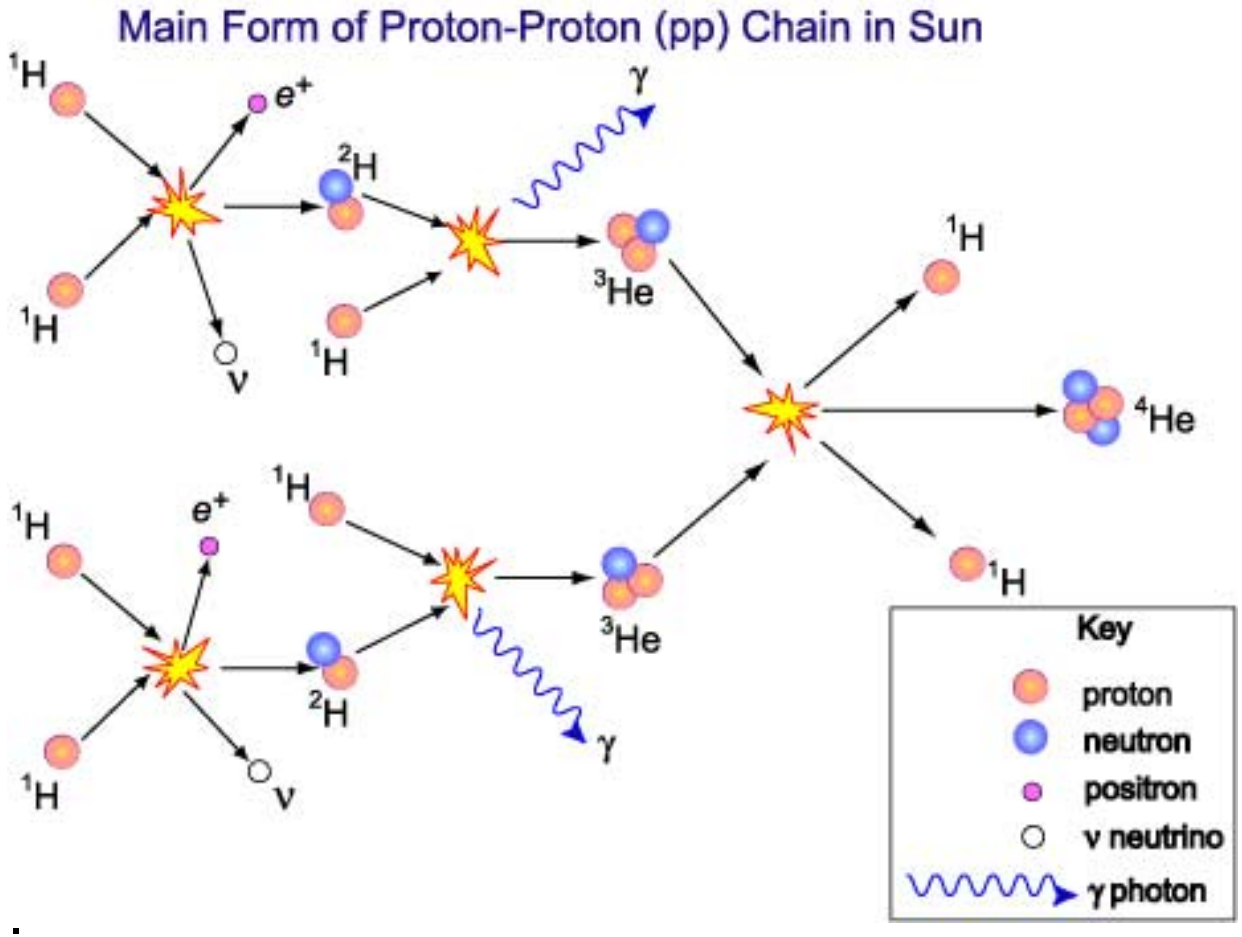
Vize: Jaderná elektrárna - slučovací/fúzní



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

Vypiplat technologii

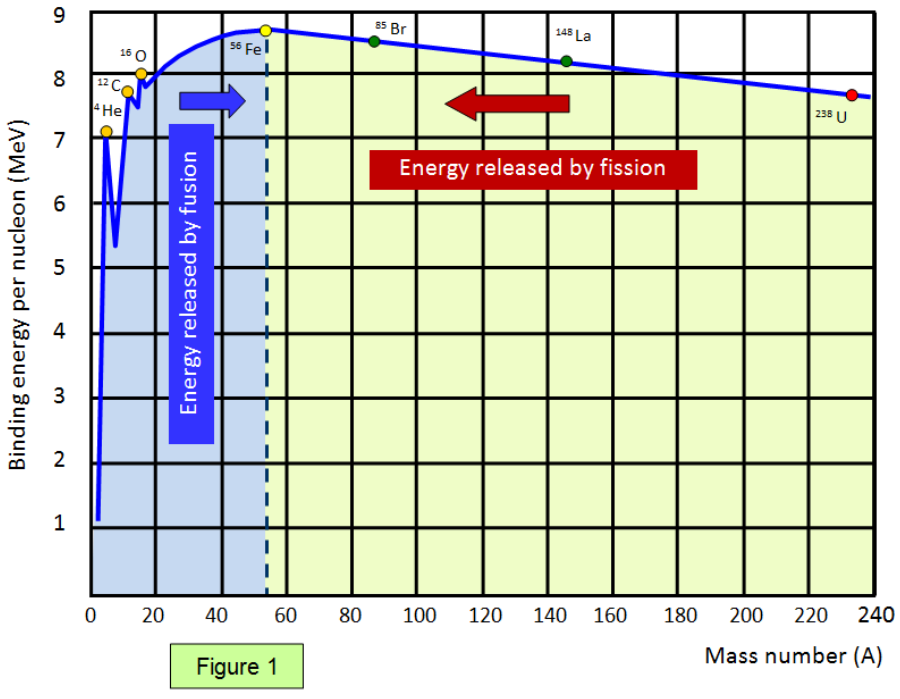
Inspirace: Slunce - protonový řetězec

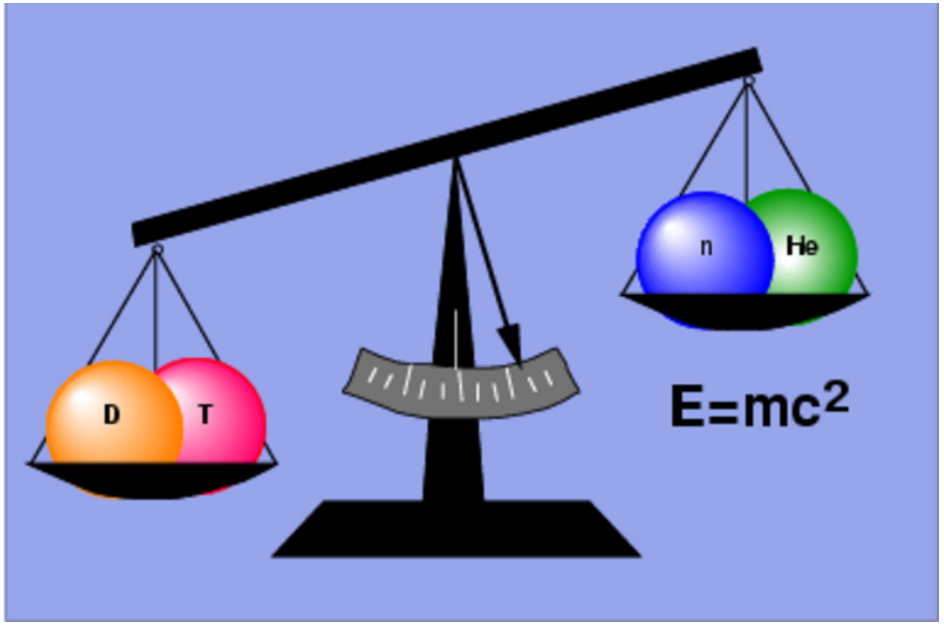


credit:CSIRO

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

Uvolnění vazebné energie atomových jader

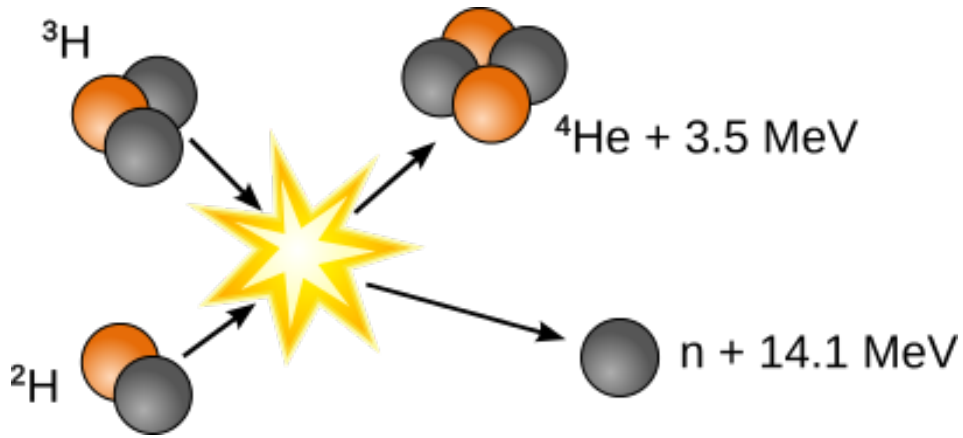




fúze lehkých jader X štěpení těžkých jader

$^{2}\mathbf{D}+^{3}\mathbf{T} \Rightarrow ^{4}\mathbf{He}+^{1}\mathbf{n}+\mathbf{17.6MeV}$ 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:?

$$\mathbf{^{2}_{1}H_{10\ keV} + {}^{3}_{1}H_{10\ keV} \Rightarrow {}^{4}_{2}He_{3.5\ MeV} + {}^{1}_{0}n_{14.1\ MeV}}$$

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

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

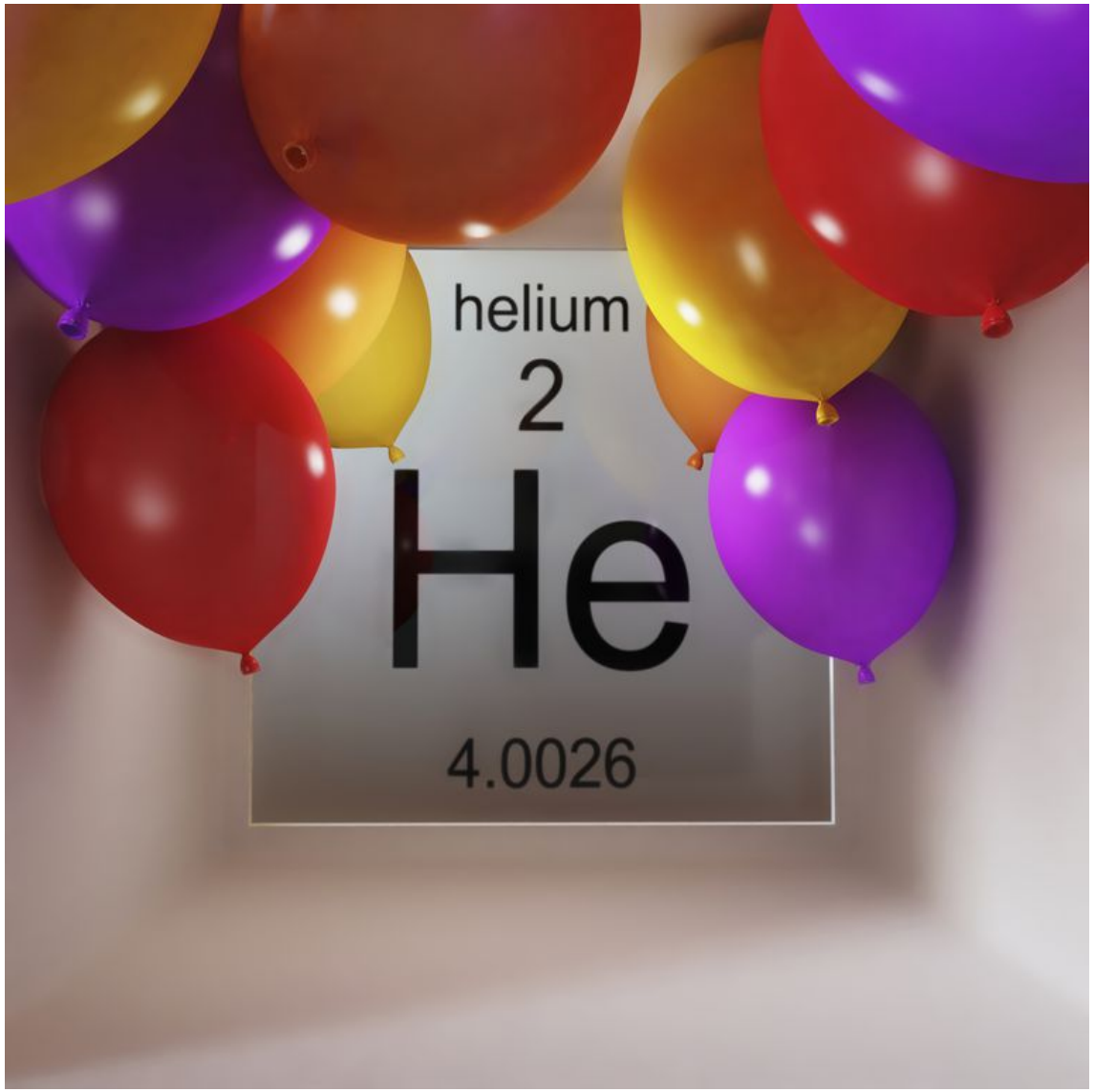
pak hmotnostní schodek $\Delta m = 0.01888 m_u$.

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

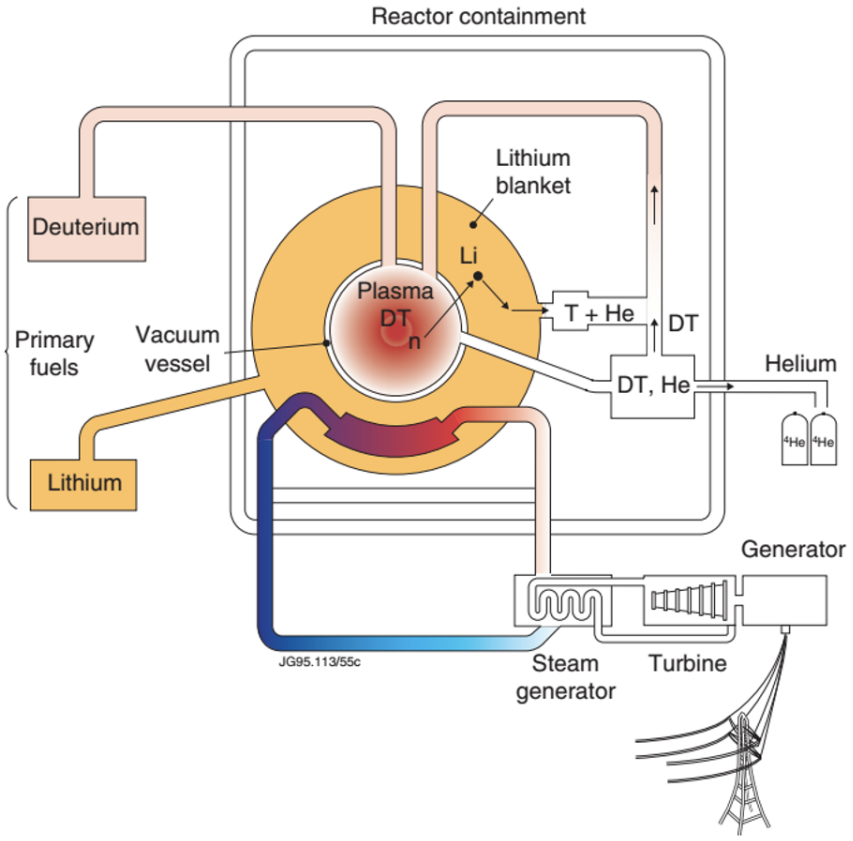
$$1\mathrm{eV} \sim 11600^{\circ}\mathrm{C} \approx \quad \mathbf{^{2}_{1}H_{100\ M\circ C} + {}^{3}_{1}H_{100\ M\circ C} \Rightarrow {}^{4}_{2}He_{35\ G\circ C} + {}^{1}_{0}n_{141\ G\circ C}}$$

Palivo: IAEA "Natural water"

Odpad



Bezpečnost



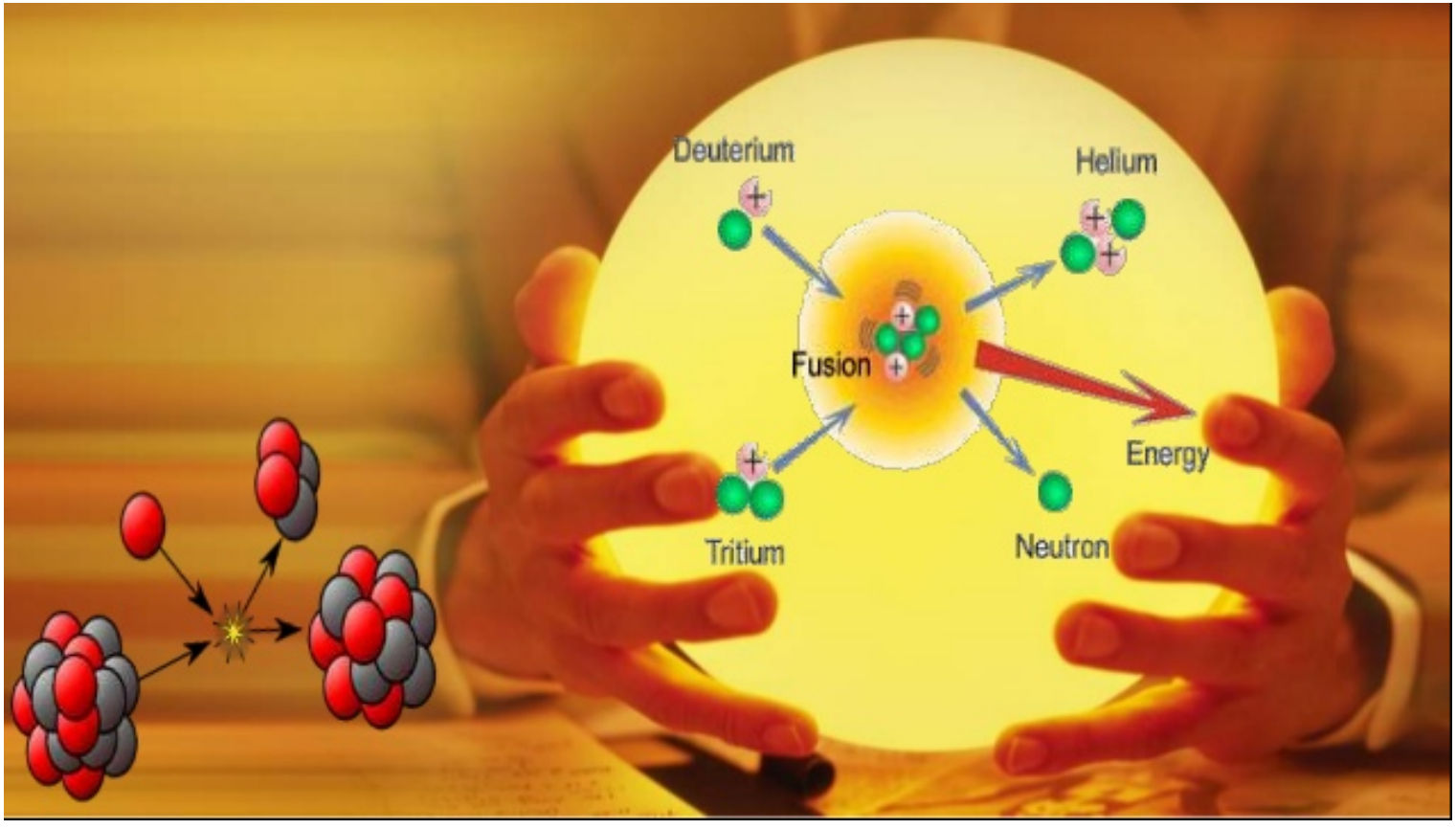
* Nejde o řetězovou reakci.
* Tritium: slabý β zářič $T_{1/2} = 12.5\ \mathrm{roku}$. Minimální nebezpečí.
* Minimalizovaný potenciál aktuálně přítomného D-T paliva.

1952 "Operation Ivy - Mike" První test vodíkové bomby

credit:YouTube:Ivy Mike Countdown and detonation

Toto není vhodná technologie

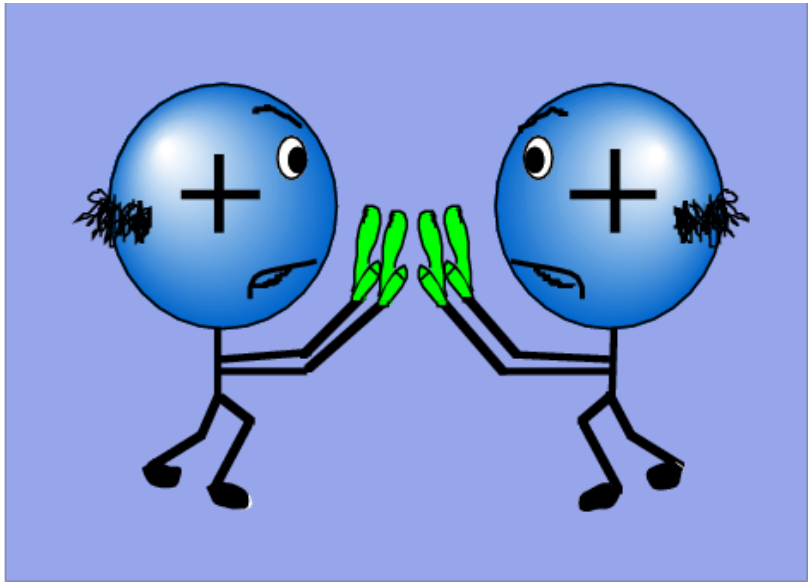
Hledá se vhodná fúzní technologie



Podmínky:

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

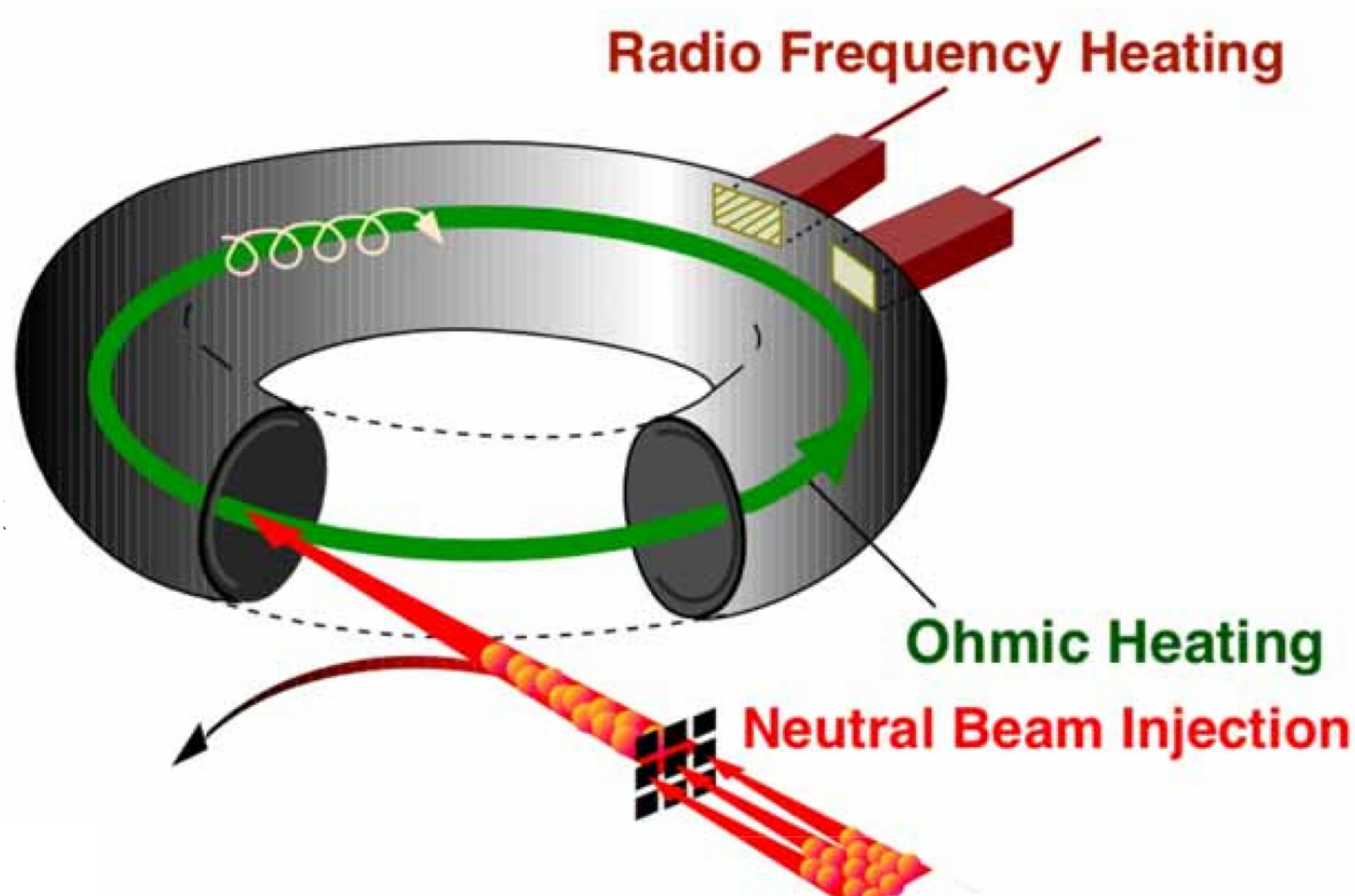
Proč tak obrovské teploty?



- Coulomb law:
  $F_E = \frac{1}{4\pi\epsilon_0}\frac{Q_1\ Q_2}{r^2}$

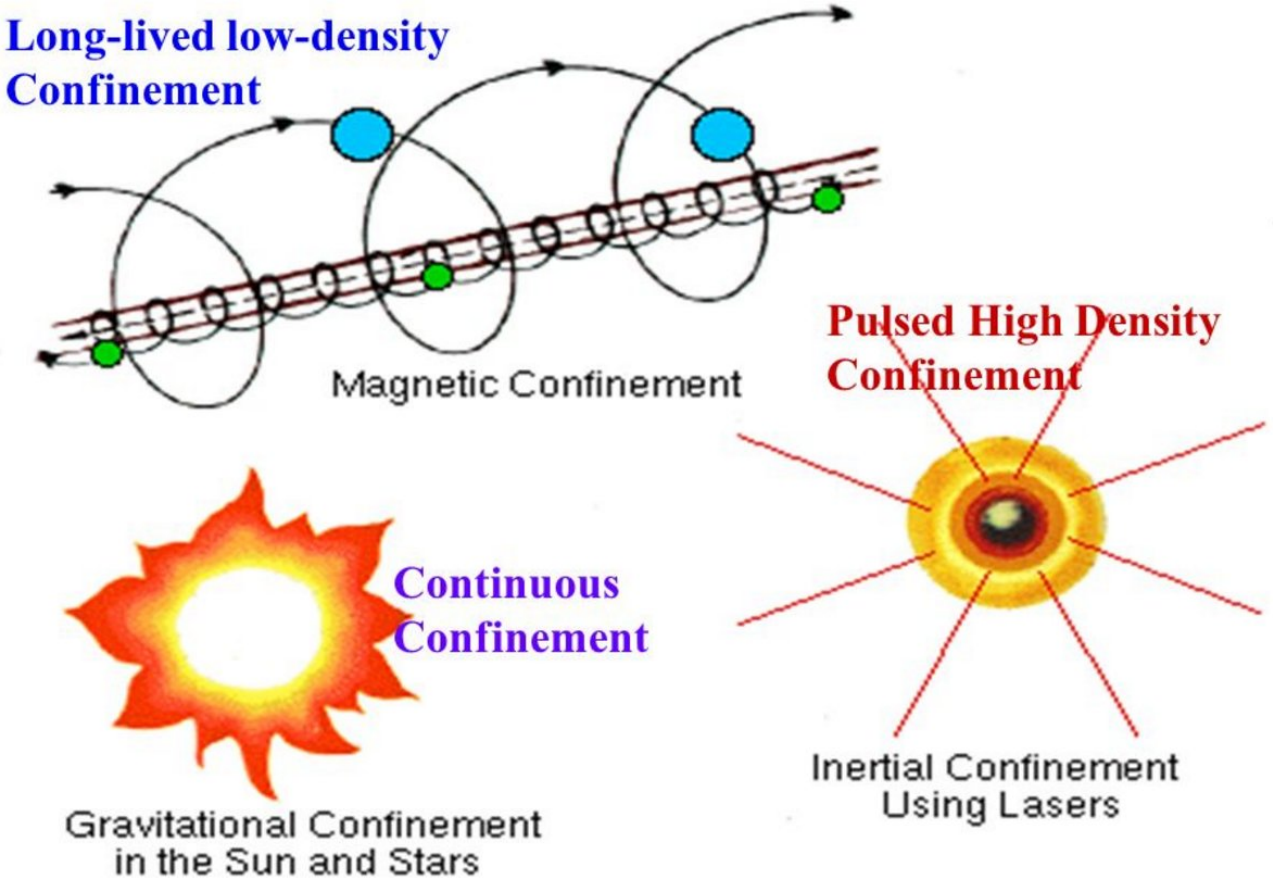
$$ {}^{2}_{1}\mathbf{D}_{(\mathbf{10keV})} + {}^{3}_{1}\mathbf{T}_{(\mathbf{10keV})} \Rightarrow {}^{4}_{2}\mathbf{He}_{(\mathbf{3.5MeV})} + \mathbf{n}_{(\mathbf{14.1MeV})} $$

Ohřev plazmatu

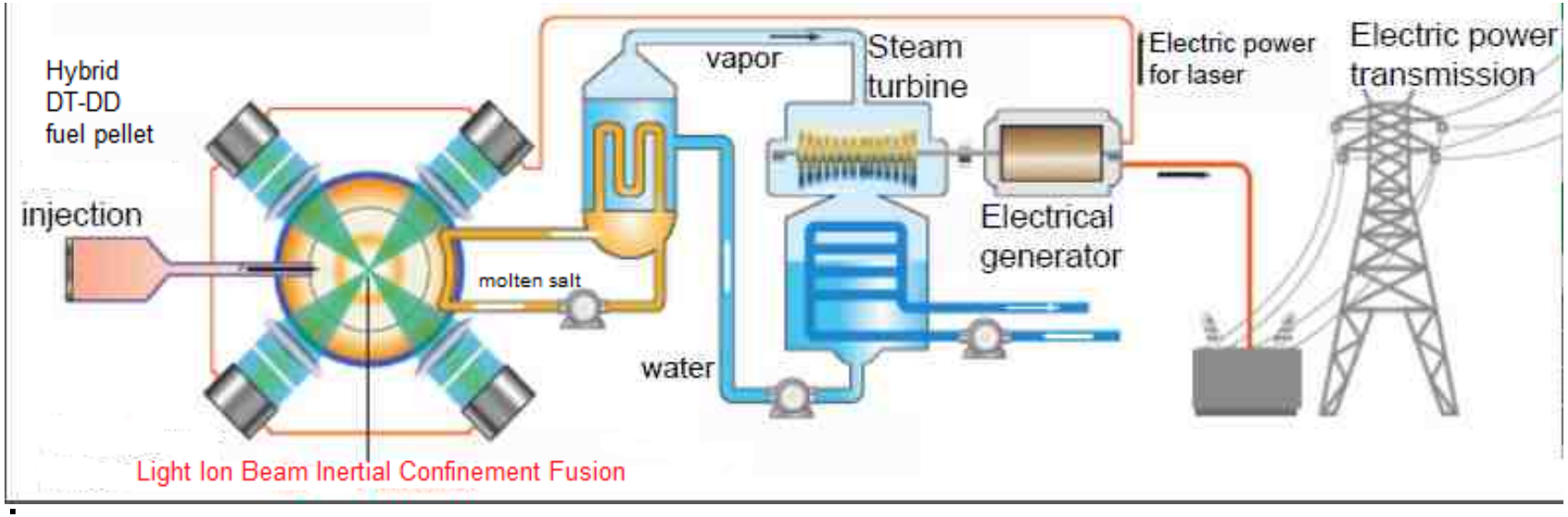


Tři možné cesty jak udržet plazma pro fúzi

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



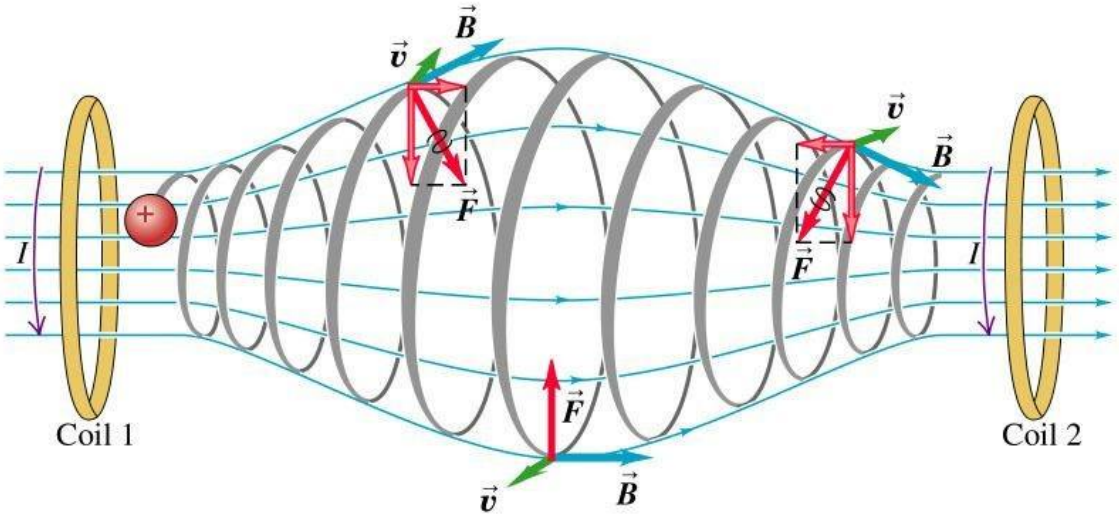
Inerciální fúze



credit:mext.jp

Velká výzva

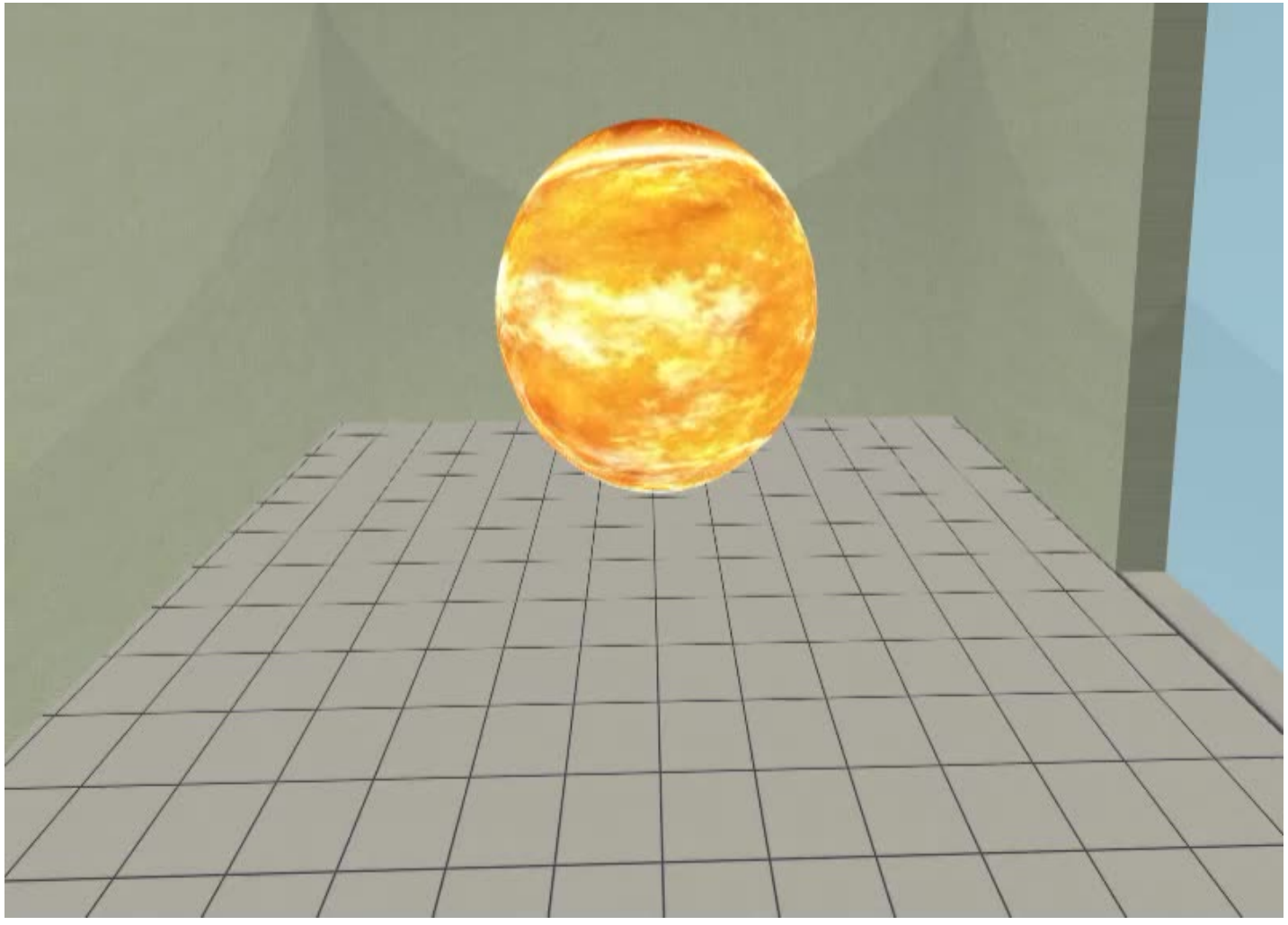
Magnetické udržení: magnetická nádoba



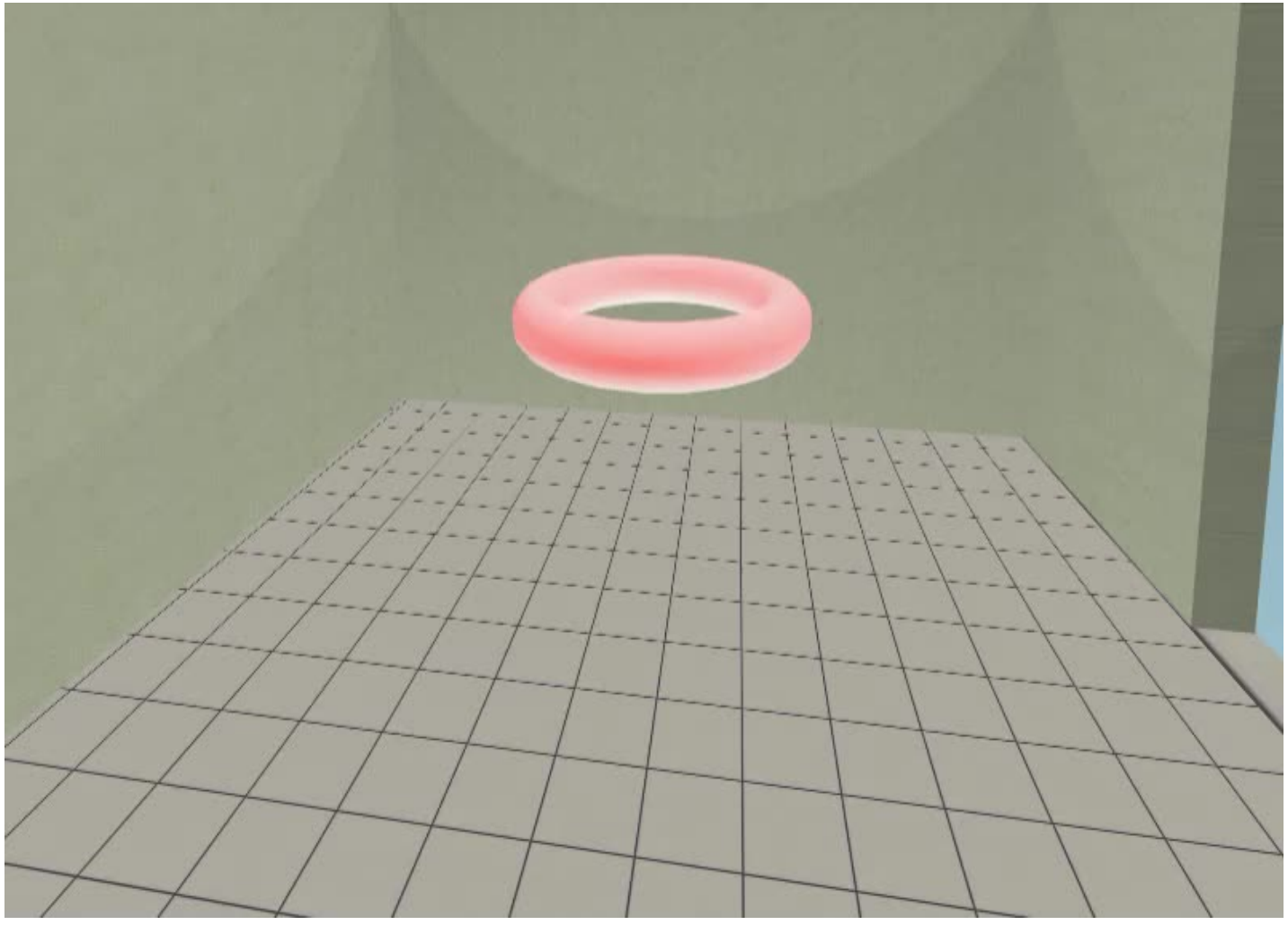
Musíme ji ale svinout do kruhu (zbavit se podstav)

záchranný kruh/duše pneumatiky/kobliha - donut

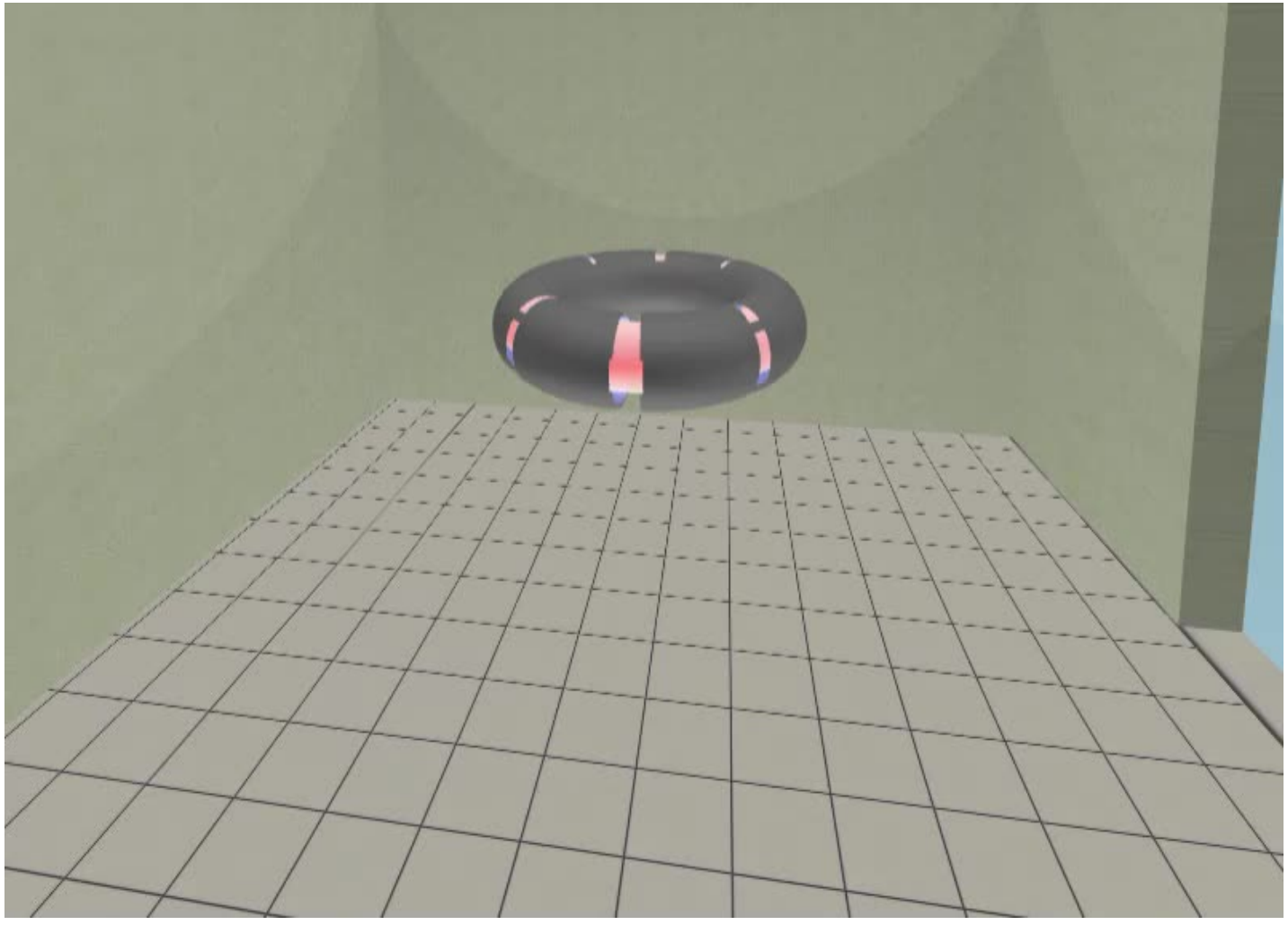
Náš cíl: vytvořit μSlunce v pozemských podmínkách



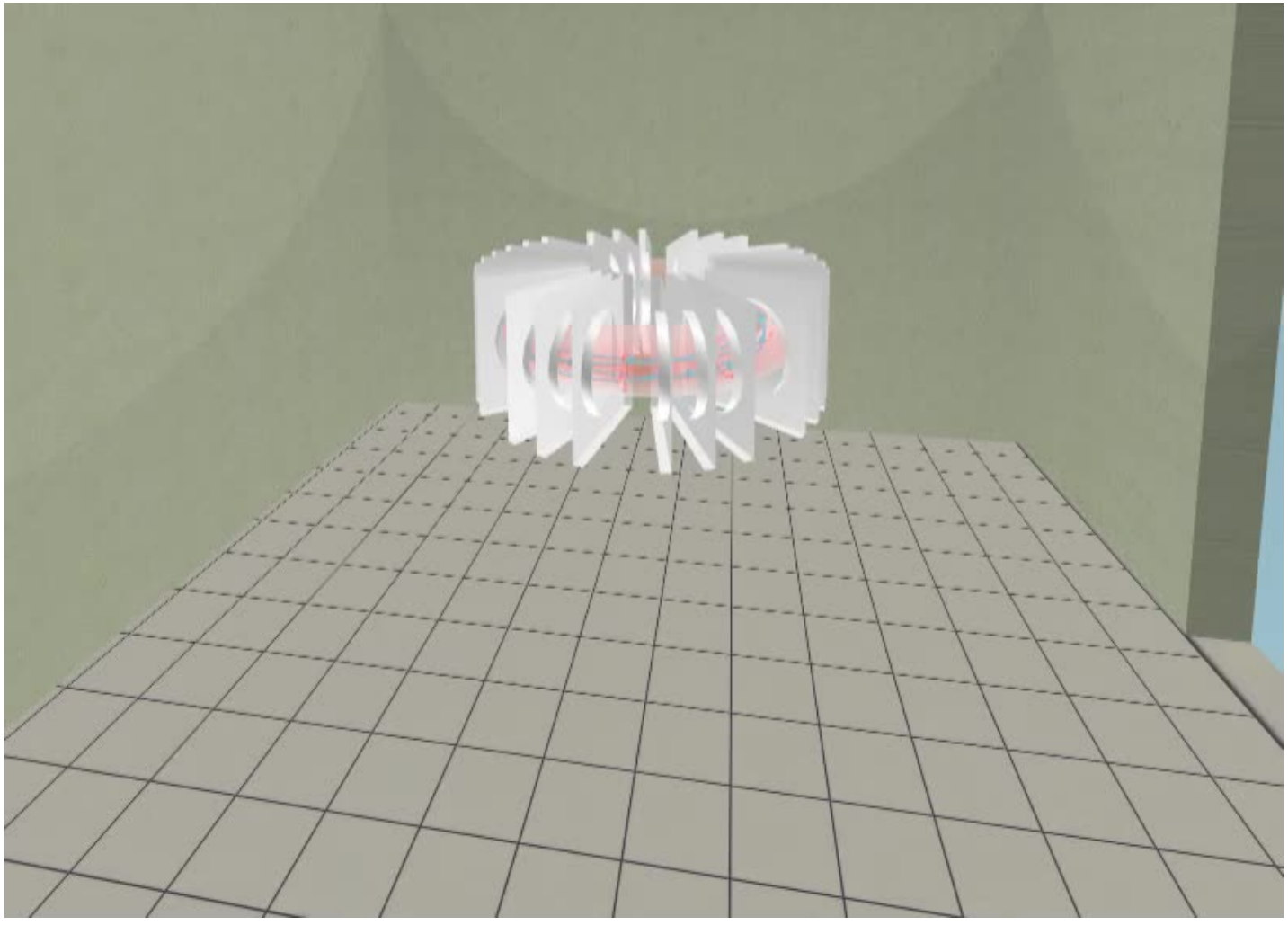
Magnetické udržení vyžaduje toroidální geometrii
Svinutá magnetická nádoba



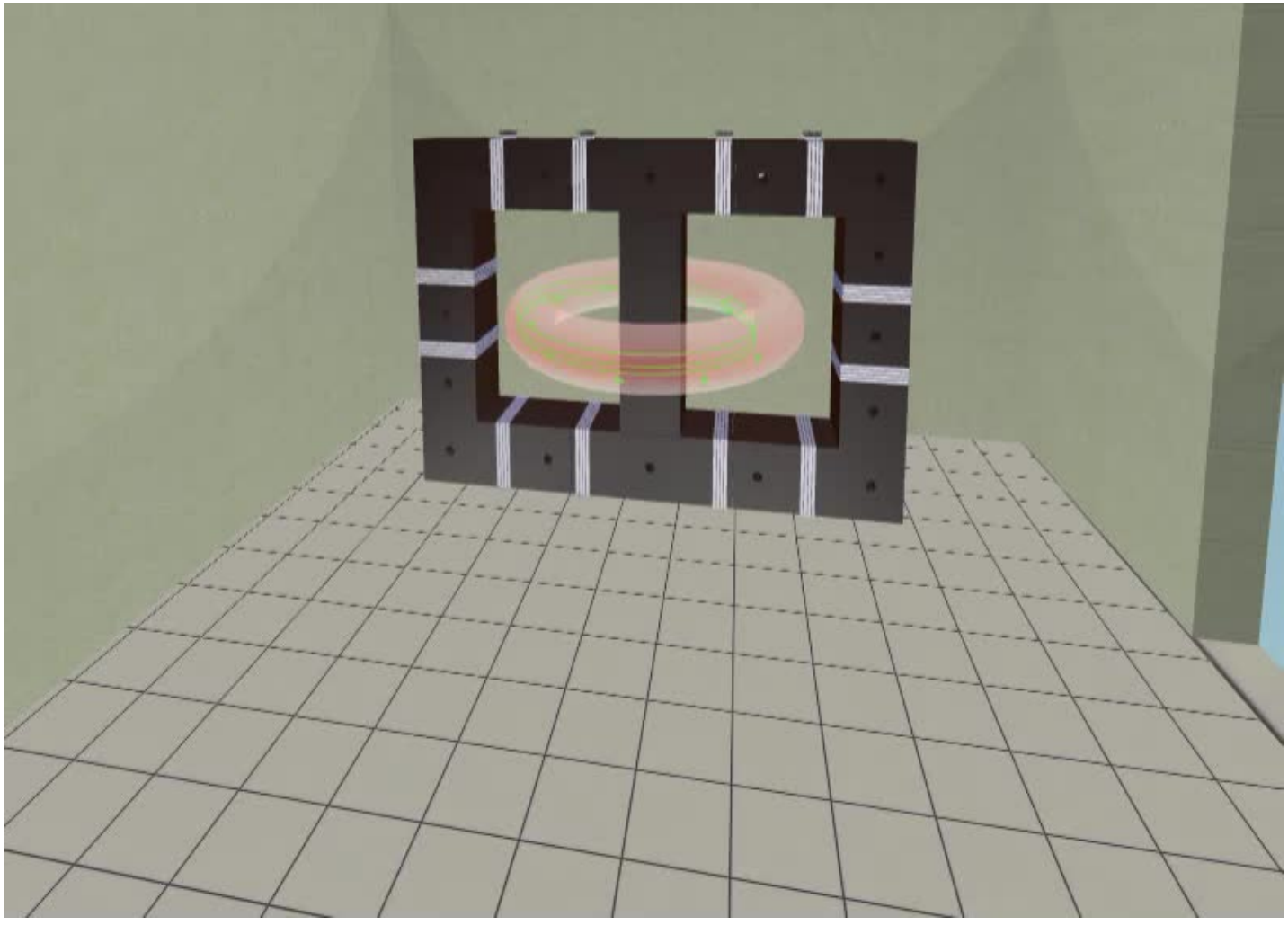
Musíme to celé umístit do reaktorové nádoby - komory



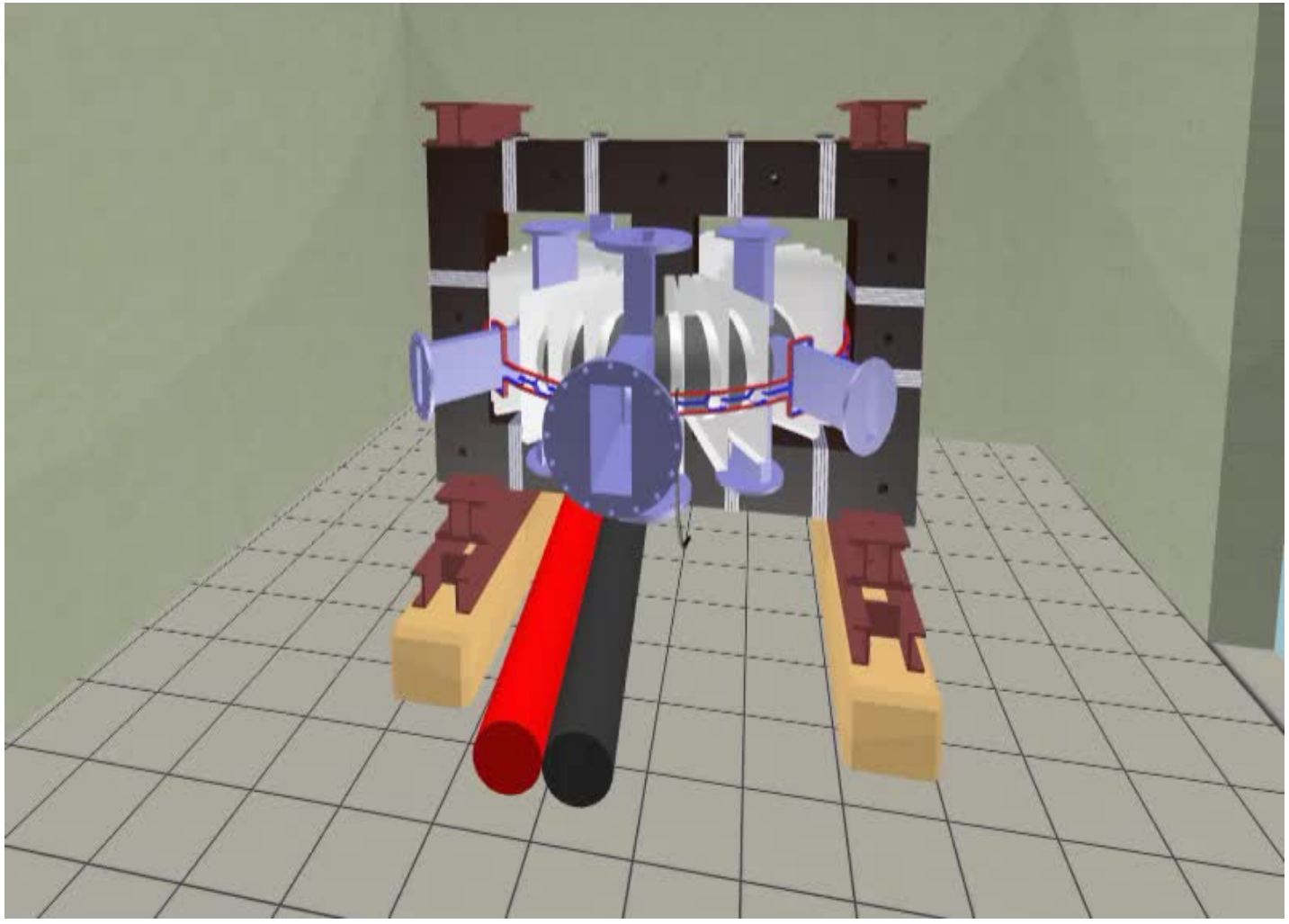
Toroidální magnetické pole udržuje plazma



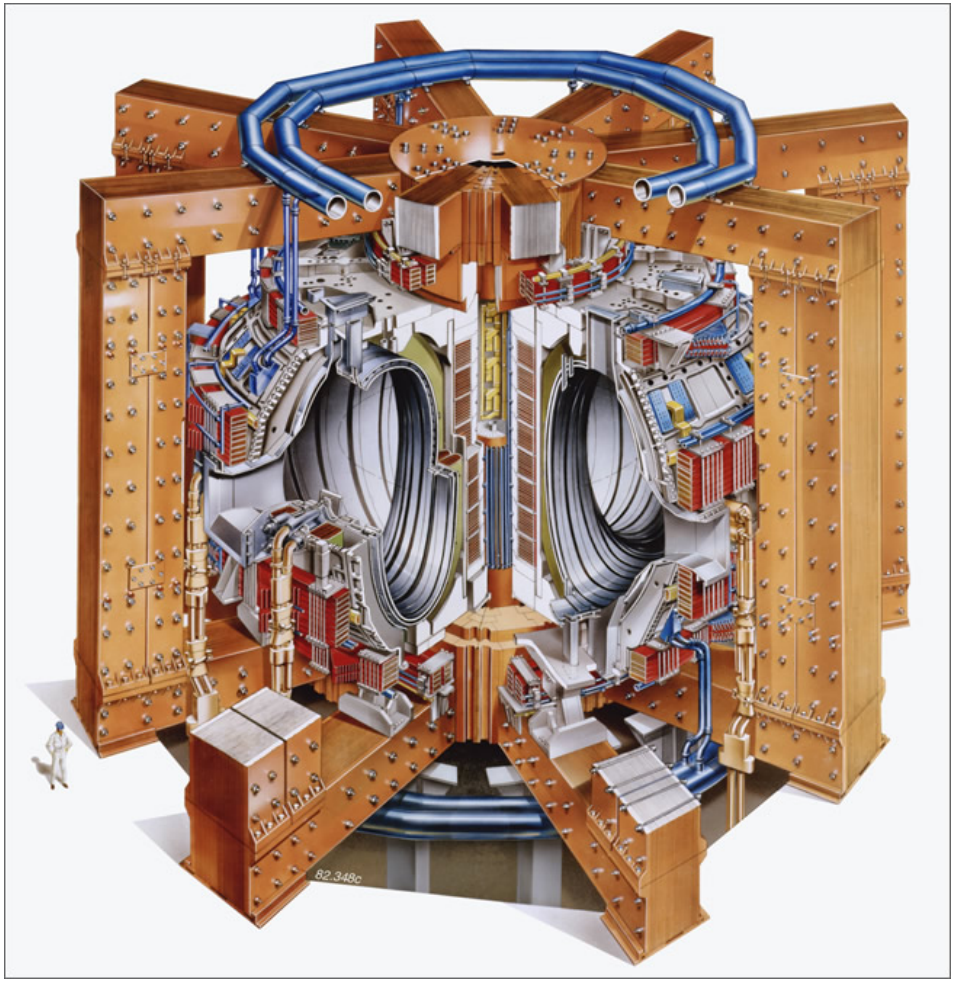
Transformátorová akce vytvoří a zahřeje plazma

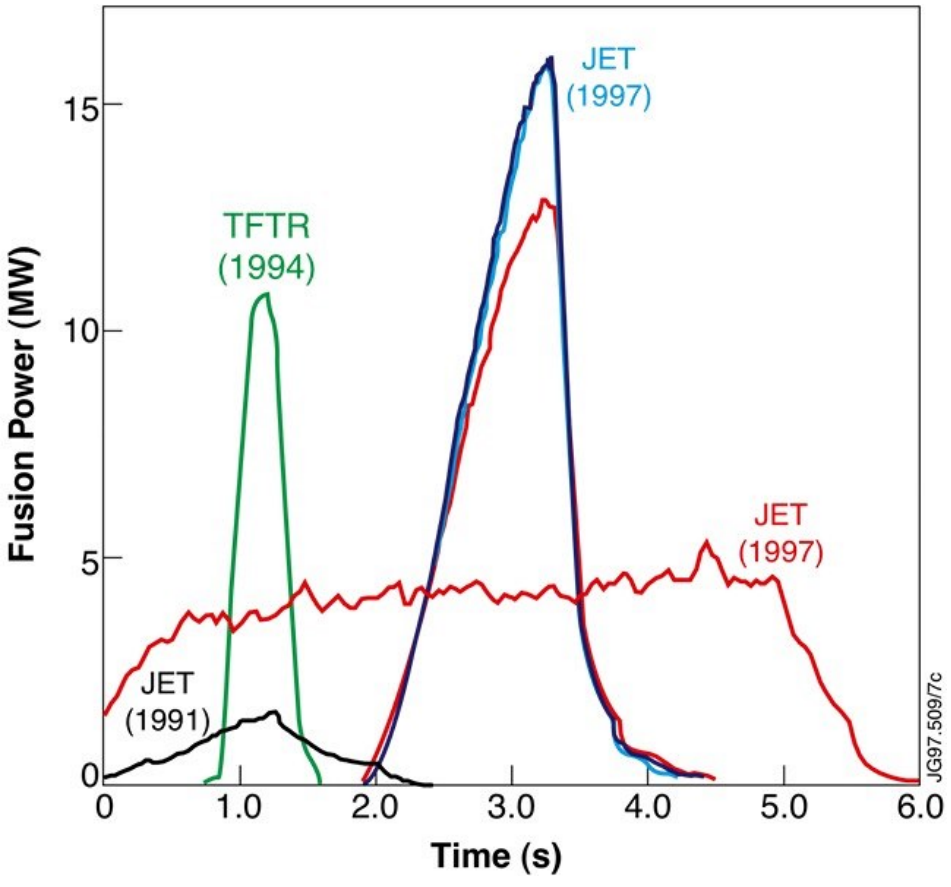


Vše dohromady - voilà tokamak



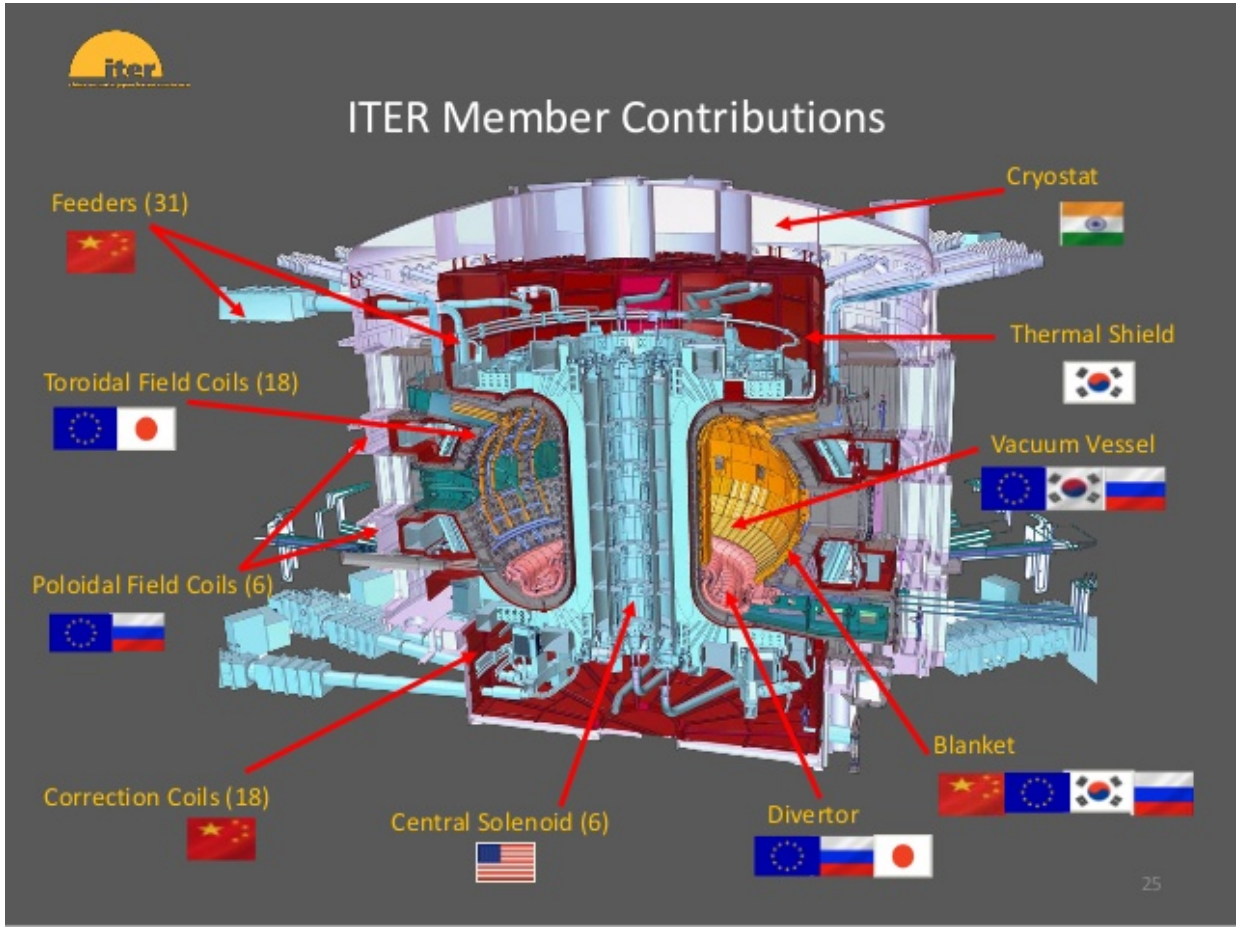
1997: Světový fúzní rekord @ JET (EU)





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

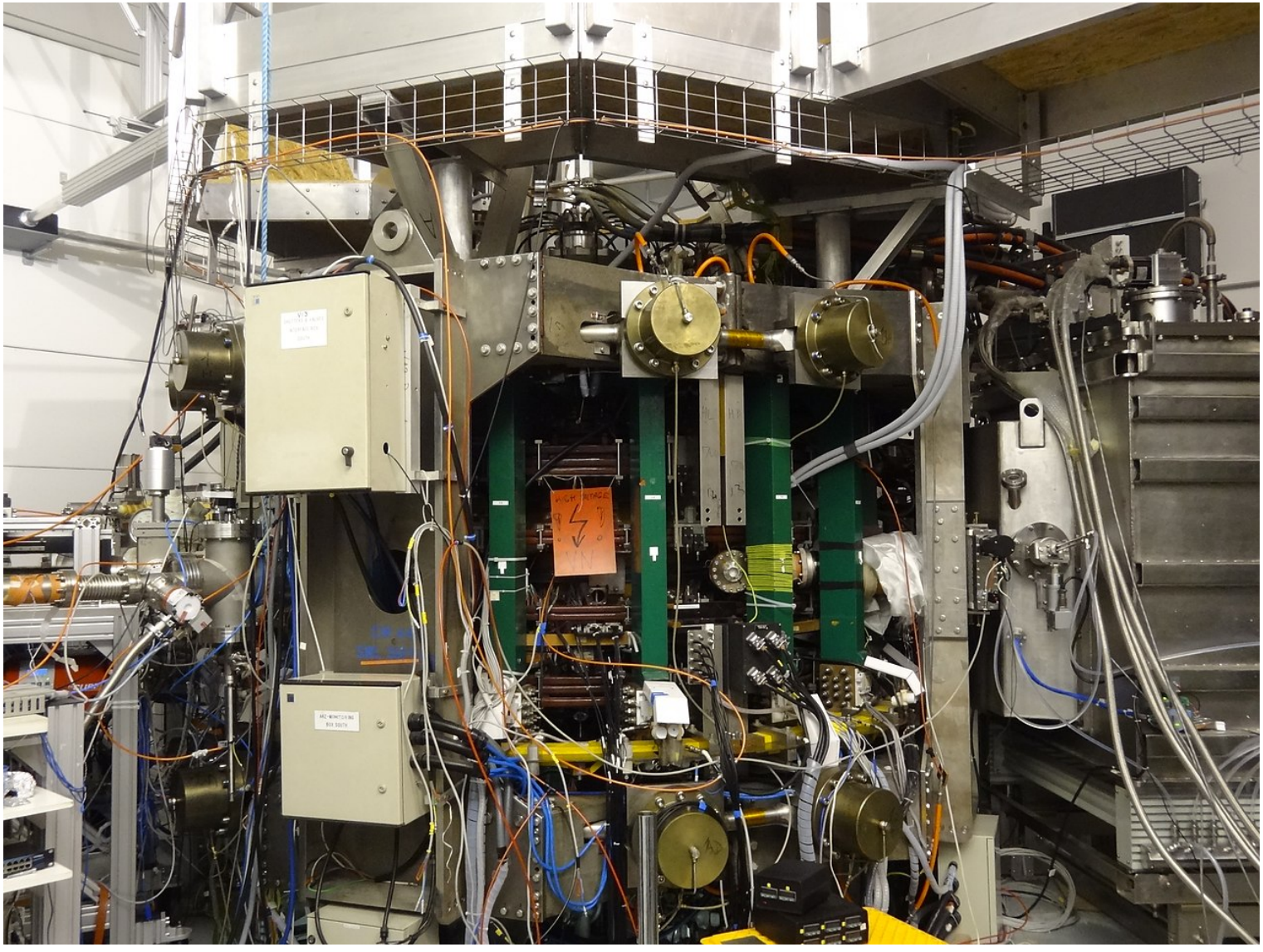
ITER (jižní Francie) $\approx$ 18 miliard EUR



Mise:

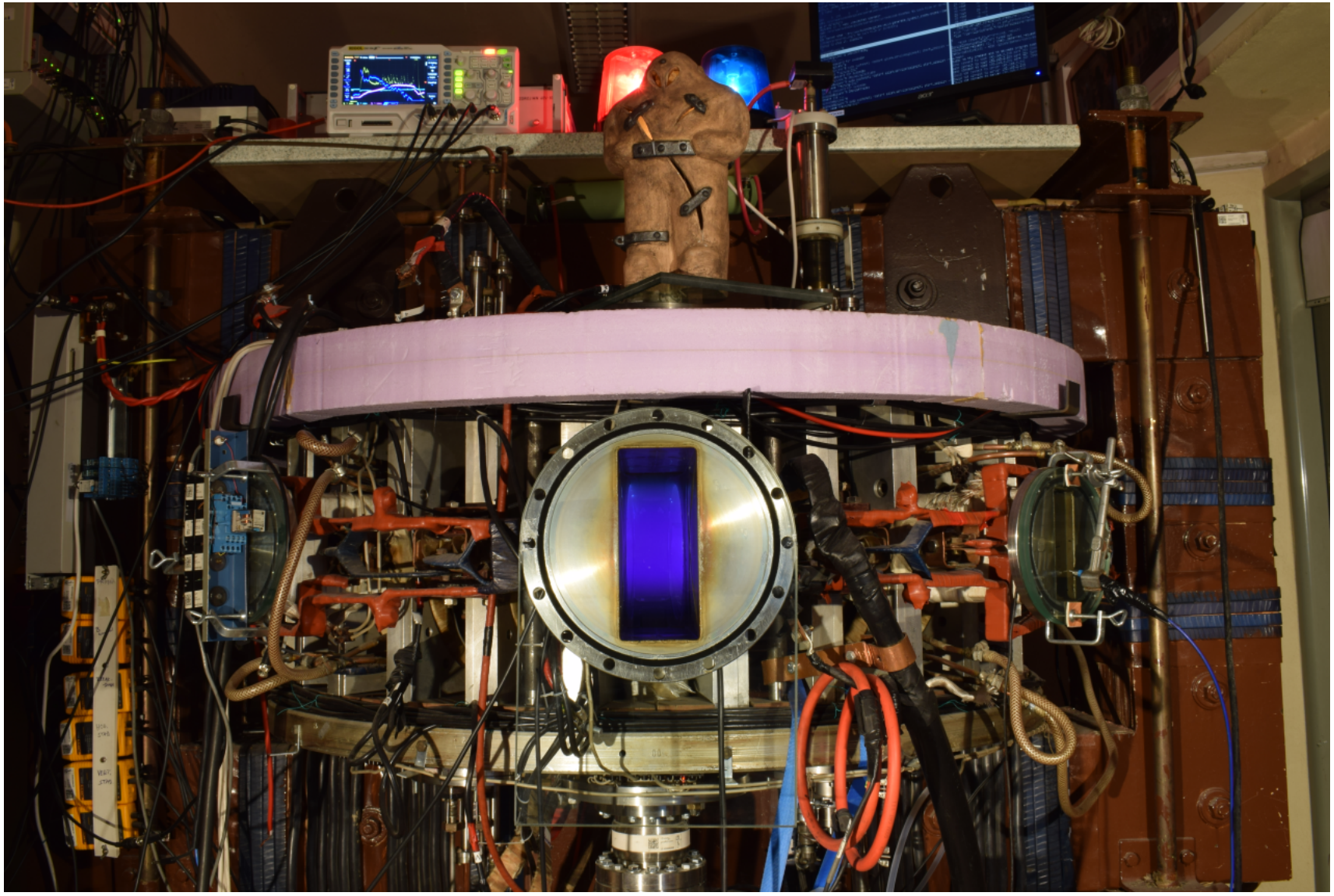
$P \approx 500$ MW, $Q \approx 10$, $\Delta T \approx 10$ minut, konkurenceschopná cena elektřiny

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

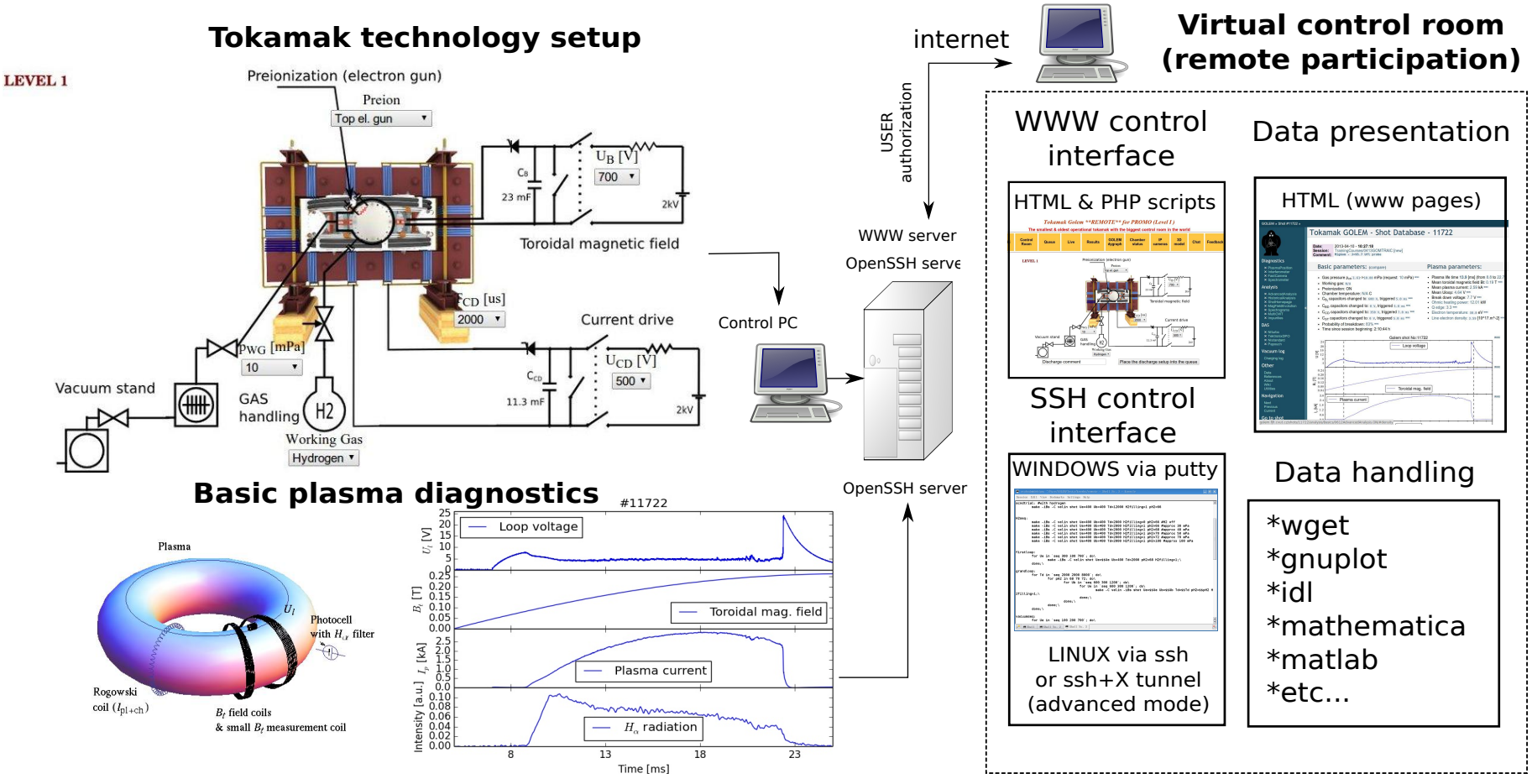


Velké ambice ....

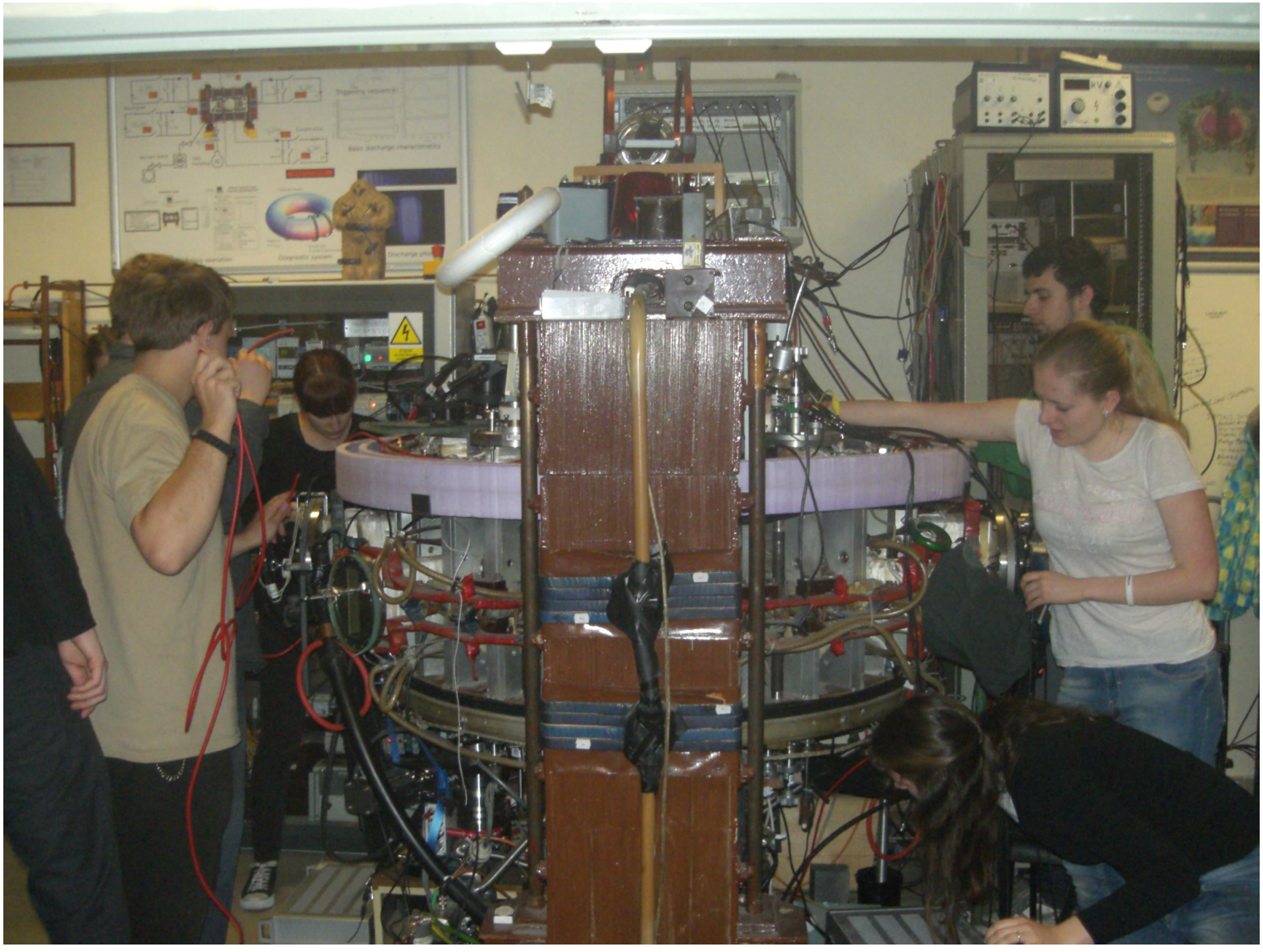
Tokamak GOLEM



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

Pozvánka na workshop
Big Bang stage dnes 20:00, zítra 14:00

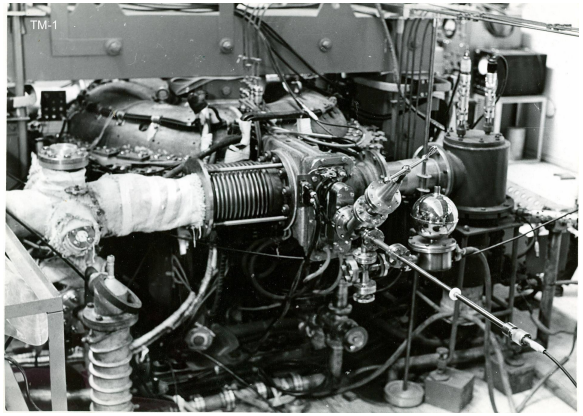
Go to http://golem.fjfi.cvut.cz/CoO

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

GOLEM

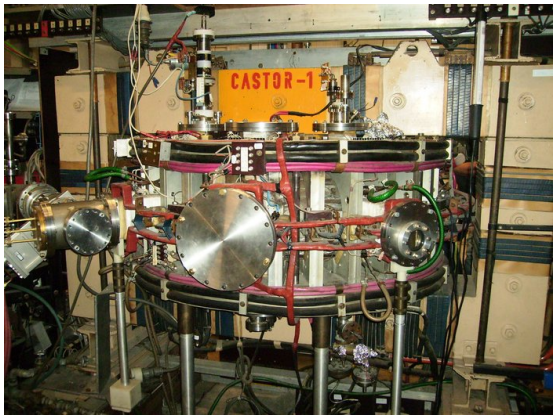
Děkuji za pozornost

Tokamak TM1
@Kurchatov Institute near Moscow
~1960-1977



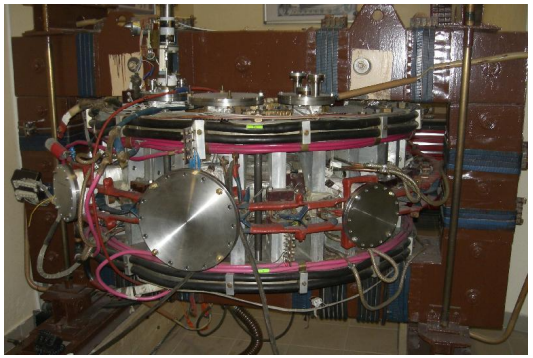
SCIENCE

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



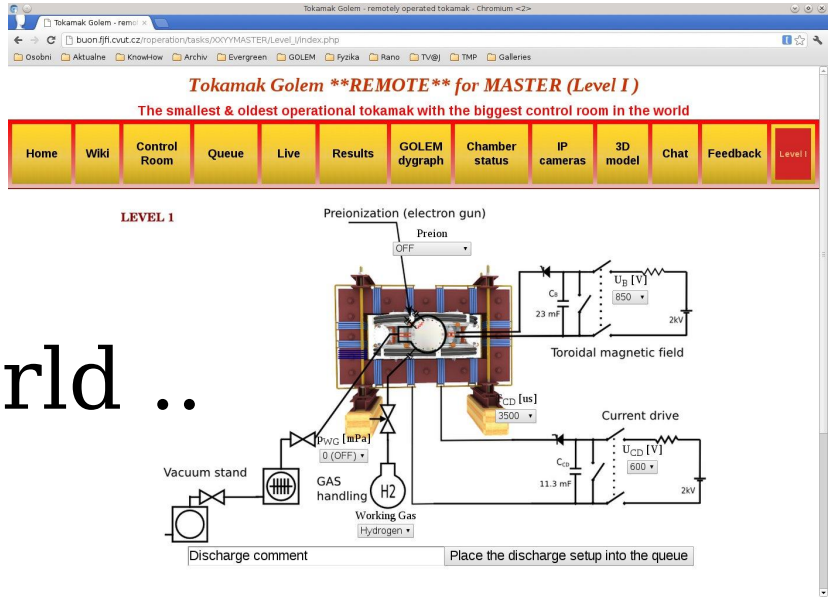
SCIENCE
& education

Tokamak GOLEM
@Czech Technical University, Prague
2007-



EDUCATION
& science

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



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home Kalendář Produkce Forecast Slovník Rano

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Current events

Tokamak

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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

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