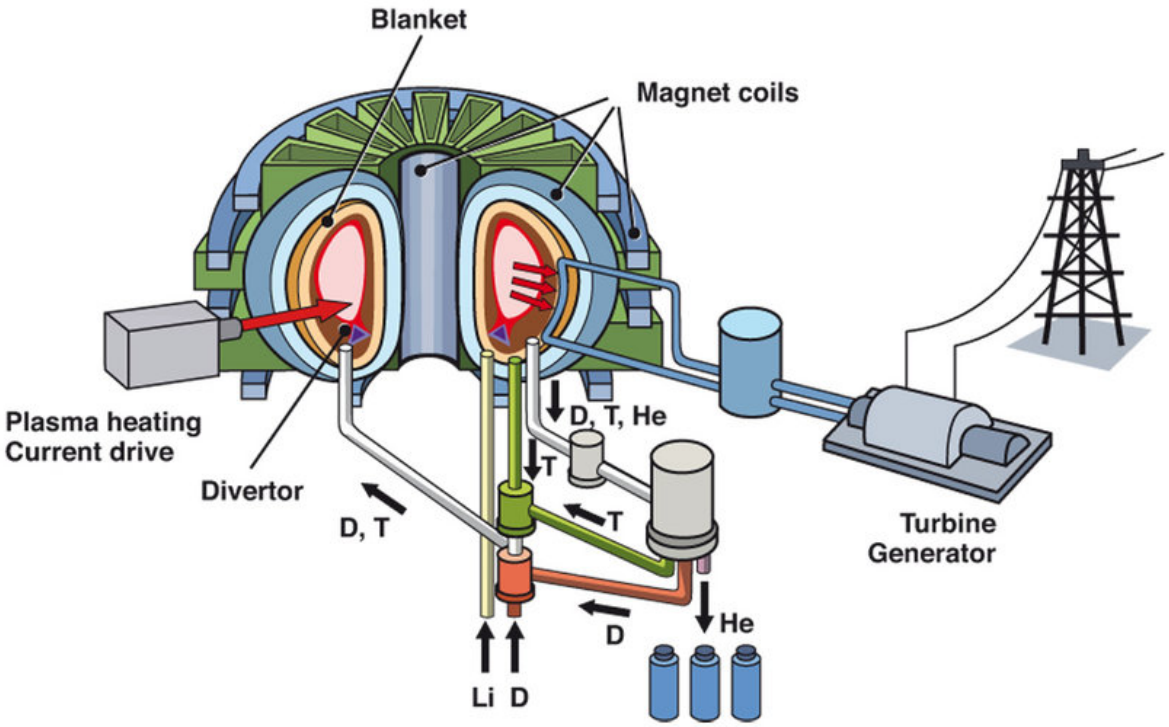
Jak se v centru Prahy zažehává hvězda

Vojtěch Svoboda

přednáška v rámci Týdne vědy a techniky - živě na FB

November 3, 2020

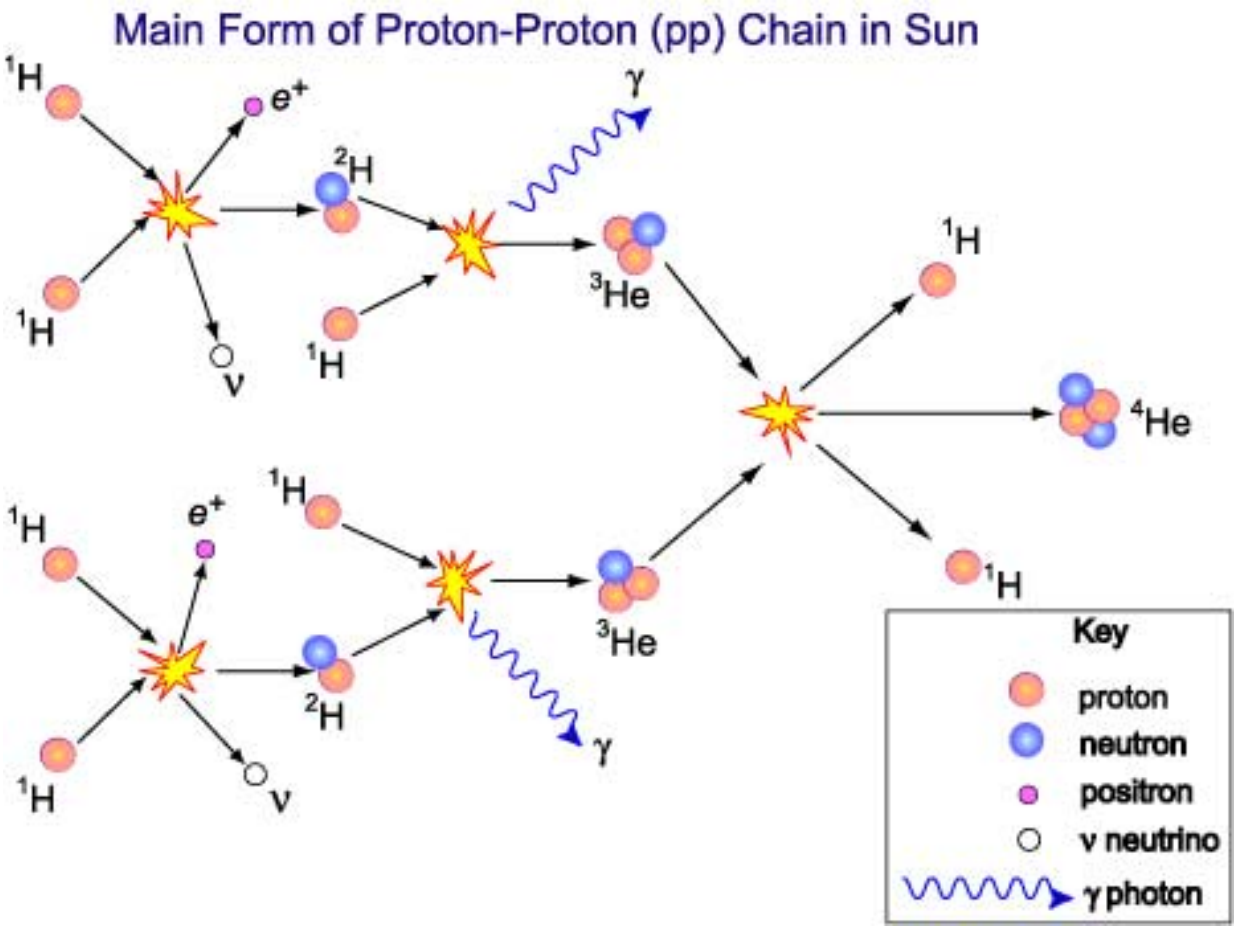
Vize: Jaderná elektrárna - slučovací/fúzní



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

Vypiplat technologii

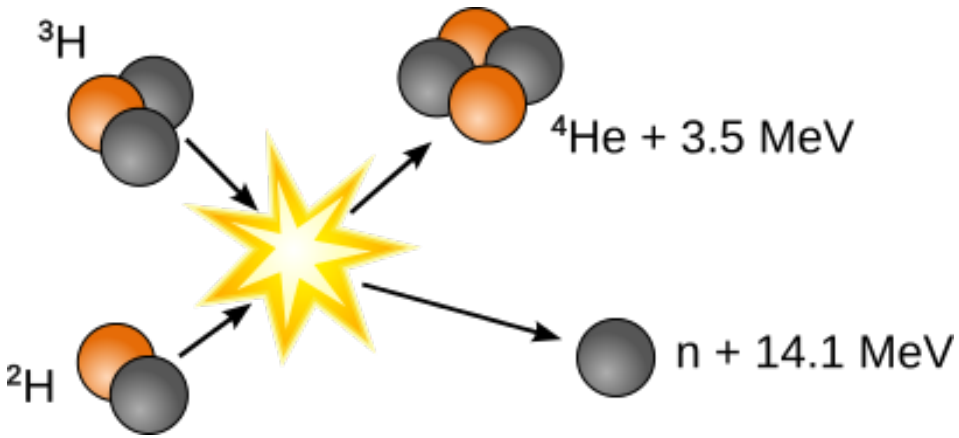
Inspirace: Slunce - protonový řetězec



credit:CSIRO

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

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



credit:?

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

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

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

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

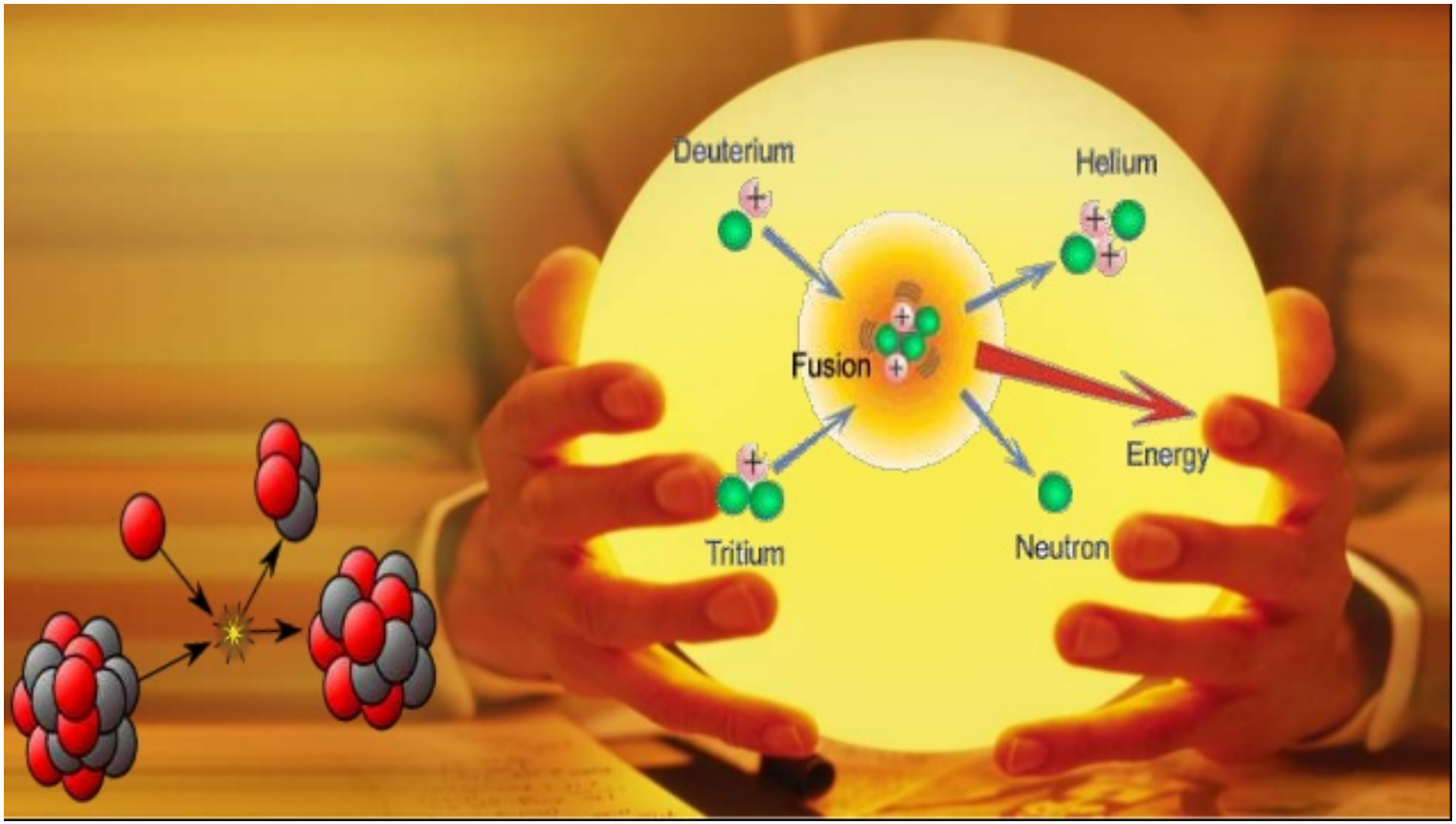
$$1\mathrm{eV} \sim 11600°\mathrm{C} \approx \mathbf{^2_1H_{100\ M°C} + ^3_1H_{100\ M°C} \Rightarrow ^4_2He_{35\ G°C} + ^1_0n_{141\ G°C}}$$

1952 "Operation Ivy - Mike" První test vodíkové bomby

credit:YouTube:Ivy Mike Countdown and detonation

Toto není vhodná technologie

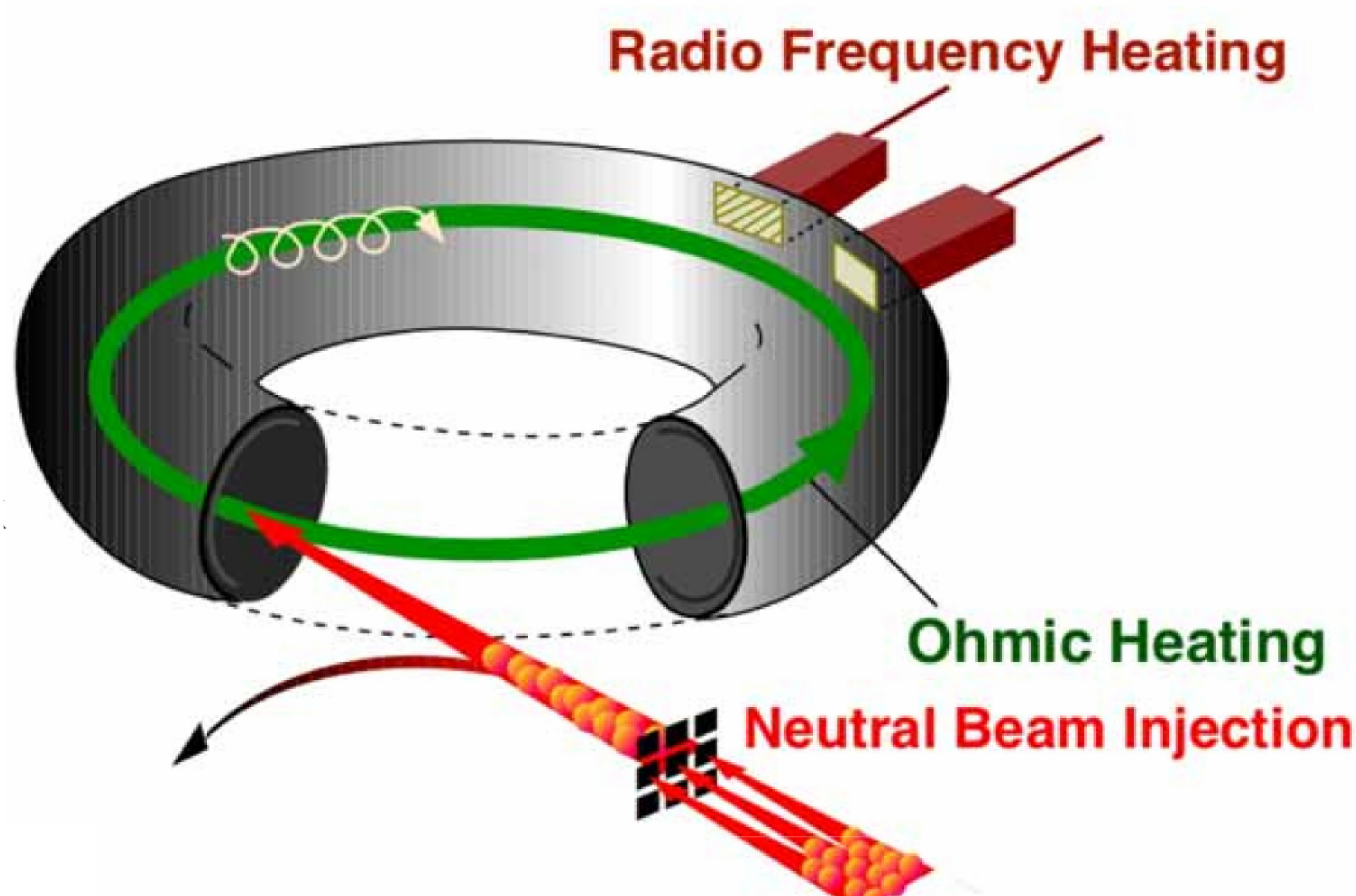
Hledá se vhodná fúzní technologie



Podmínky:

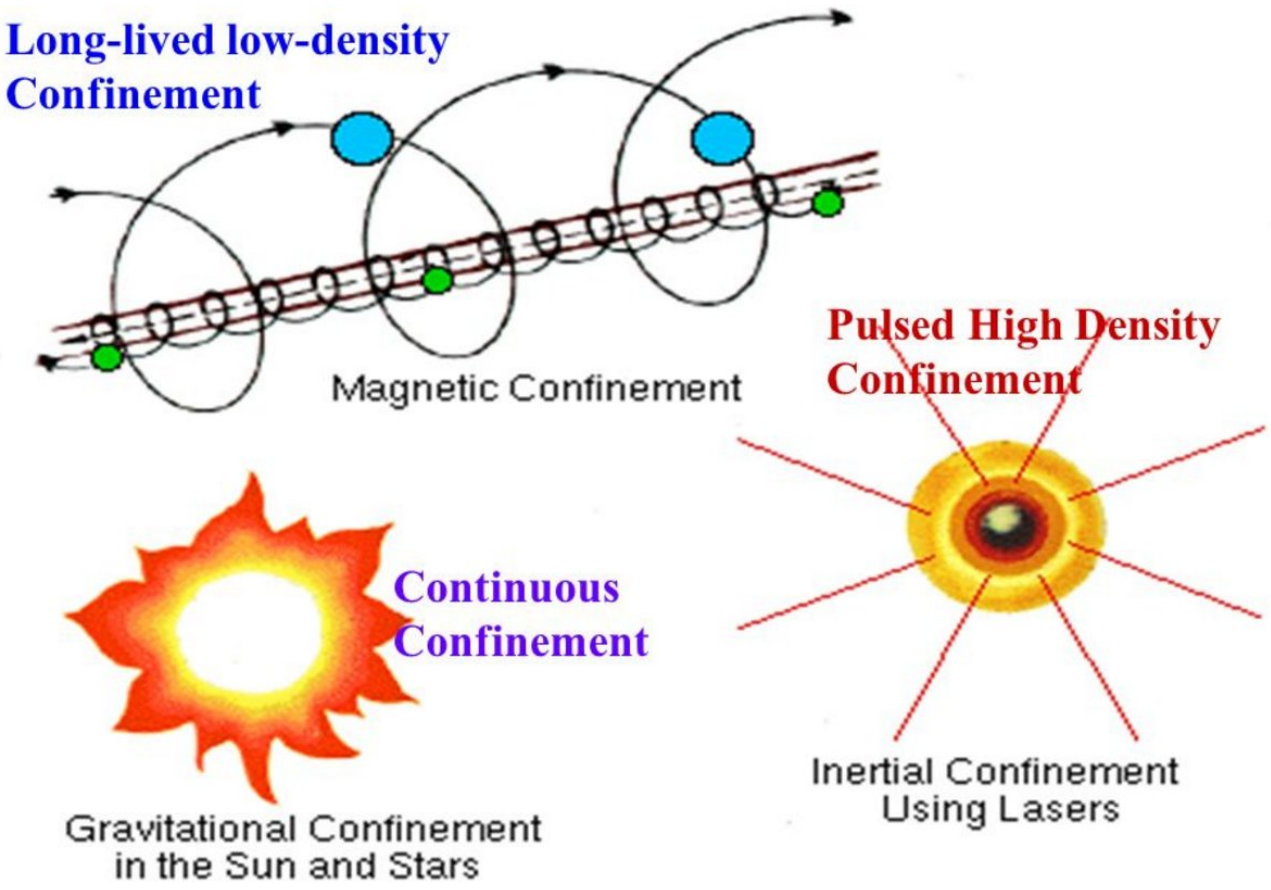
Zahřát na $\sim$ 100 000 000 °C & **udržet** po dobu $\sim$ 30 let

Ohřev plazmatu

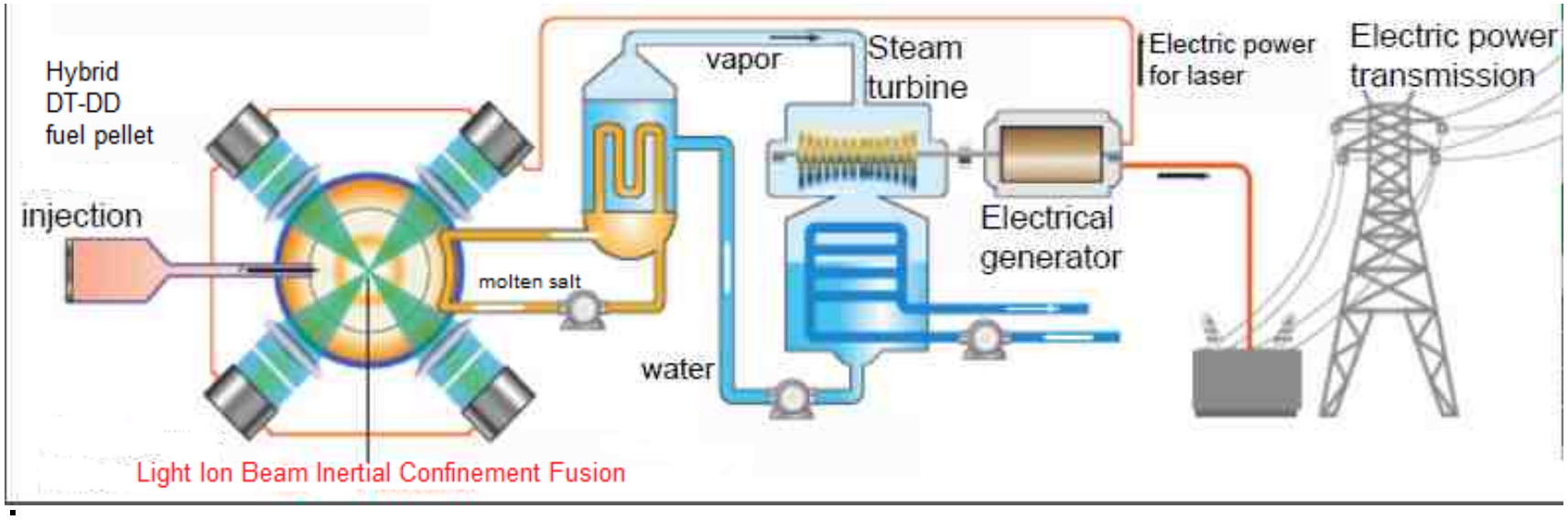


Tři možné cesty jak udržet plazma pro fúzi

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



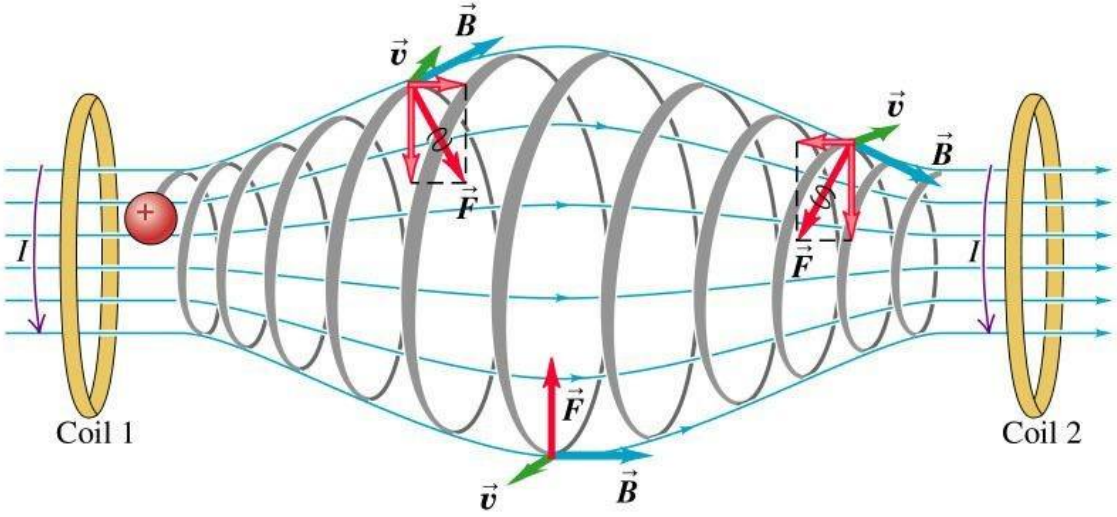
Inerciální fúze



credit:mext.jp

Velká výzva

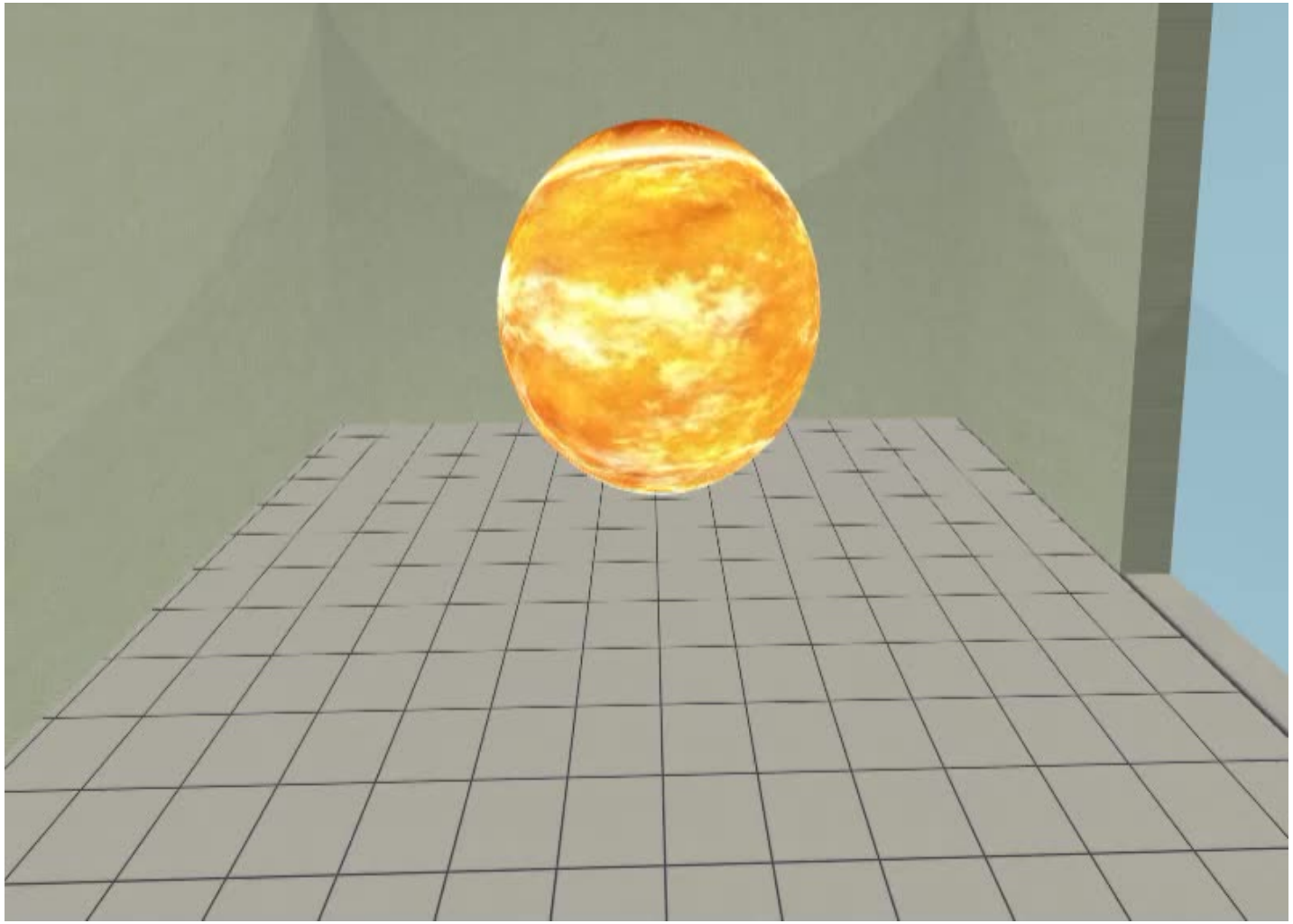
Magnetické udržení: magnetická nádoba



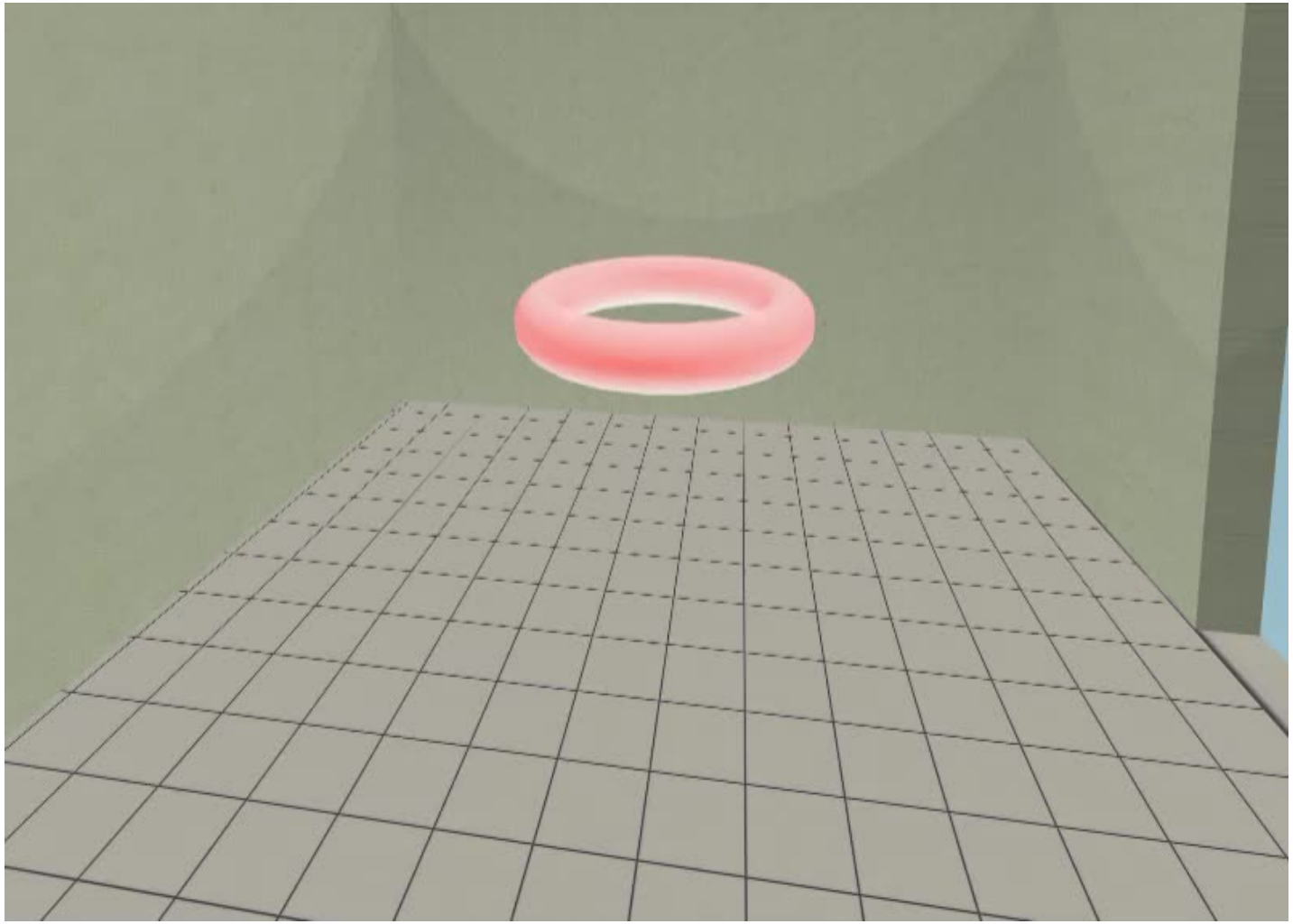
Musíme ji ale svinout do kruhu (zbavit se podstav)

záchranný kruh/duše pneumatiky/donut

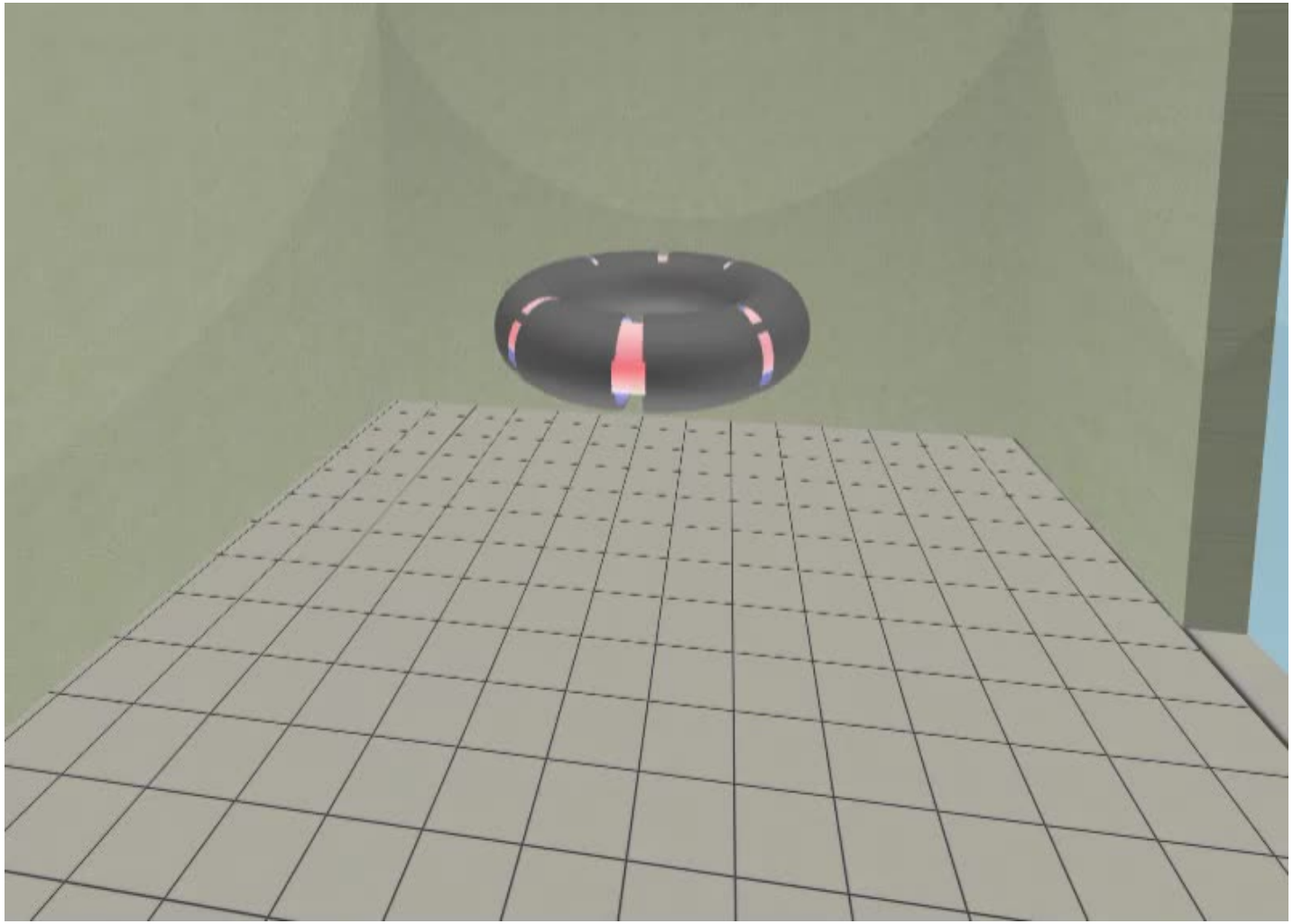
Náš cíl: vytvořit μSlunce v pozemských podmínkách



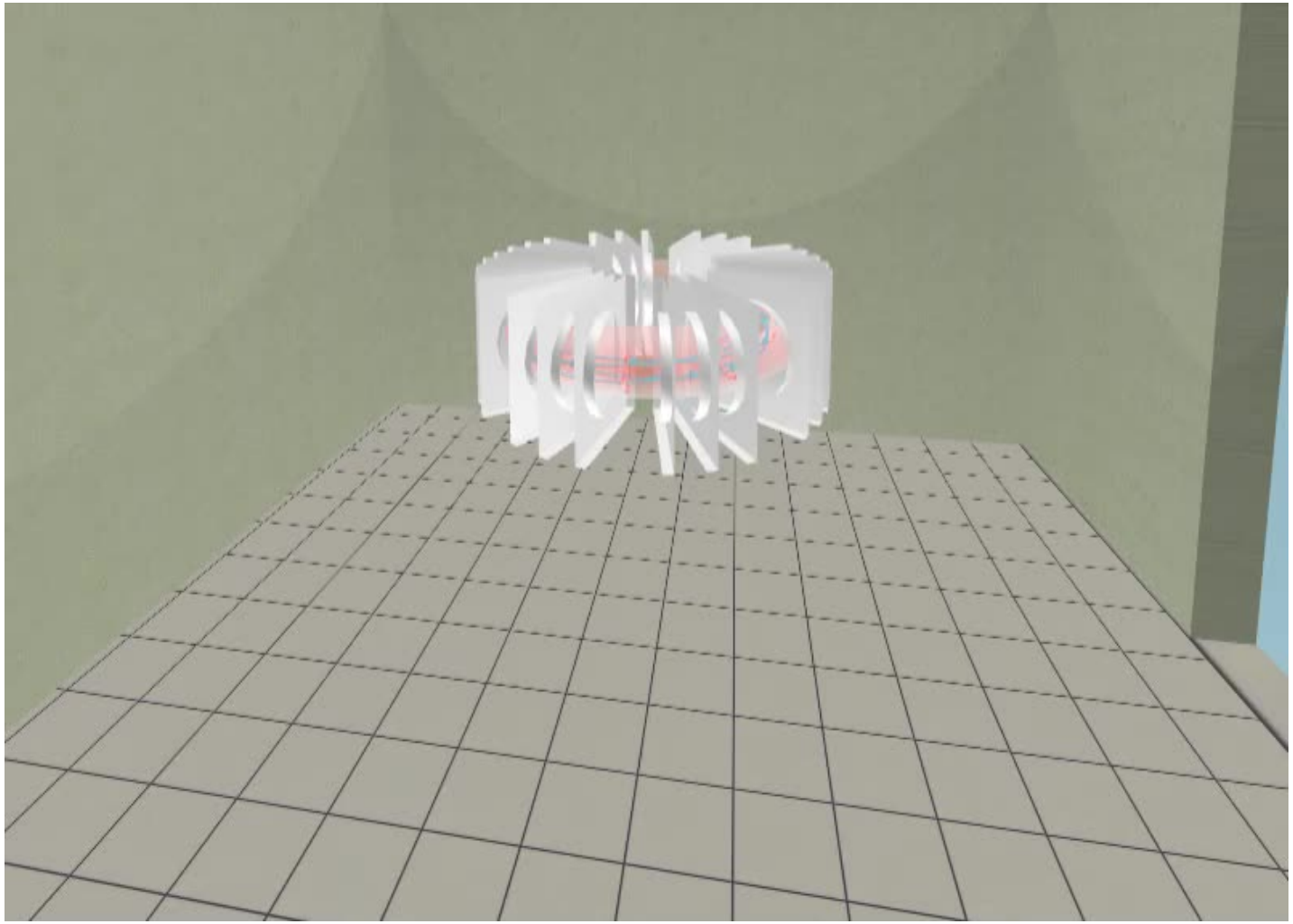
Magnetické udržení vyžaduje toroidální geometrii
Svinutá magnetická nádoba



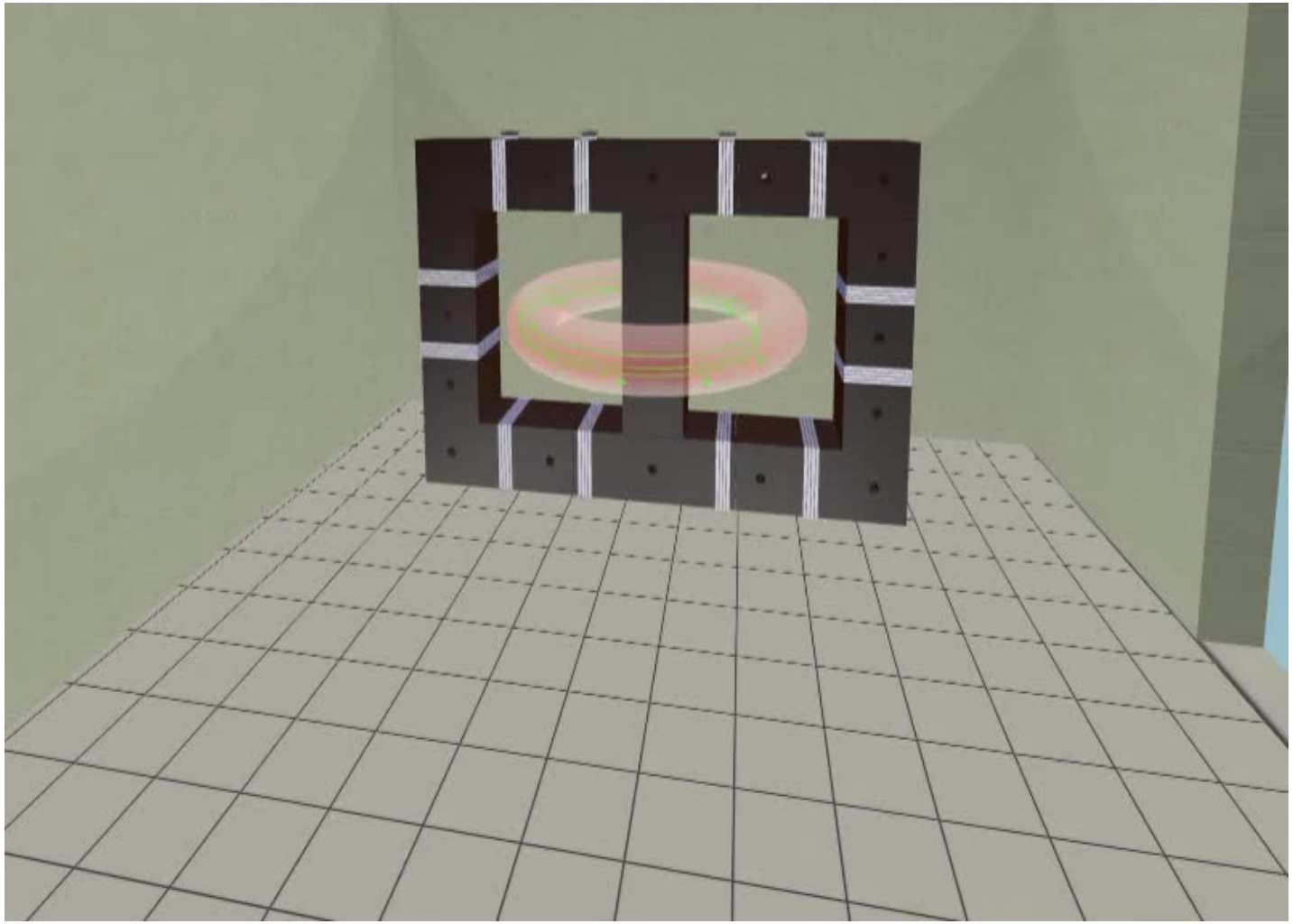
Musíme to celé umístit do reaktorové nádoby - komory



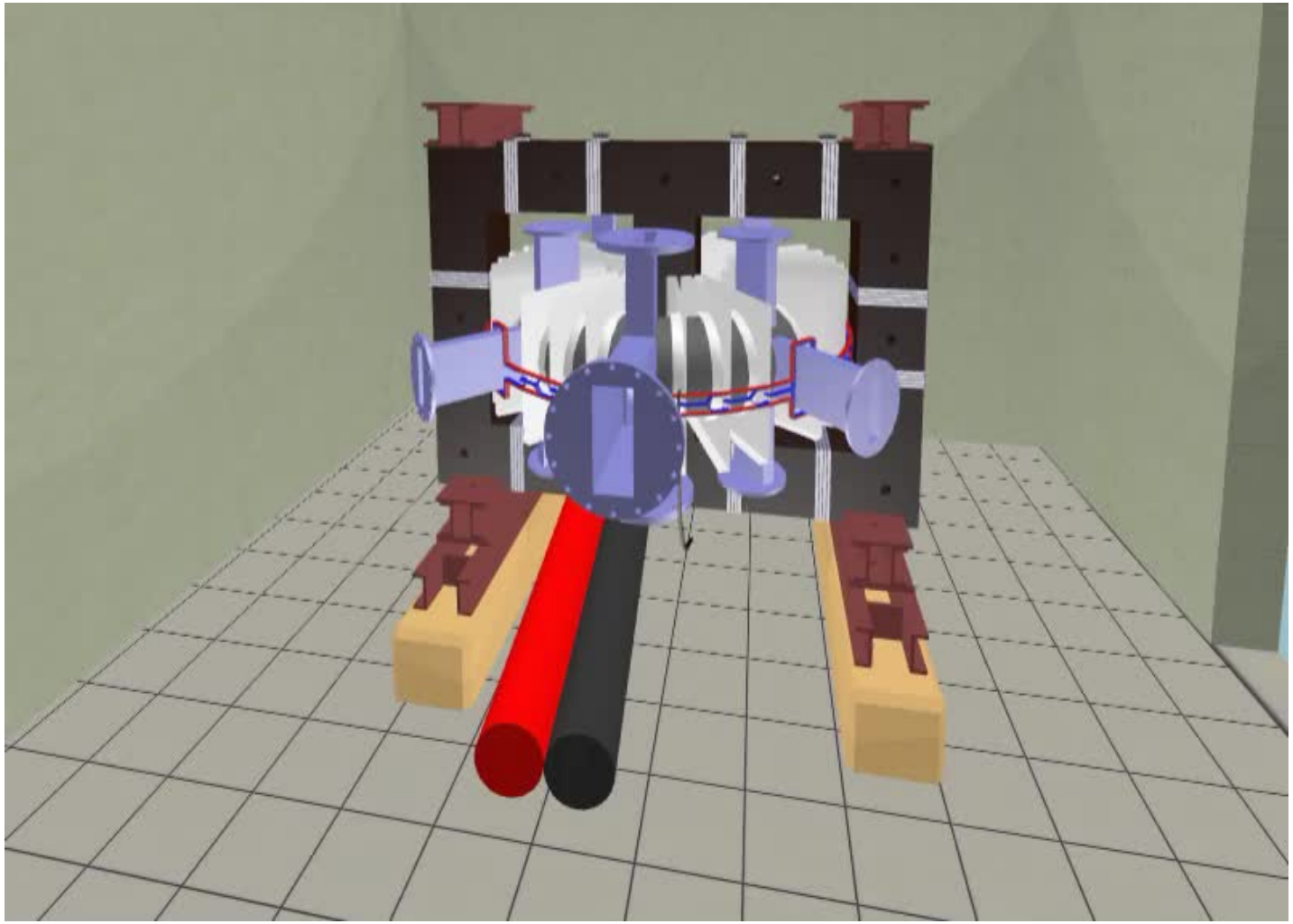
Toroidální magnetické pole udržuje plazma



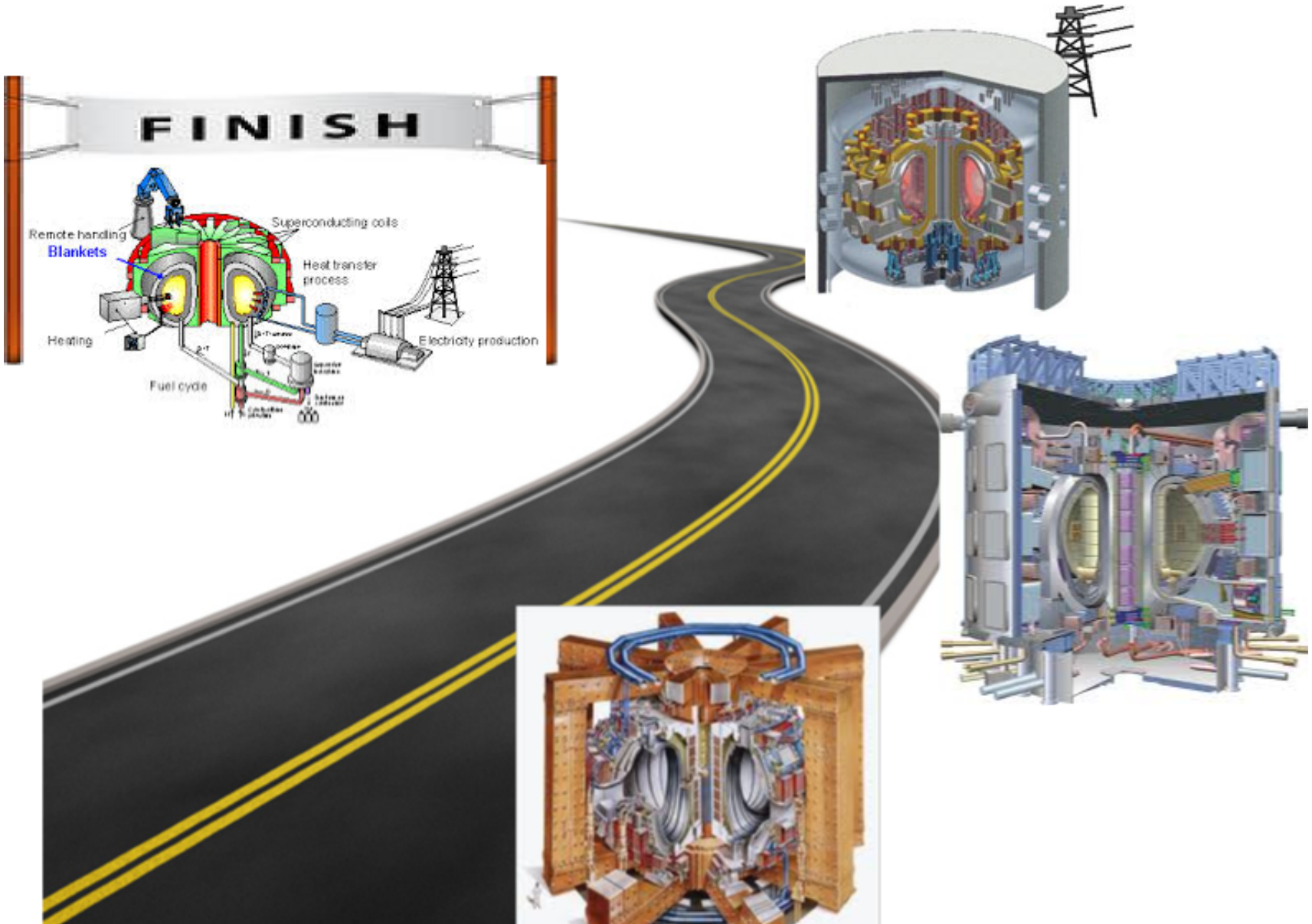
Transformátorová akce vytvoří a zahřeje plazma



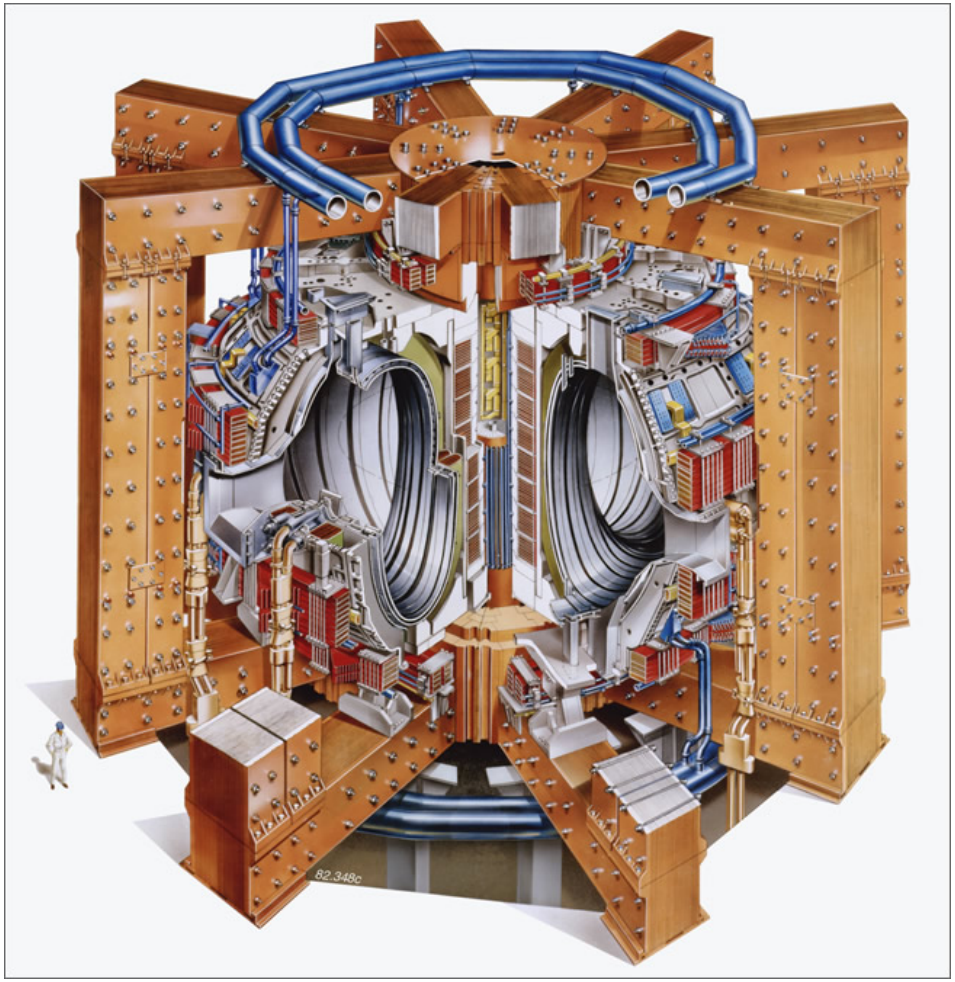
Vše dohromady - voilà tokamak

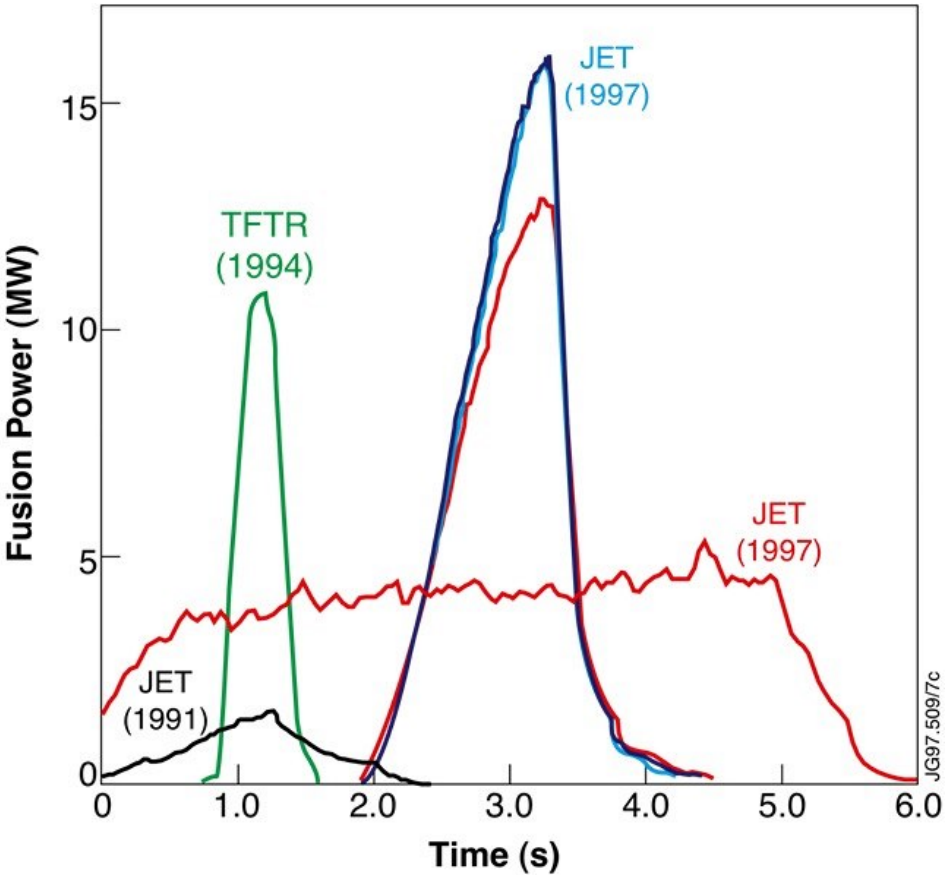


Milestones to Fusion Power Plant



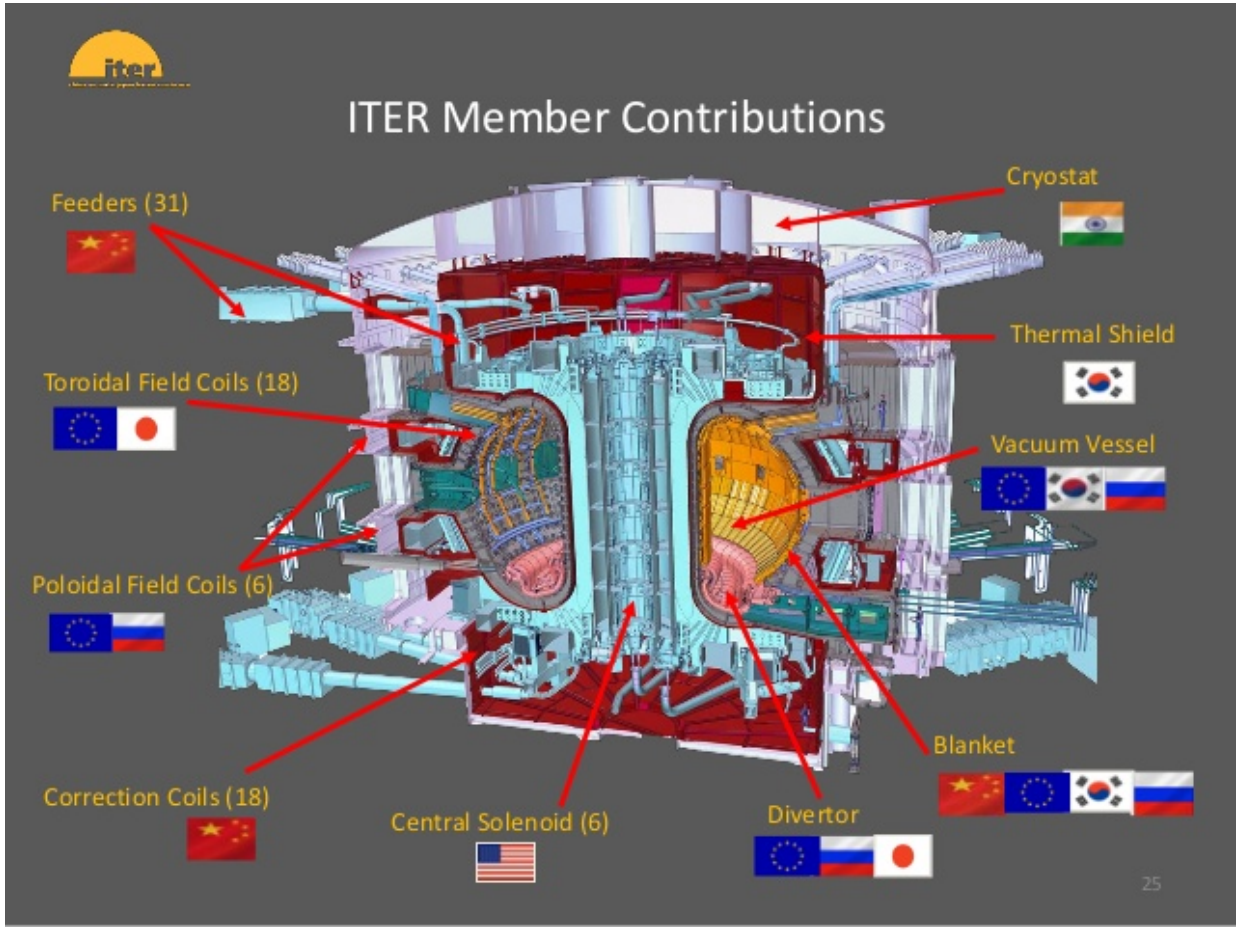
1997: Světový fúzní rekord @ JET (EU)





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

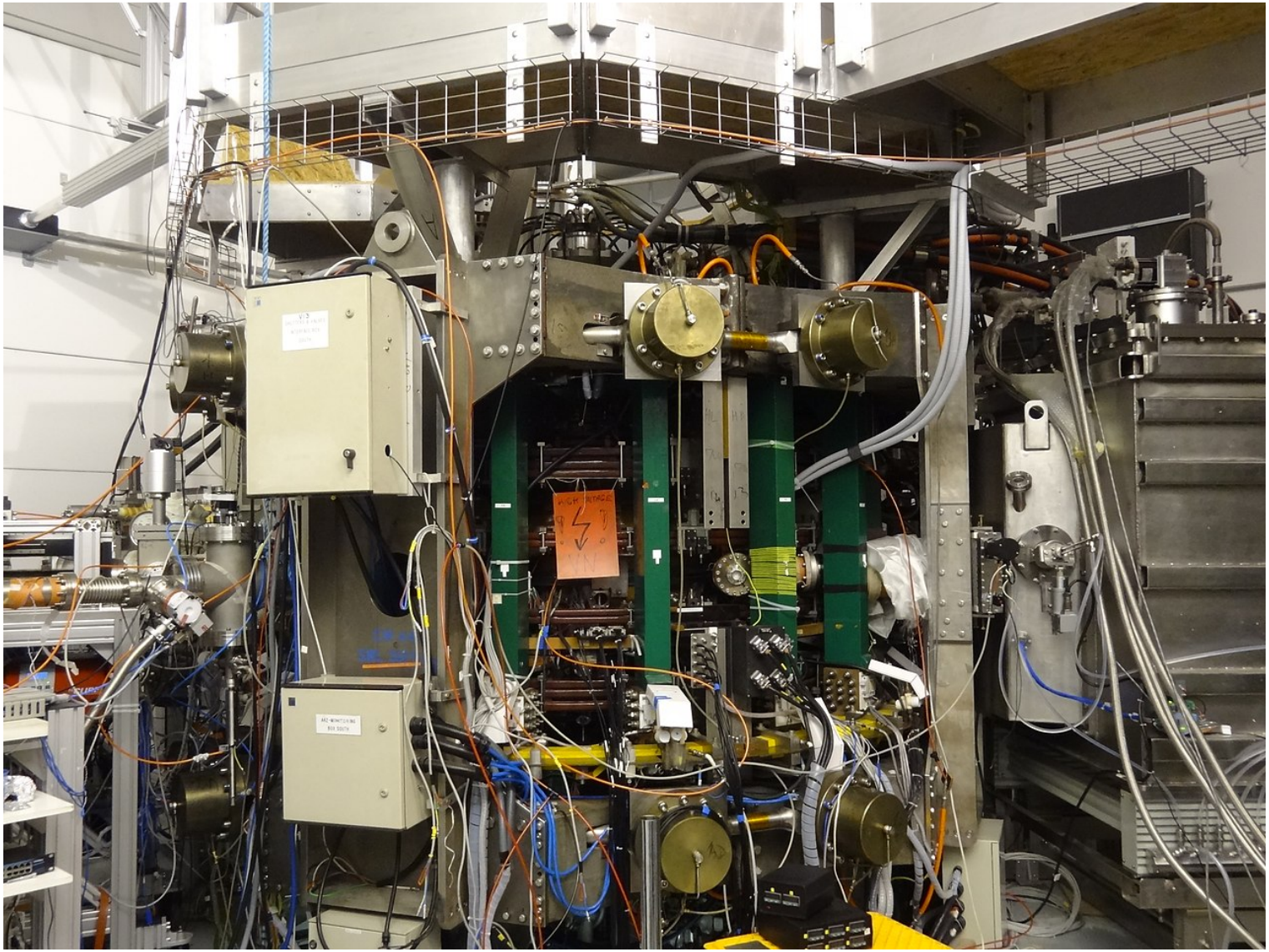
ITER (jižní Francie) $\approx$ 18 miliard EUR



Mise:

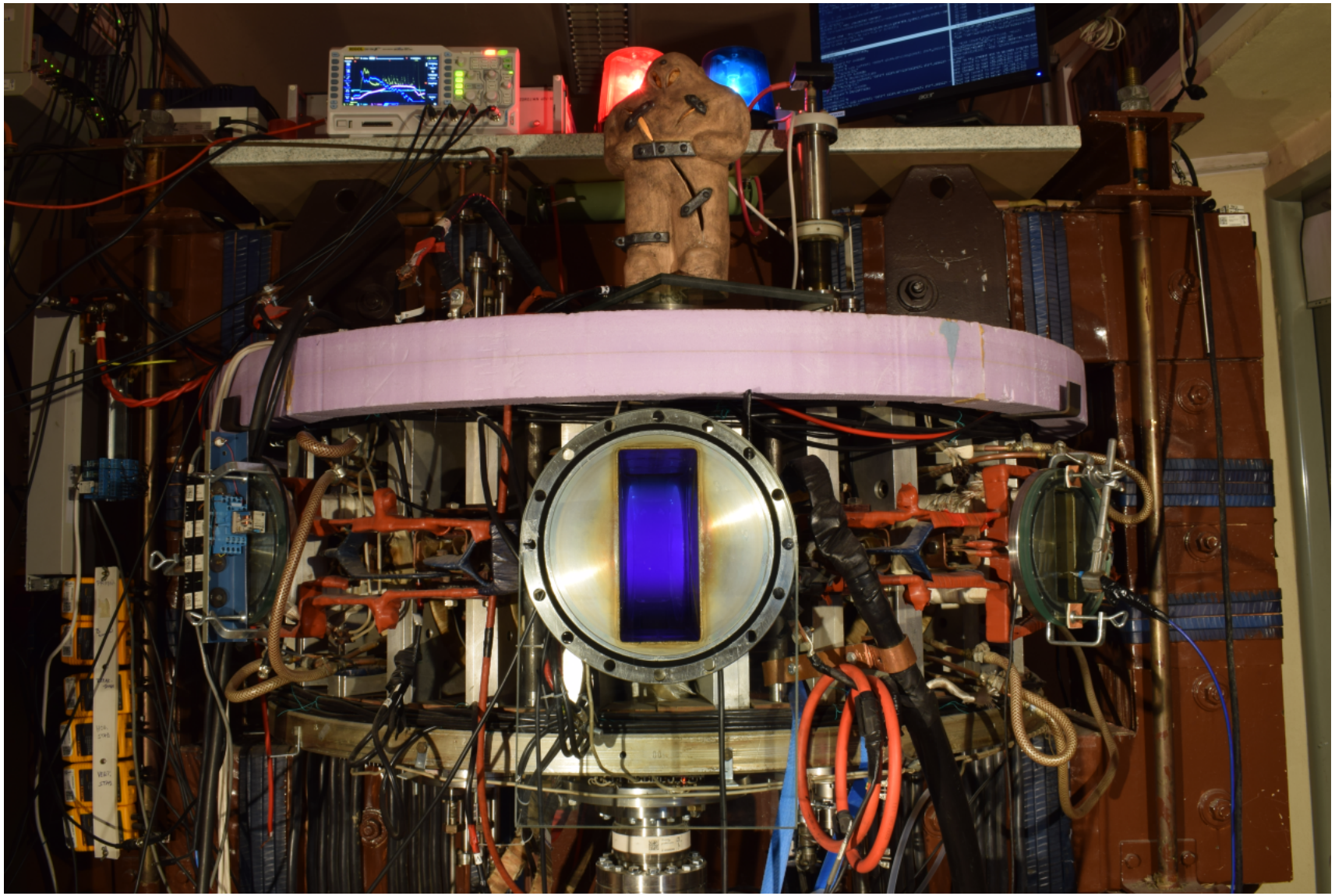
$P \approx 500$ MW, $Q \approx 10$, $\Delta T \approx 10$ minut, konkurenceschopná cena elektřiny

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

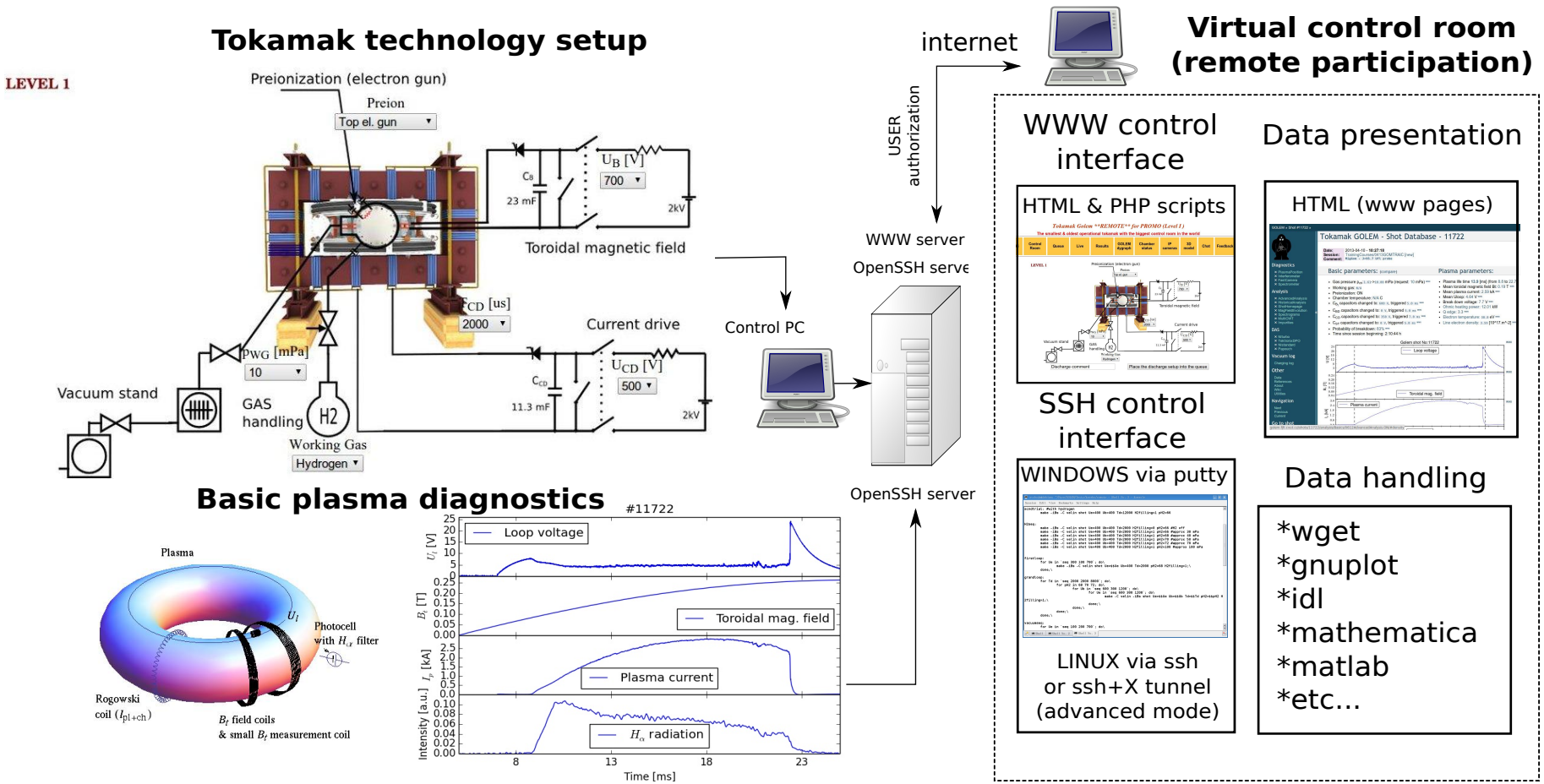


Velké ambice ....

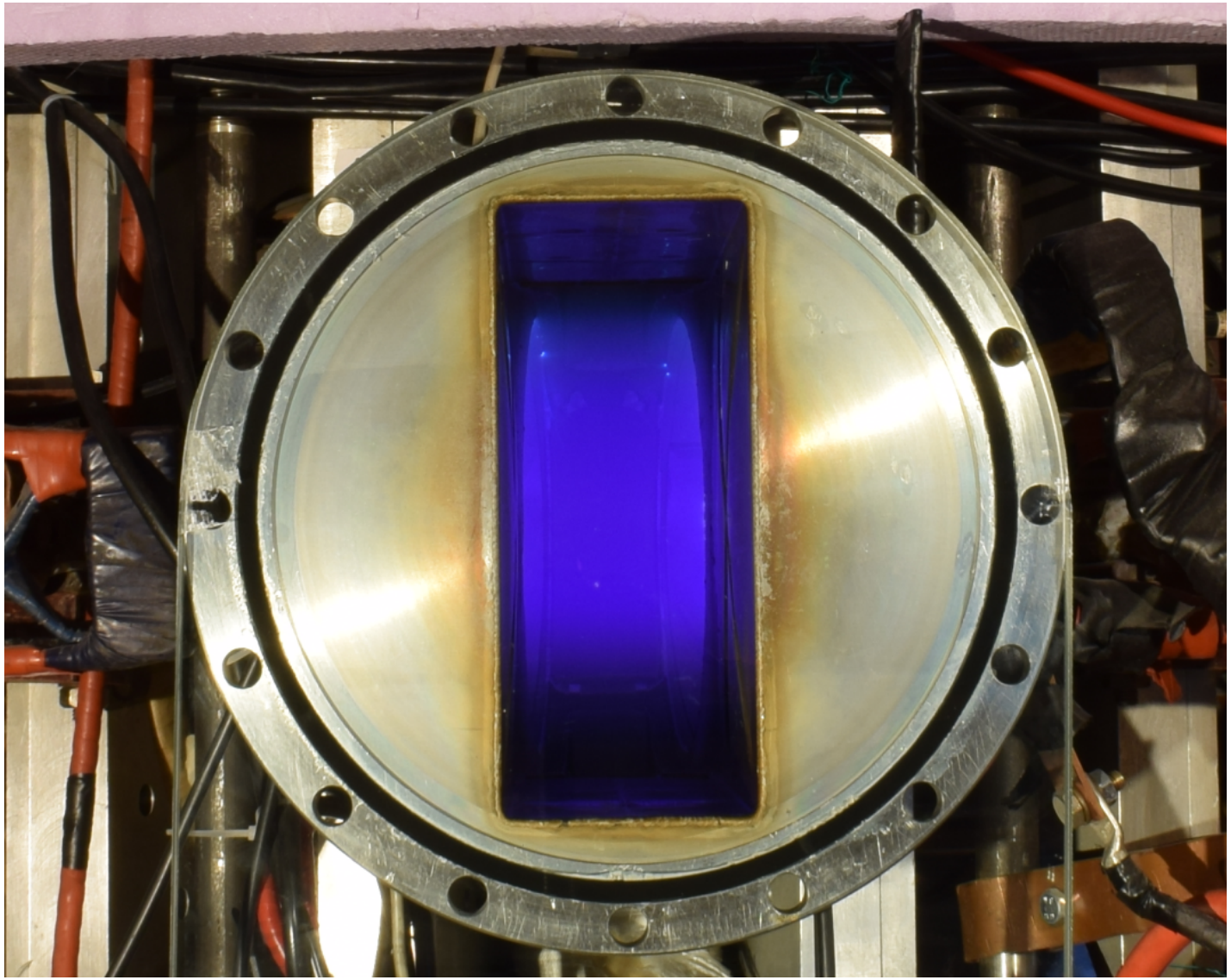
Tokamak GOLEM



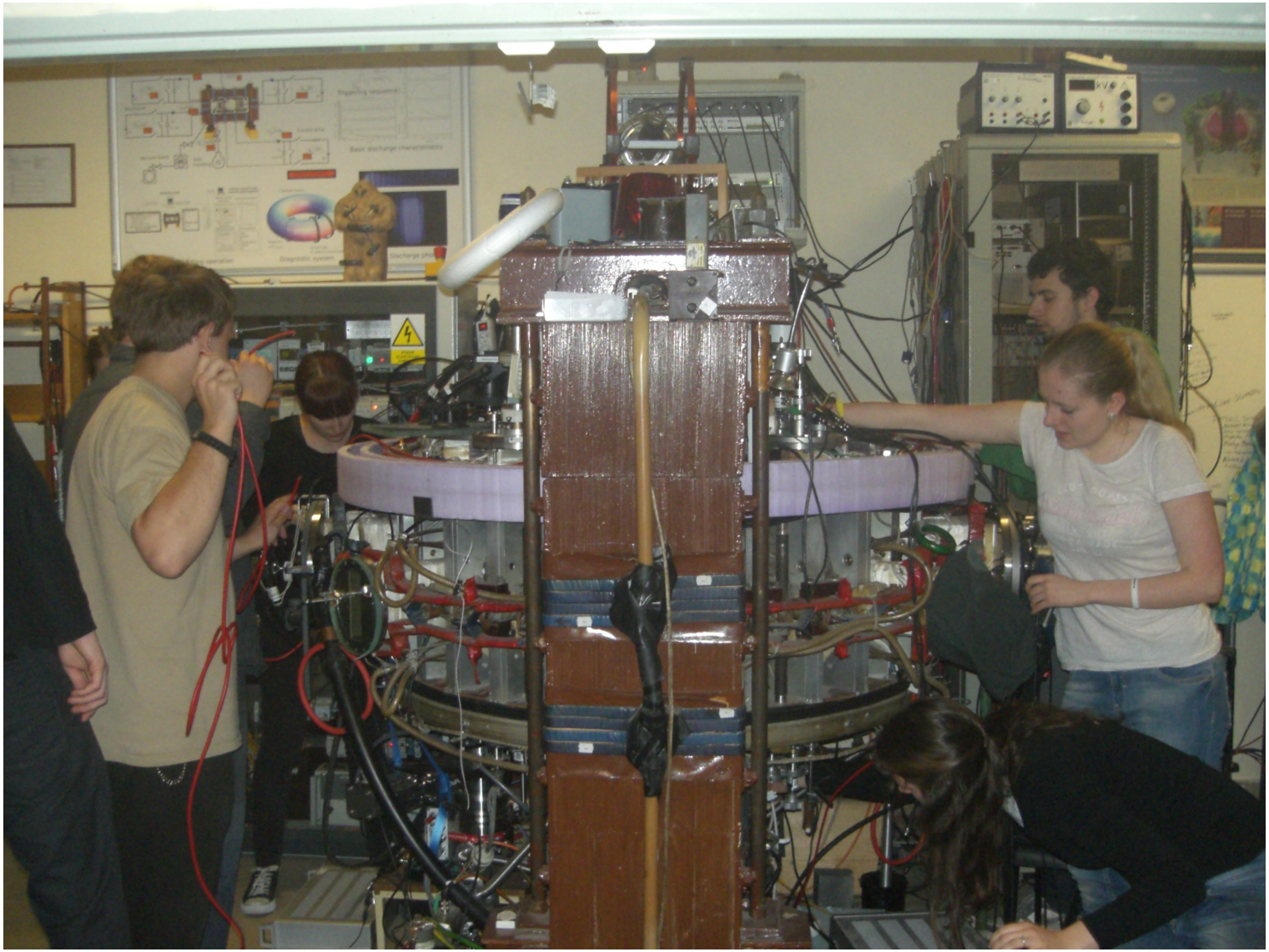
Tokamak GOLEM - experimentální schéma



Let's make a discharge



Hands on tokamak



Tokamak GOLEM - vzdálené řízení: 2009-2019 inventura

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

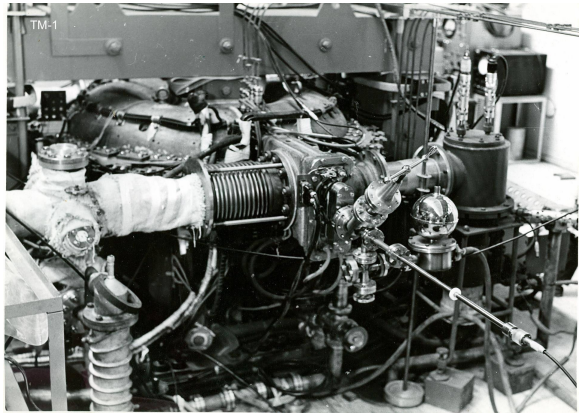
- Demonstrace: Ghent University 09; Bochum University 13; Garching 13; Lemvig High School 14; Instituto Tecnologico Costa Rica 10; Armidale University 17.
- Zimní a letní školy: French Training Course & EM 12-14,16-19; Bangkok 16-19; TU Eindhoven 11,15-19;TU Kobehaven 14,15,18;Grenoble TU 15, University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

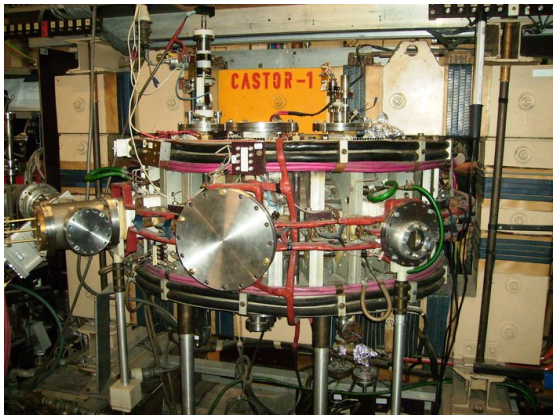
Děkuji za pozornost

Tokamak TM1
@Kurchatov Institute near Moscow
~1960-1977



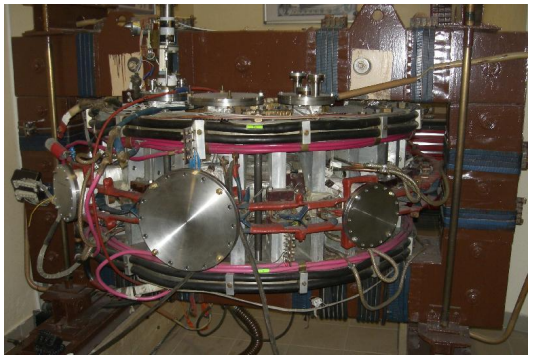
SCIENCE

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



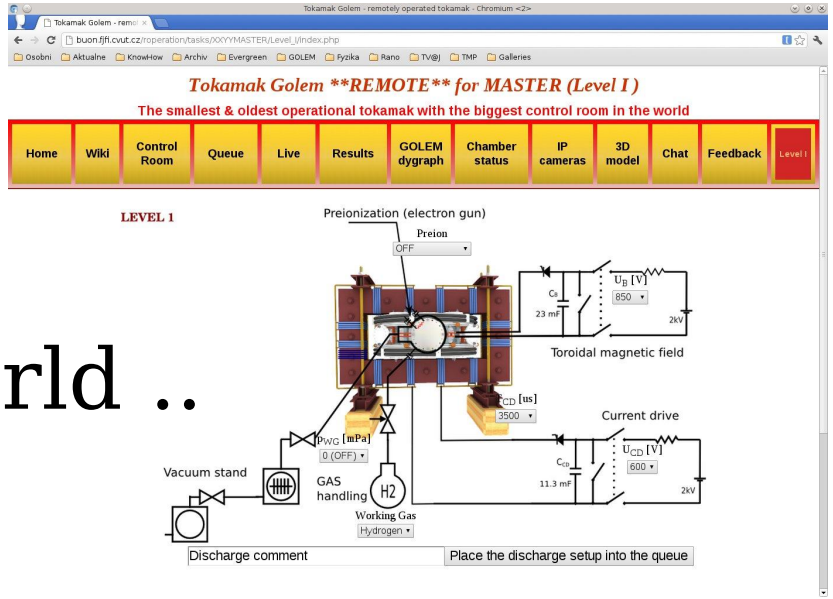
SCIENCE
& education

Tokamak GOLEM
@Czech Technical University, Prague
2007-



EDUCATION
& science

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



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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.

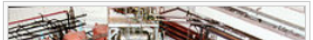
Experimental tokamaks [edit]

Currently in operation [edit]

(in chronological order of start of operations)

- 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



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Students, teachers, technicians (random order):

Vladimír Fuchs, Ondřej Grover, Jindřich Kocman, Tomáš Markovič, Michal Odstrčil, Tomáš Odstrčil, Gergo Pokol, Igor Jex, Gabriel Vondrášek, František Žácek, Lukáš Matěna, Jan Stockel, Jan Mlynář, Jaroslav Krbec, Radan Salomonovič, Vladimír Linhart, Kateřina Jiráková, Ondřej Ficker, Pravesh Dhyani, Juan Ignacio Monge-Colepicolo, Jaroslav Čeřovský, Bořek Leitl, Martin Himmel. Petr Švihra, Petr Mácha, Vojtěch Fišer, Filip Papoušek, Sergei Kulkov, Martin Imríšek.