Fusion and ITER

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Outline

Introduction

Fusion principles

Fusion devices

Fusion experiments

ITER

Fusion technology -> this afternoon

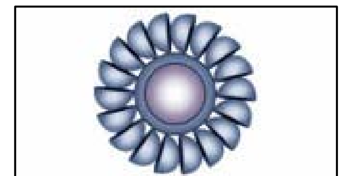
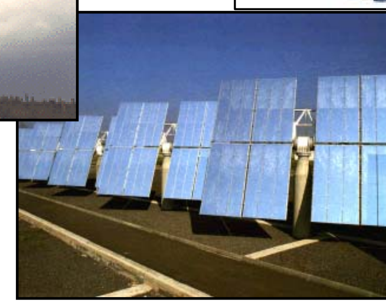
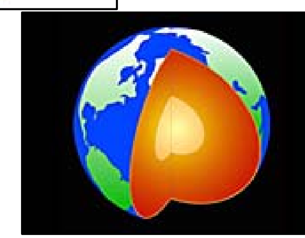
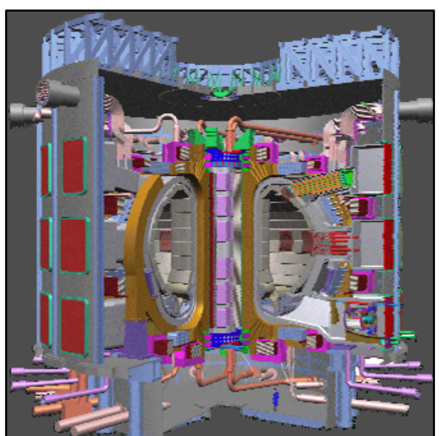
Introduction

Energy needs severely increase
- Population growth
- Economic development

Depletion of fossil resources
Environmental issues
Wastes
Security of supply

Fusion offers a solution



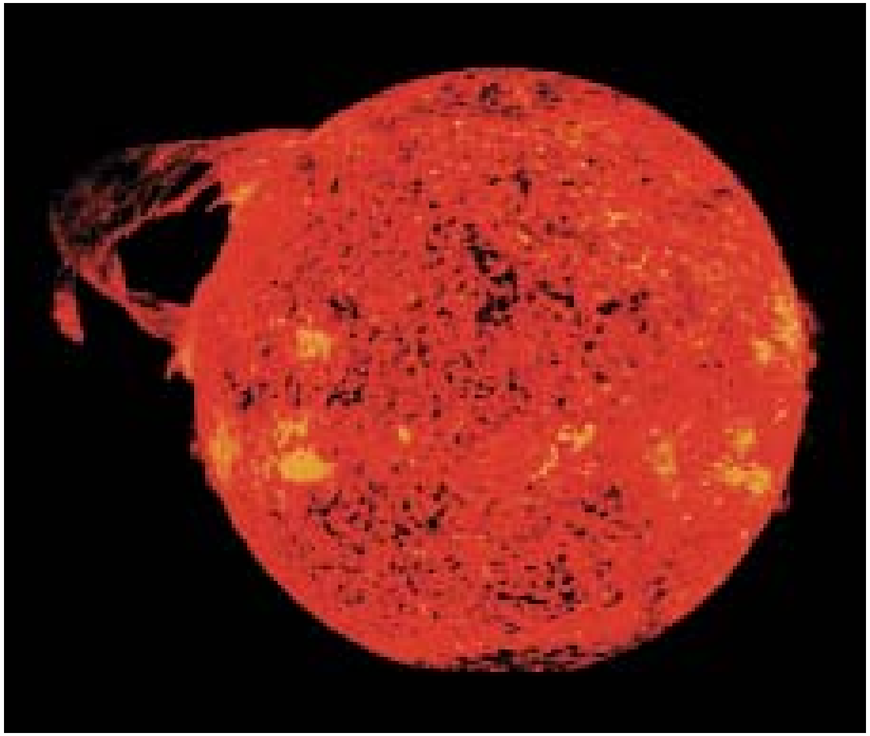
The Sun: a fusion reactor

Fusion: the Sun burns hydrogen, which is converted to Helium

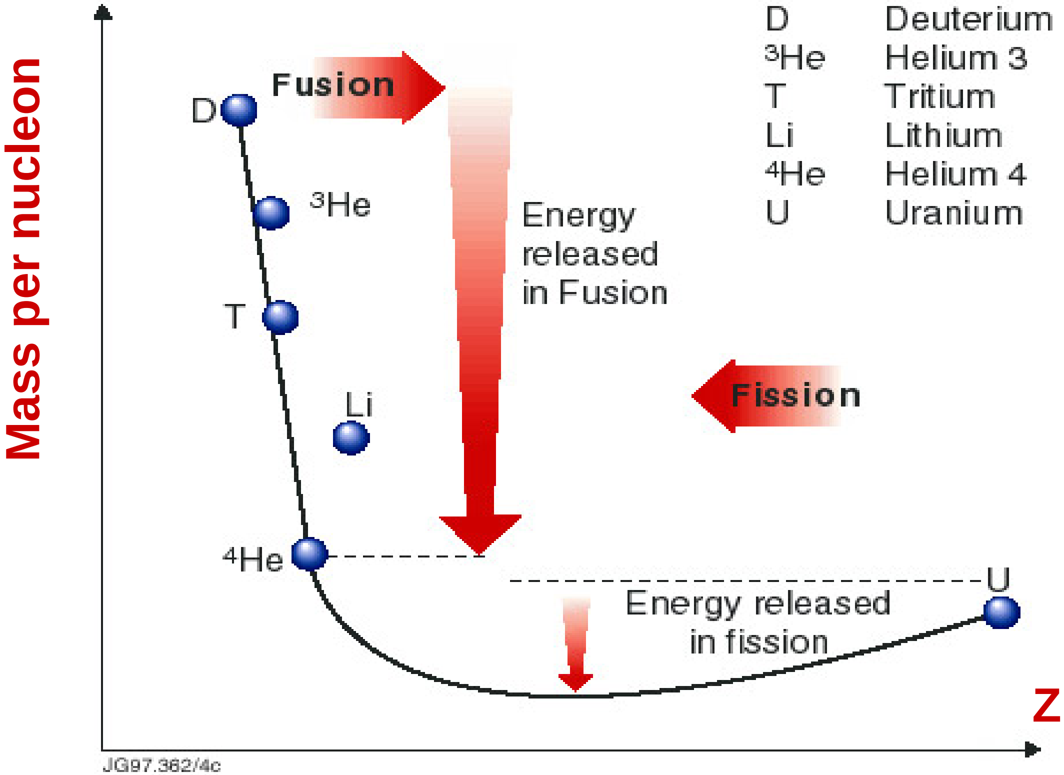
$p+p \Rightarrow D+e^{+}+\nu+0.42MeV$
$D+p \Rightarrow {}^{3}He+\gamma+5.49MeV$
${}^{3}He+{}^{3}He \Rightarrow {}^{4}He+p+p+12.86MeV$

Sun temperature: ~15 millions degree

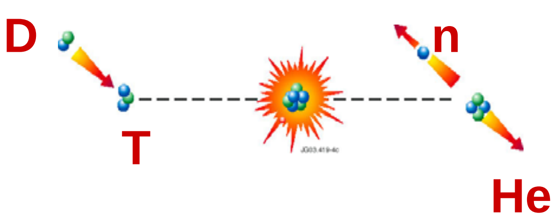
The Sun is still composed of 90% of hydrogen

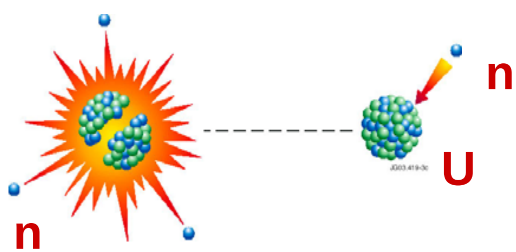


Fusion / fission energy



Energy can be released through 2 distinct processes
- Fusion of light atoms
- Fission of heavy atoms





Fusion reactions

D+D⇨ { T+p+4.03Mev ; ^{3}He+n+3.27MeV }

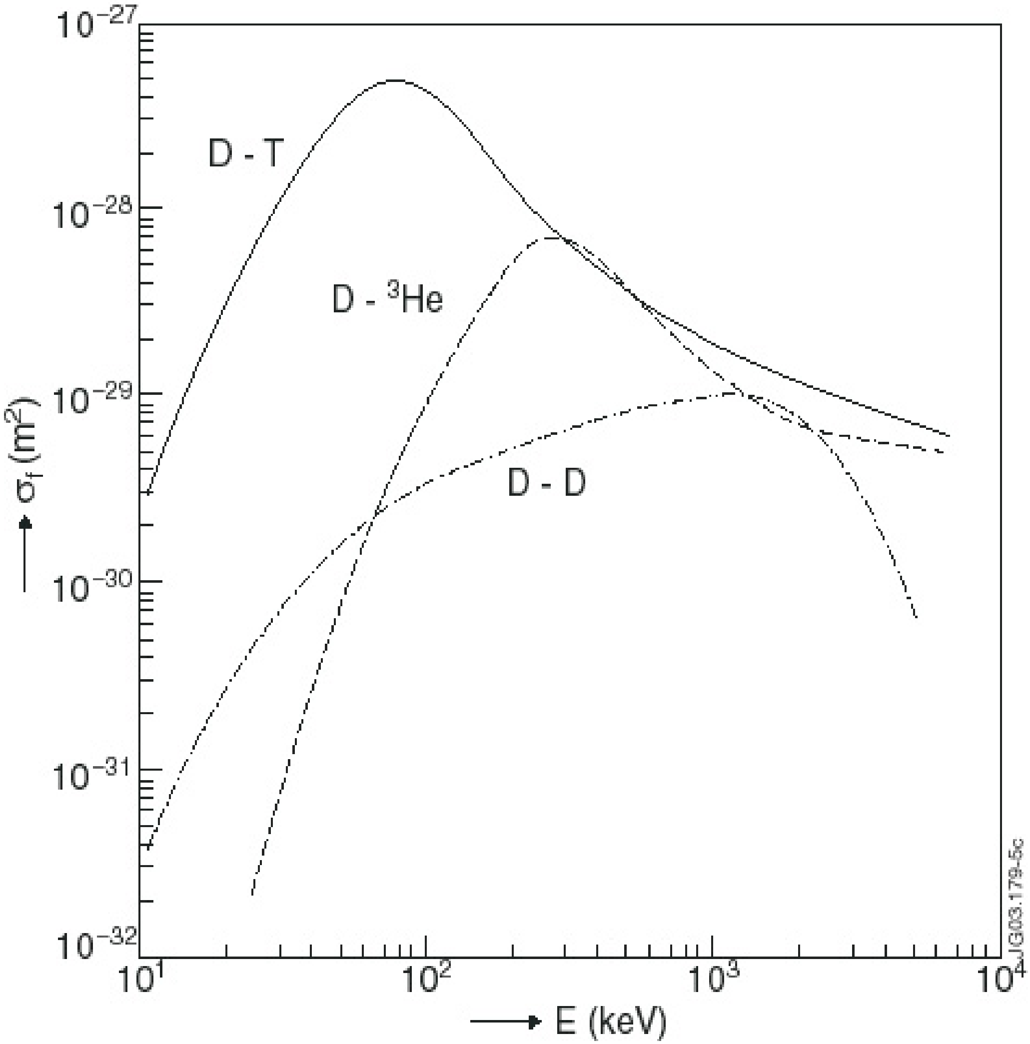
D+T ⇨ ^{4}He+n+17.6MeV

D+^{3}He⇨ ^{4}He+p+18.3MeV

D-T reaction is the 'easiest':

- highest cross section at
- 'lowest' temperature

Deuterium in water
Tritium not available in nature



Tritium cycle

Tritium is obtained from Lithium

$^{6}Li+n \Rightarrow {}^{4}He+T+4.8MeV$

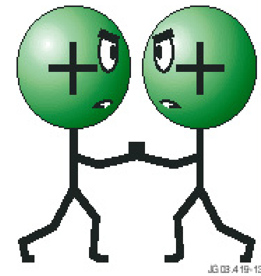
$^{7}Li+n \Rightarrow {}^{4}He+T+n-2.5MeV$

In summary

$D + Li \rightarrow {}^{4}He + 100 \times 10^{6}$ kWh/ kg

See next talk!

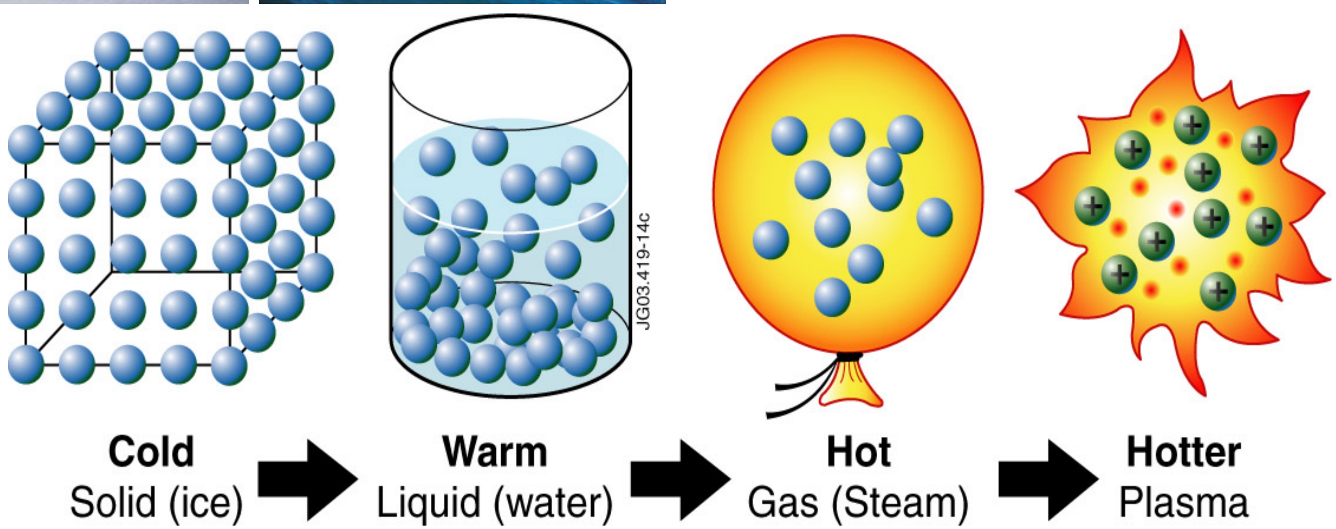
High temperature required



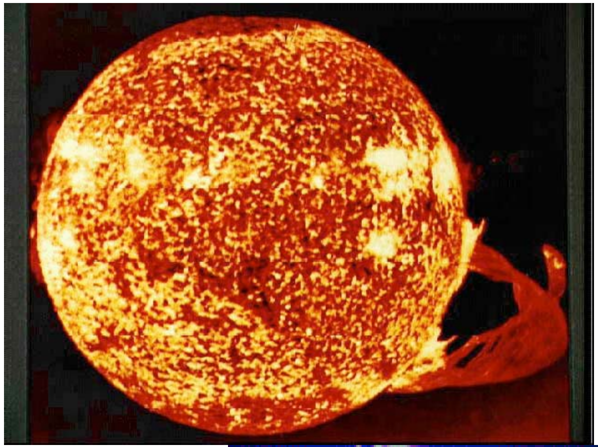
Fusion reactions occur at high temperature (100Mº)

- Due to electrical repulsive force between two nuclei

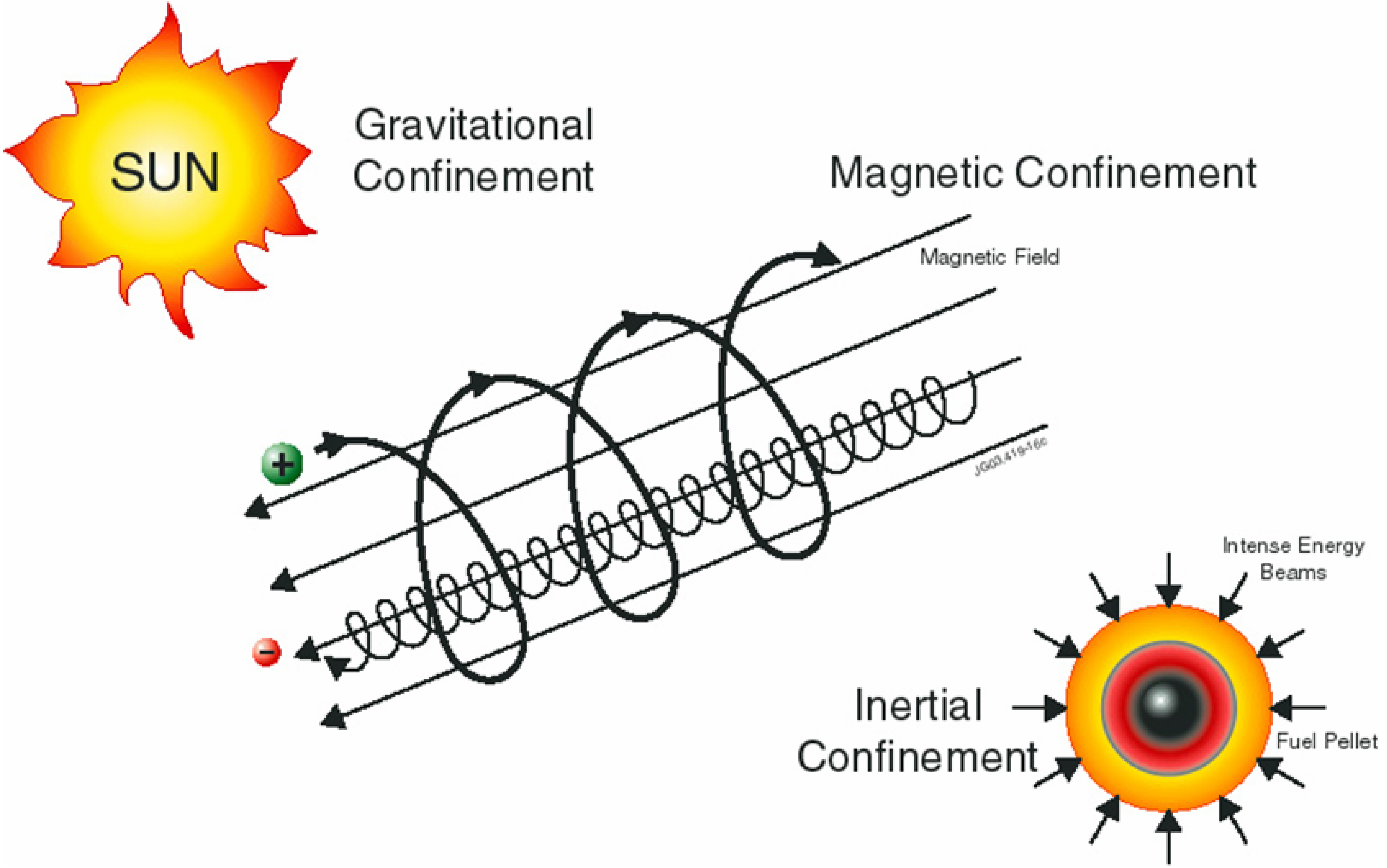
At high temperature gases become plasmas (ionised part. + …)



Plasma examples



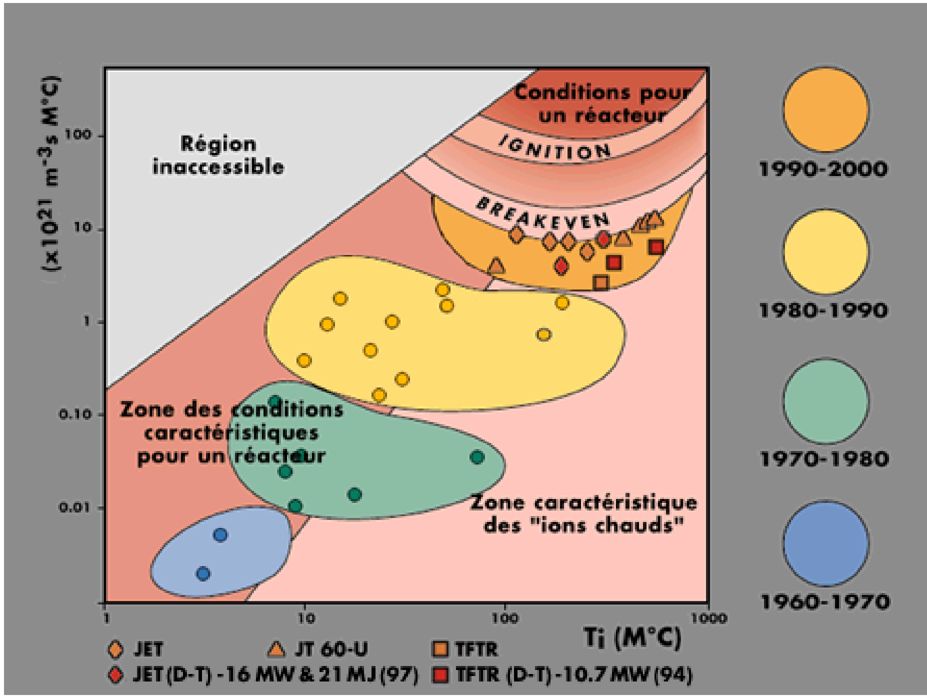
Plasma confinement



Breakeven is given by Lawson criterium

Power ratio

- Input power
- Fusion power
- Loss power (bremsstrahlung,…



Output power > input power

<=>

$n\tau > 10^{20}$ [s/m³] pour T=10keV

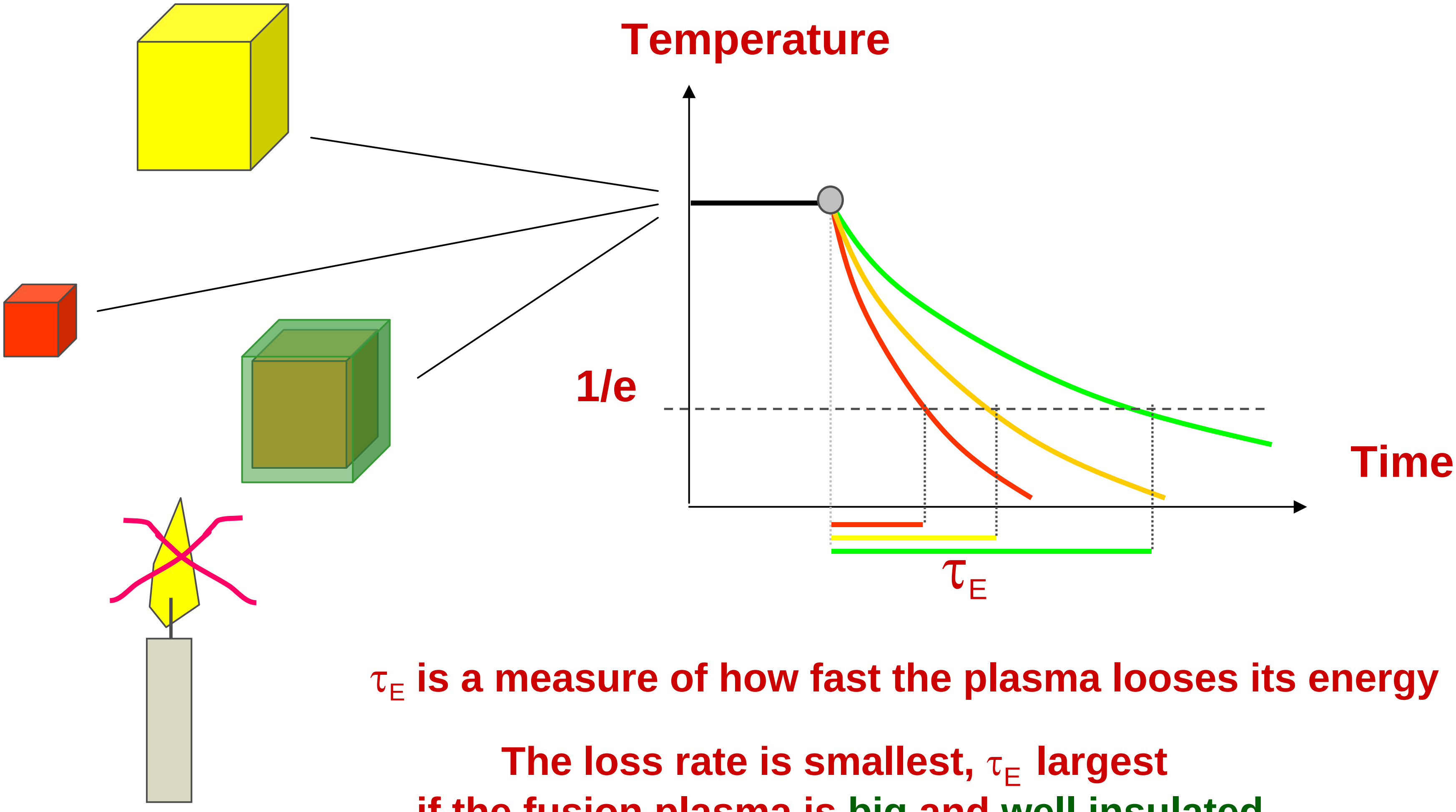
n = plasma density

τ = confinement time

Ignition criterium

- Input power can be turned off
- Losses and reheating fully compensated by fusion reactions

What is the confinement time ?

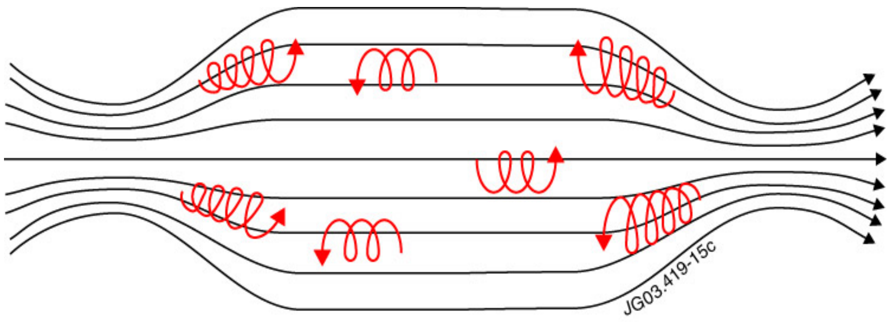


τ_E **is a measure of how fast the plasma looses its energy**

The loss rate is smallest, τ_E **largest**
if the fusion plasma is big and well insulated

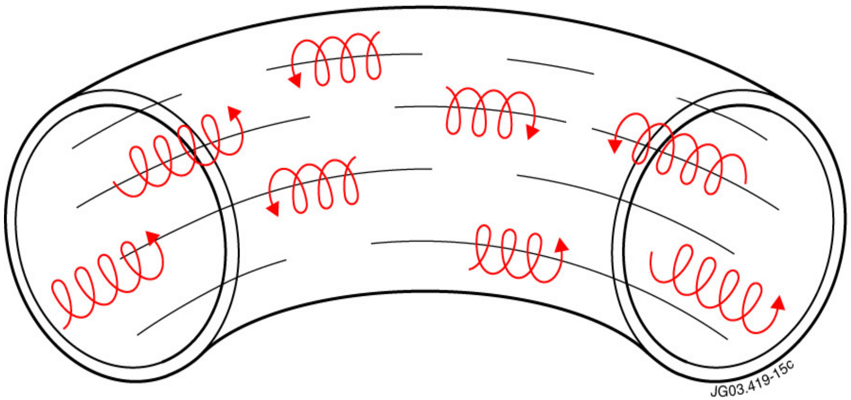
Magnetic confinement

Ionised particles move freely along field lines



2 configurations:

- Linear device with mirrors
  - Losses remain
- Closed field lines - torus
  - Inhomogenous field ->drifts



Circular motion:

- Radius depends on T and B
- Frequency depends only on magnetic field

$$\rho_L = \frac{mv_\perp}{qB}$$

$$\omega_e = \frac{eB}{m_e}$$

The Tokamak

Tokamak – from russian

- Toroidalnaja Kamera Magnetrnaja Katuska
- Toroidal Chamber with Magnetic Confinement

Principle

- Vacuum vessel
- Magnetic field

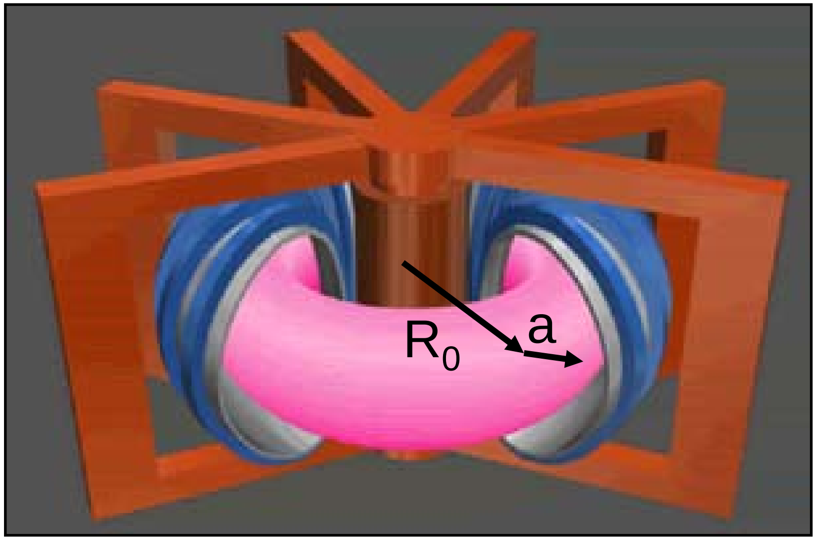
Size of tokamaks

- Major radius R_0 (.4 – 3m)
- Minor radius a (1/3 x R_0)

Toroidal field characteristics

- $B(R) \sim 1/R$
- 1-8T à $R=R_0$

The plasma is not stable !

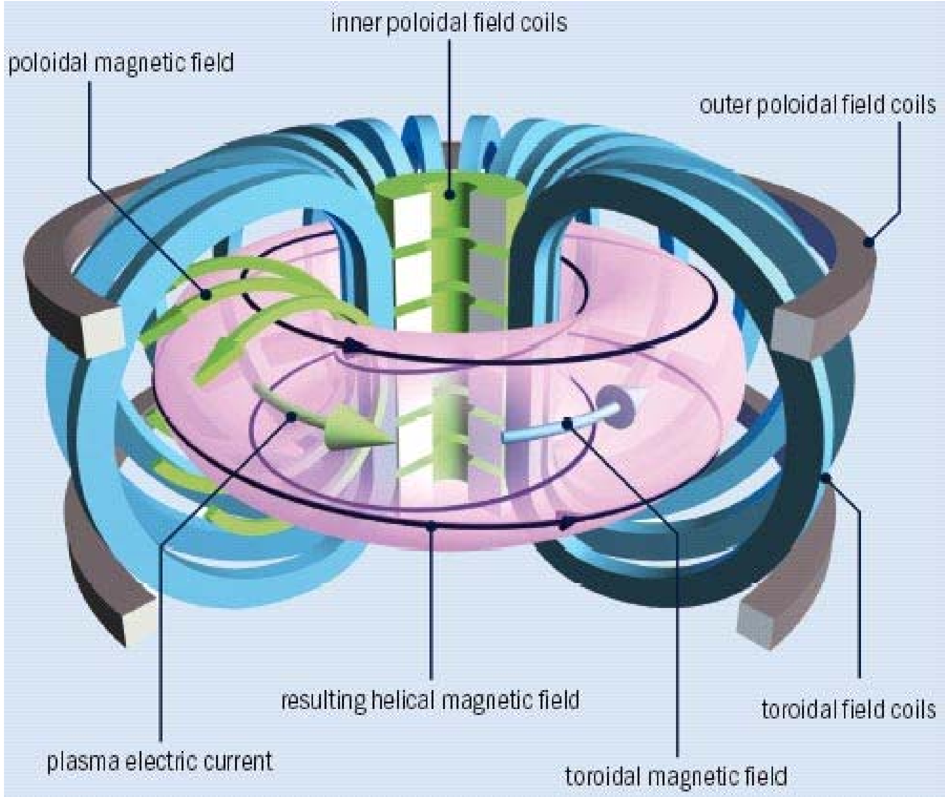


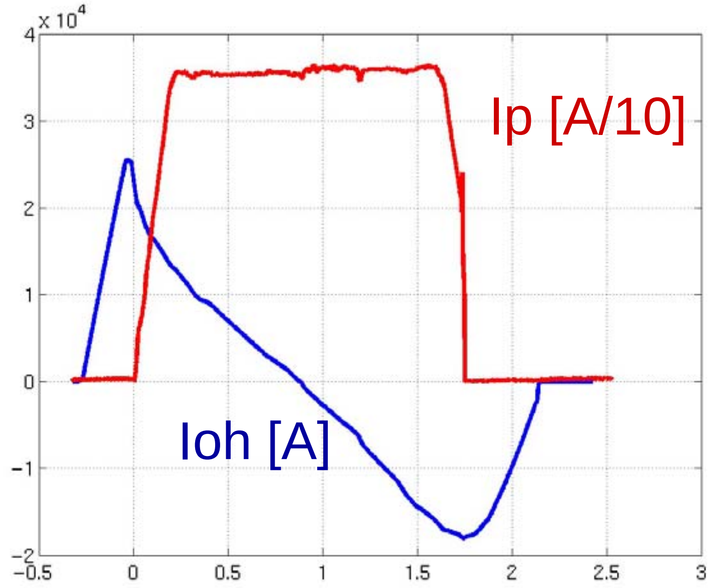
Magnetic coils / fields

Stability obtained with addition of poloidal field,

- Produced by plasma current
    - created by transformer => plasma duration is limited by flux swing

Poloidal field coils added to shape the plasma





Magnetic surfaces

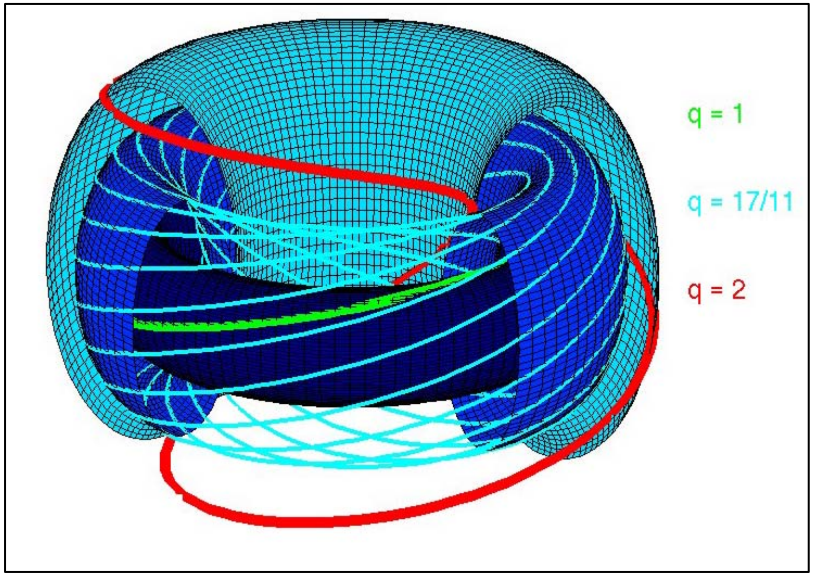
Analysis of plasma equilibrium (plasma pressure/magnetic forces)

=> Series of nested flux surfaces with

- equal pressure
- embedded field lines

Existence of ‘special’ surfaces

- Field lines closed after a few turns



Heating schemes

Ohmic heating

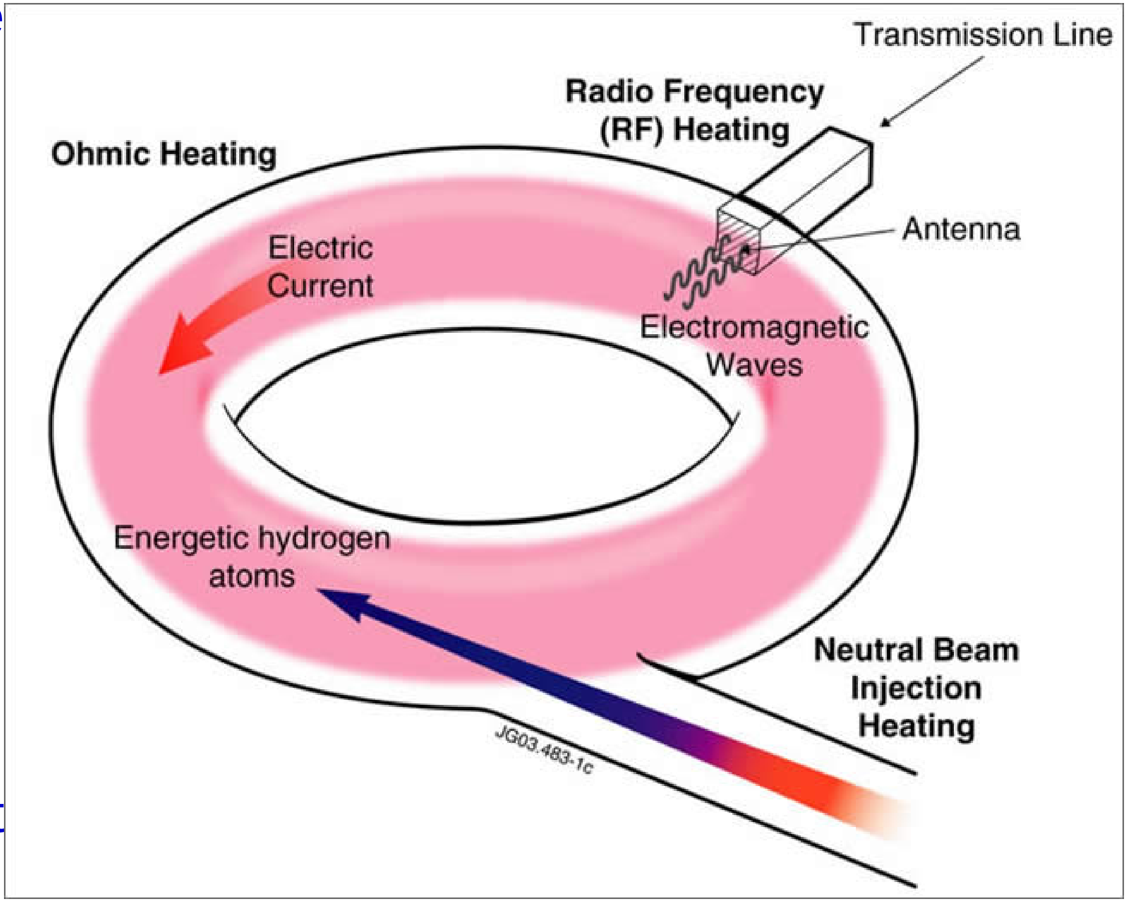
- Current flowing in the plasma heats
- Not enough

Neutral Beam Injection

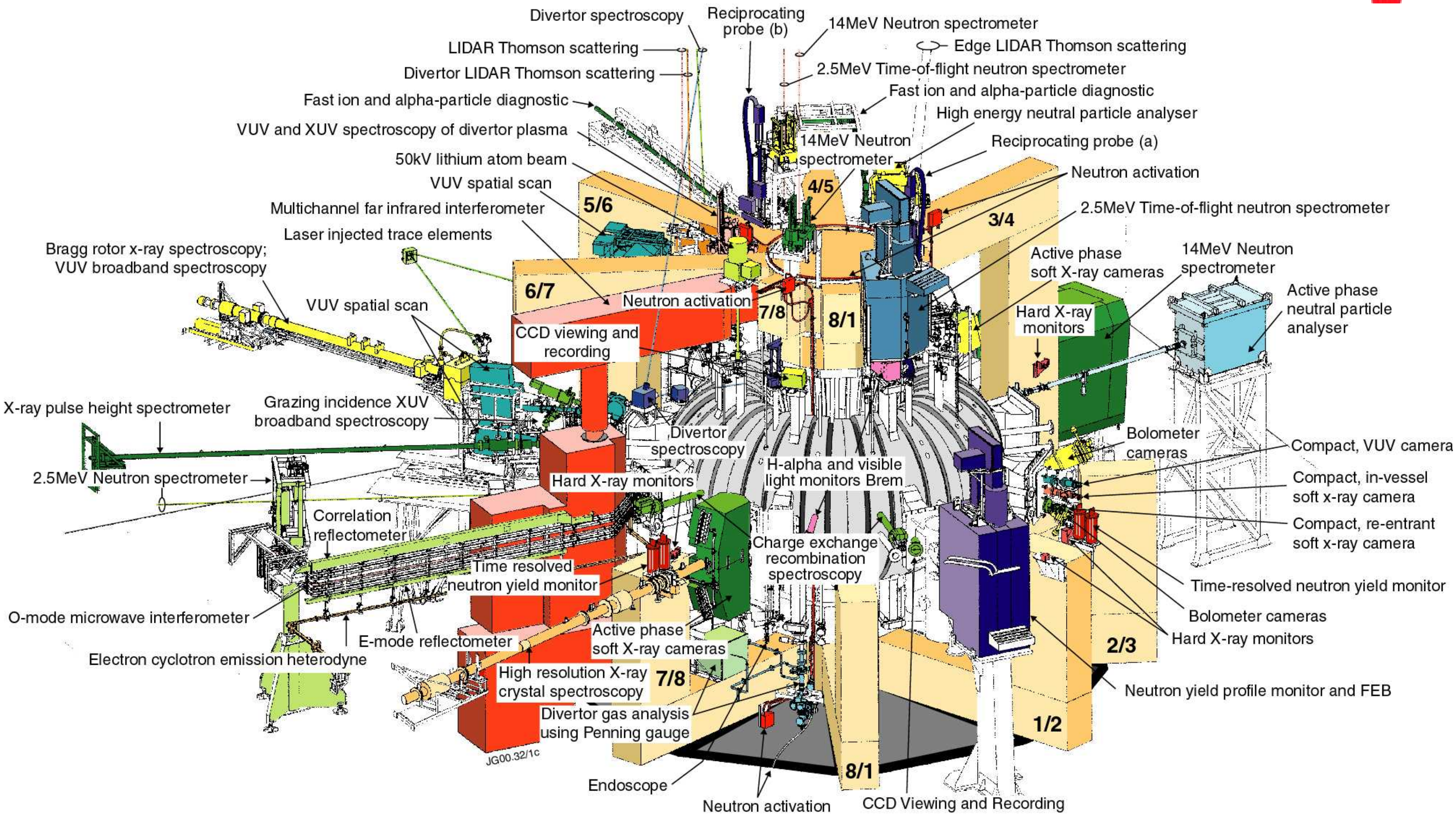
- Collisions
- Charge exchange

Radio Frequency Heating

- Gyro motion
  - Ions
  - Electrons
- Other resonant plasma frequencies



Plasma diagnostics



The TCV tokamak (CRPP, Lausanne)

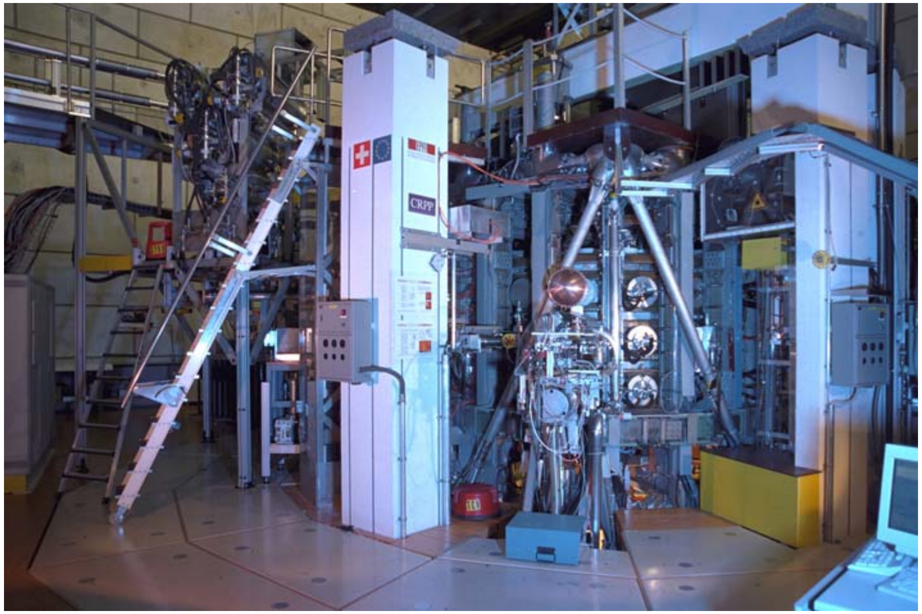
CRPP

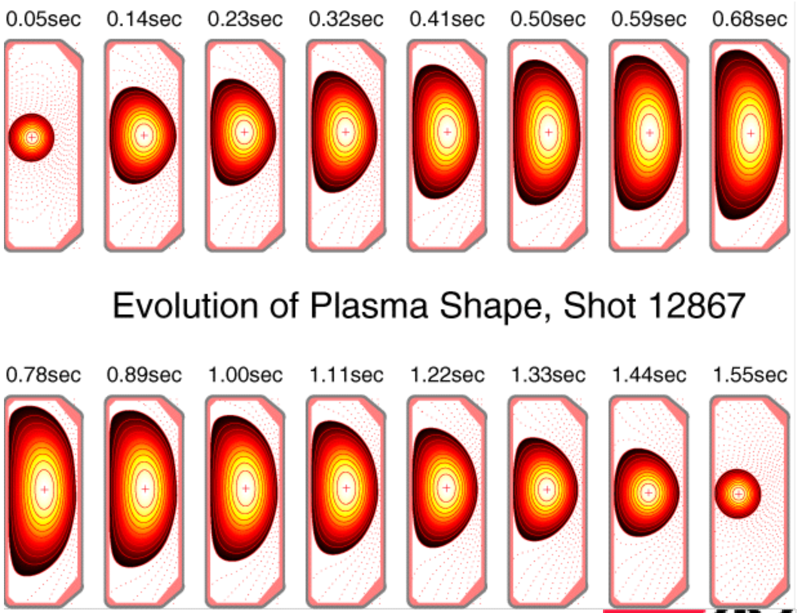
Characteristics

- R=0.9m, a=0.25, B≤1.5T, Ip≤1MA, P_{add}≤4.5MW

Goals

- Analysis of influence of plasma shape on plasma characteristics
- Electron Cyclotron Heating and Current Drive (170 Mº)





The JET tokamak (EU, Oxford)

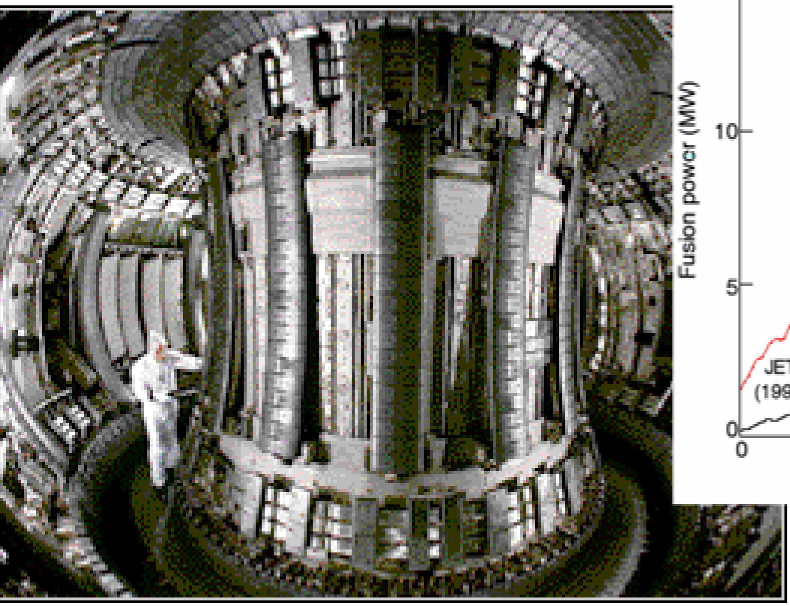
CRPP

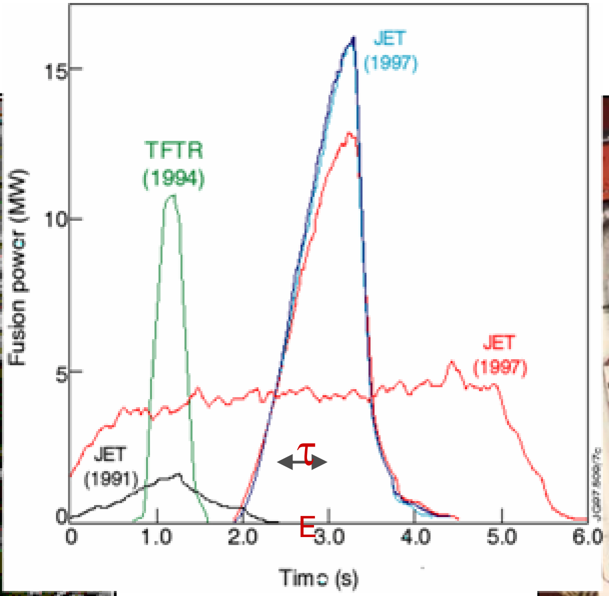
Characteristics

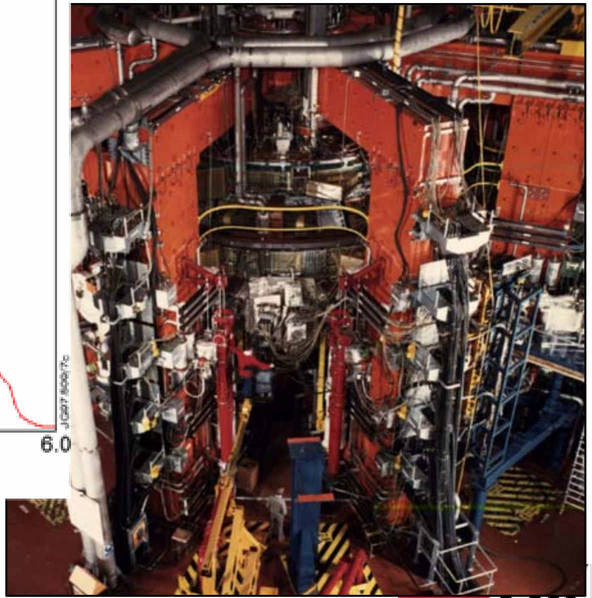
- R=2.96m, a=1.25, B≤3.5T, Ip≤5MA, P_{add}≤25MW

Goals

- Analysis of high performance plasmas
- Test stand for ITER







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The ITER tokamak

1st device designed to operate above "Lawson criterium"

- Large size (larger than JET)
- => Expensive
- => International project (EU, Japan, Russia, US, China, Korea, India)
- Several years of negotiations (siting, …)

ITER goals (performance):

- Stationary plasma with $P_{fus} \sim 10 \times P_{add}$ (P_{fus}~500MW, 400s)

ITER goals (physics):

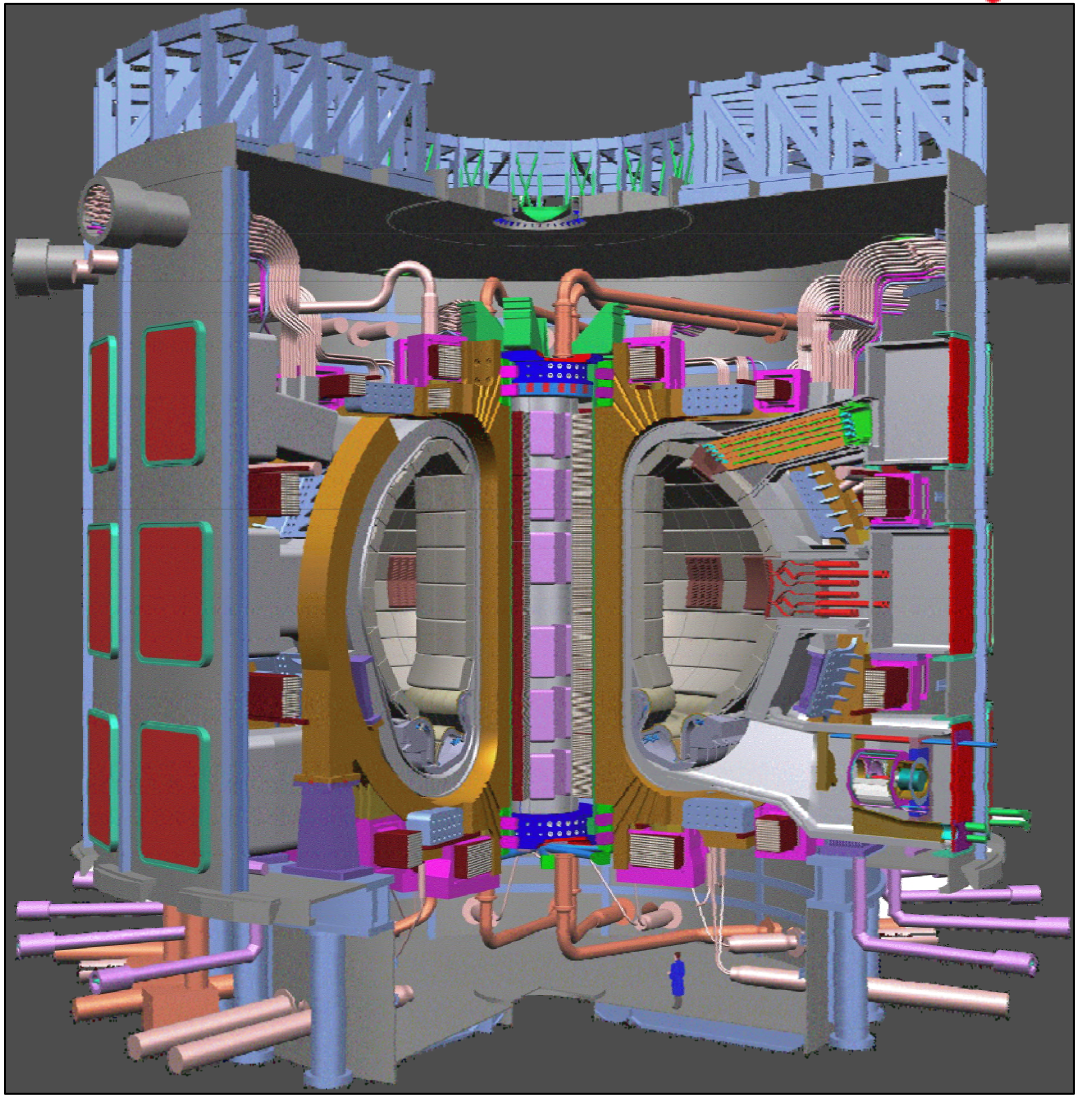
- Plasmas with α particles (heating, energy flows, instabilities,…)
- Verify scaling assumptions (confinement time, …)

ITER goals (technology):

- Materials (Test blanket modules, …)
- Supraconductivity (superconducting coils, …)

ITER

Major radius	6.2	m
Minor radius	2.0	m
Plasma current	15	MA
Elongation	1.7	
Plasma vol.	850.0	m^3
Heating	73	MW
Mag. field	5.3	T
Fus. power	500	MW
Plasma dur.	400	s



ITER will be a nuclear machine: 1.5 x 10^{20} neutrons/s

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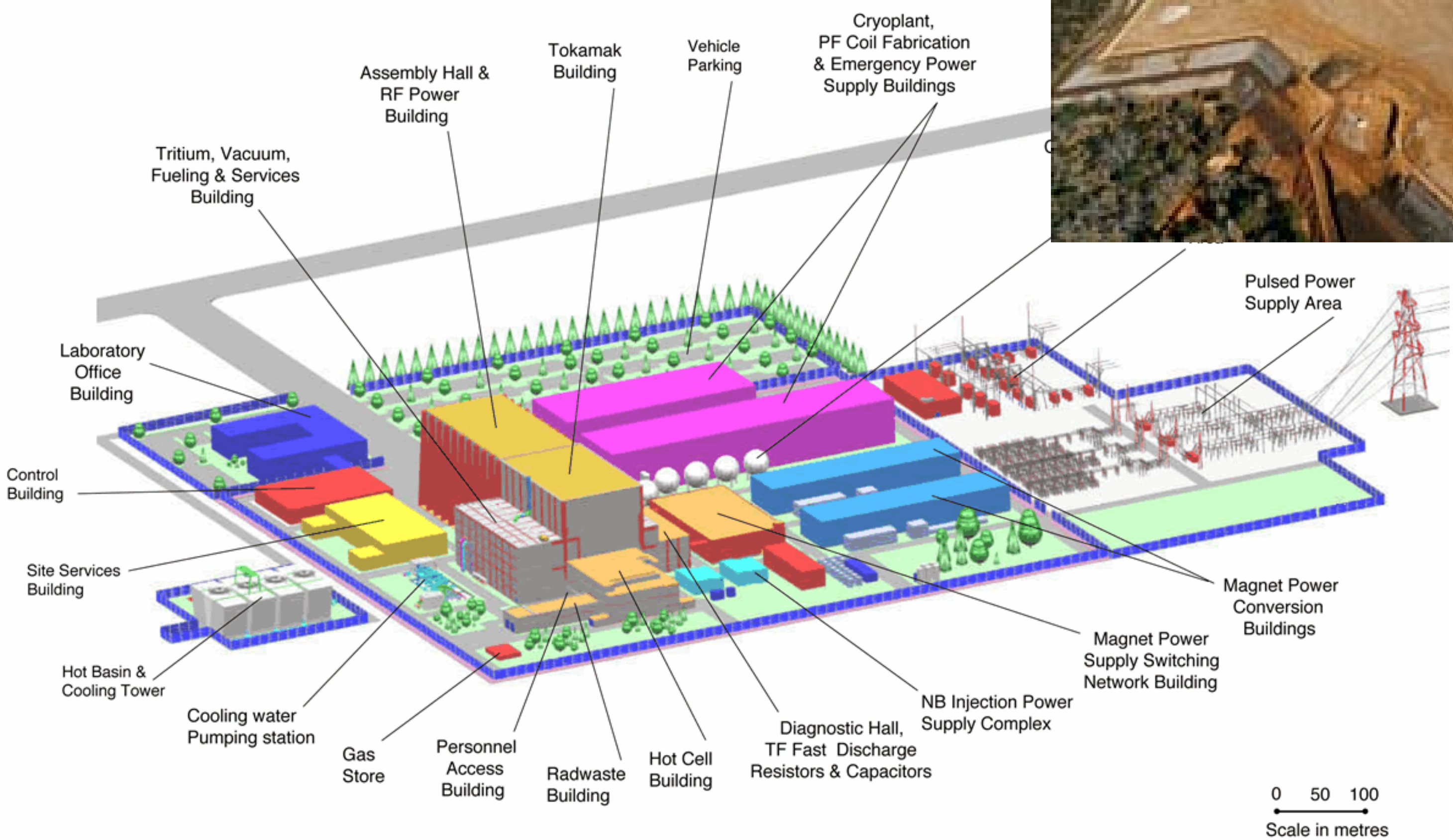
ITER site

ITER construction started in Cadarache, France



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ITER organisation, funding & planning

International collaboration

- 7 parties

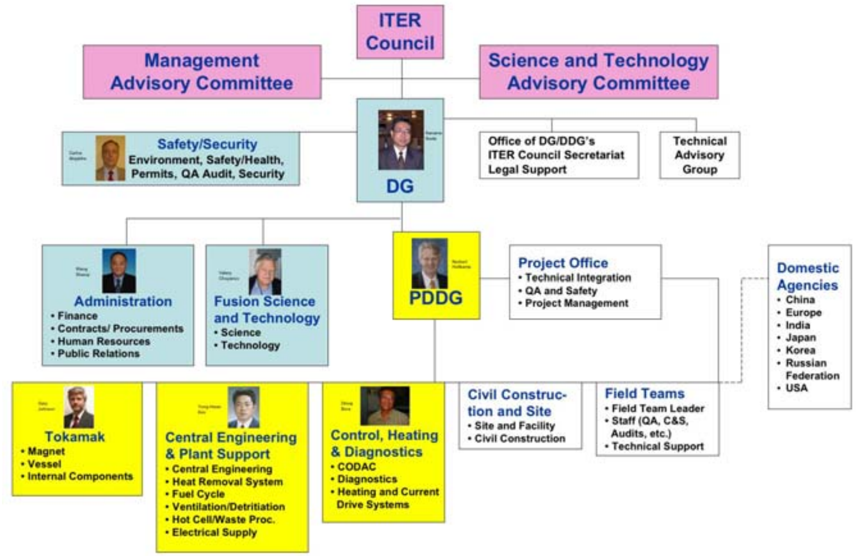
International directorate

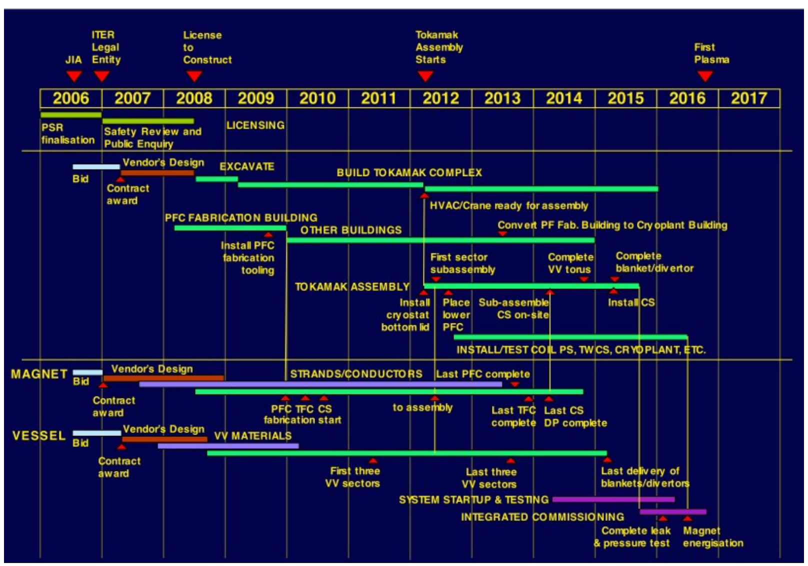
International funding

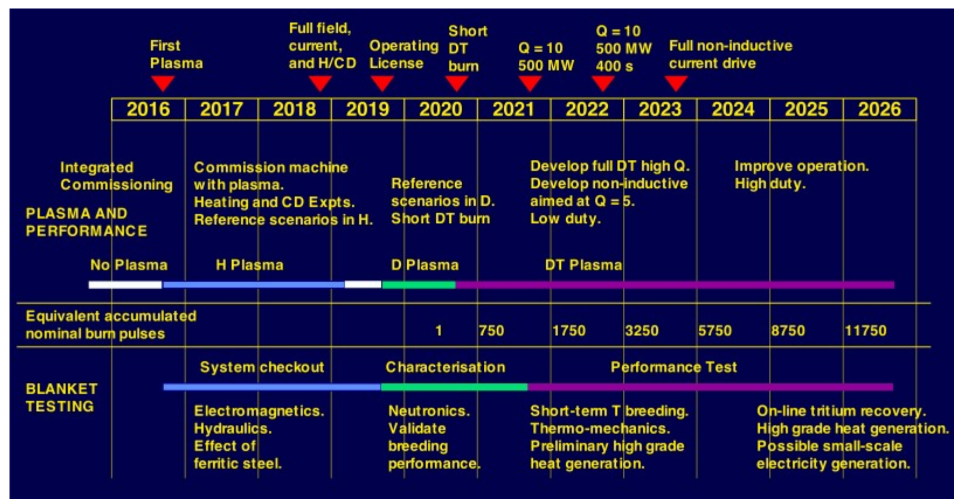
- 10 Billions €
- Large fraction for host
- Equal fractions for others

Planning

- 1st plasma in 2018



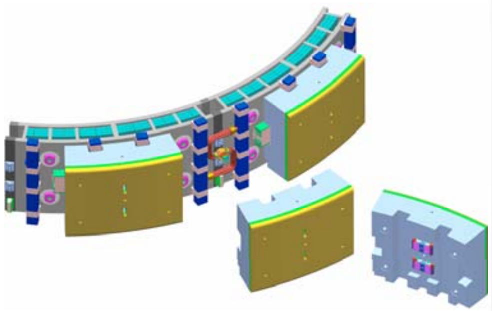




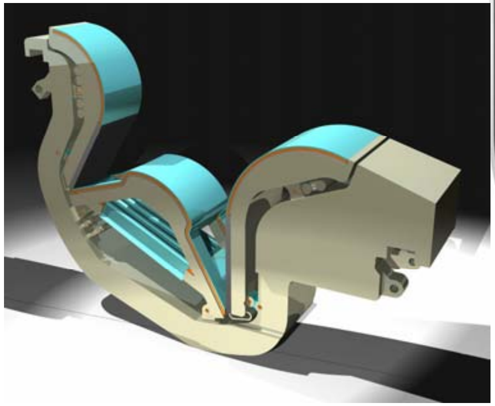
ITER challenges

Physics
- Control plasmas with α particles
- Reach good confinement regimes
- Control ELM sizes (impact)

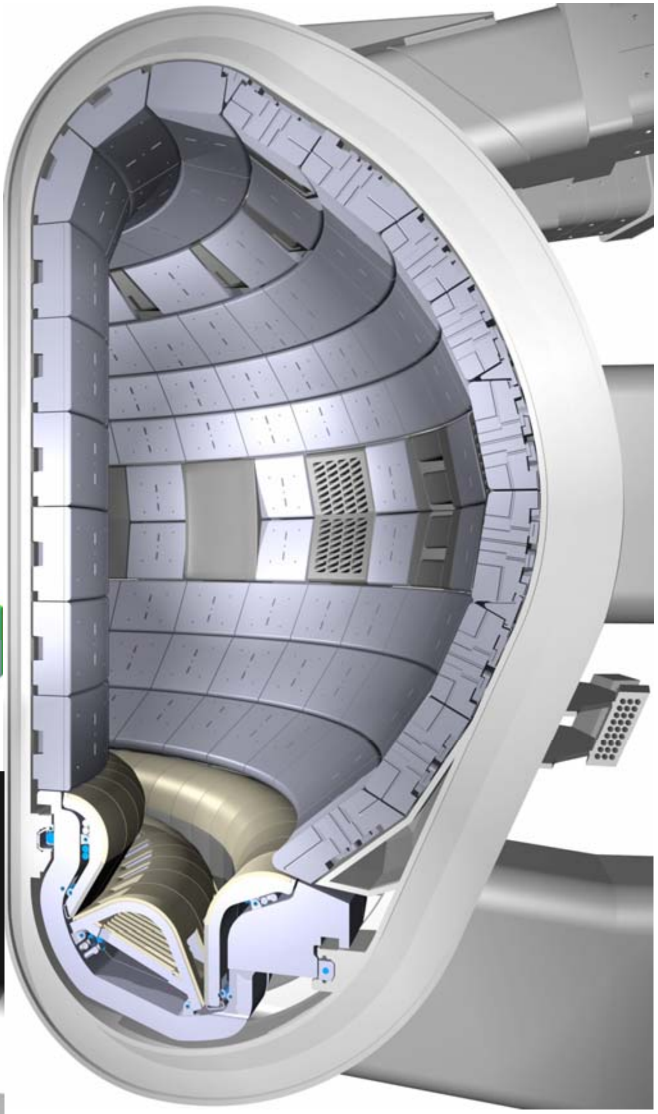
Technology
- Control
- Integration



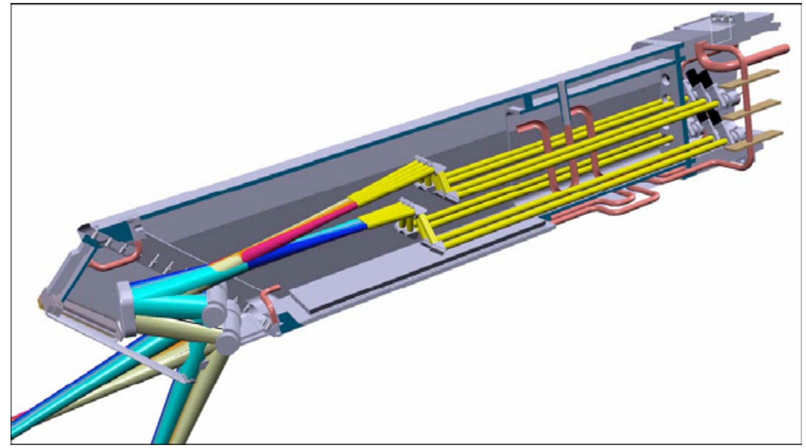
- Materials:
- Plasma facing components
- Divertor



- Diagnostics



Swiss contribution to ITER

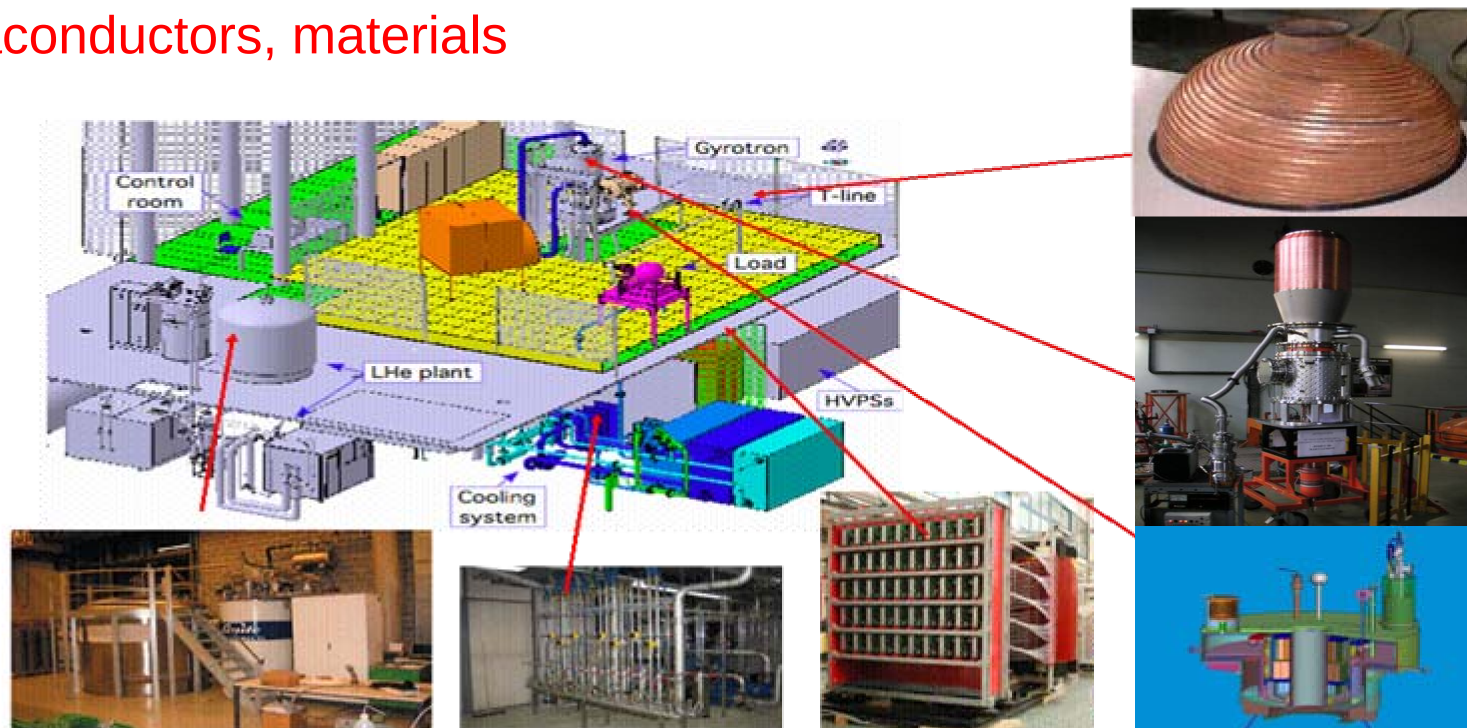


ECH launcher

Gyrotrons test stand

Magnetics measurement

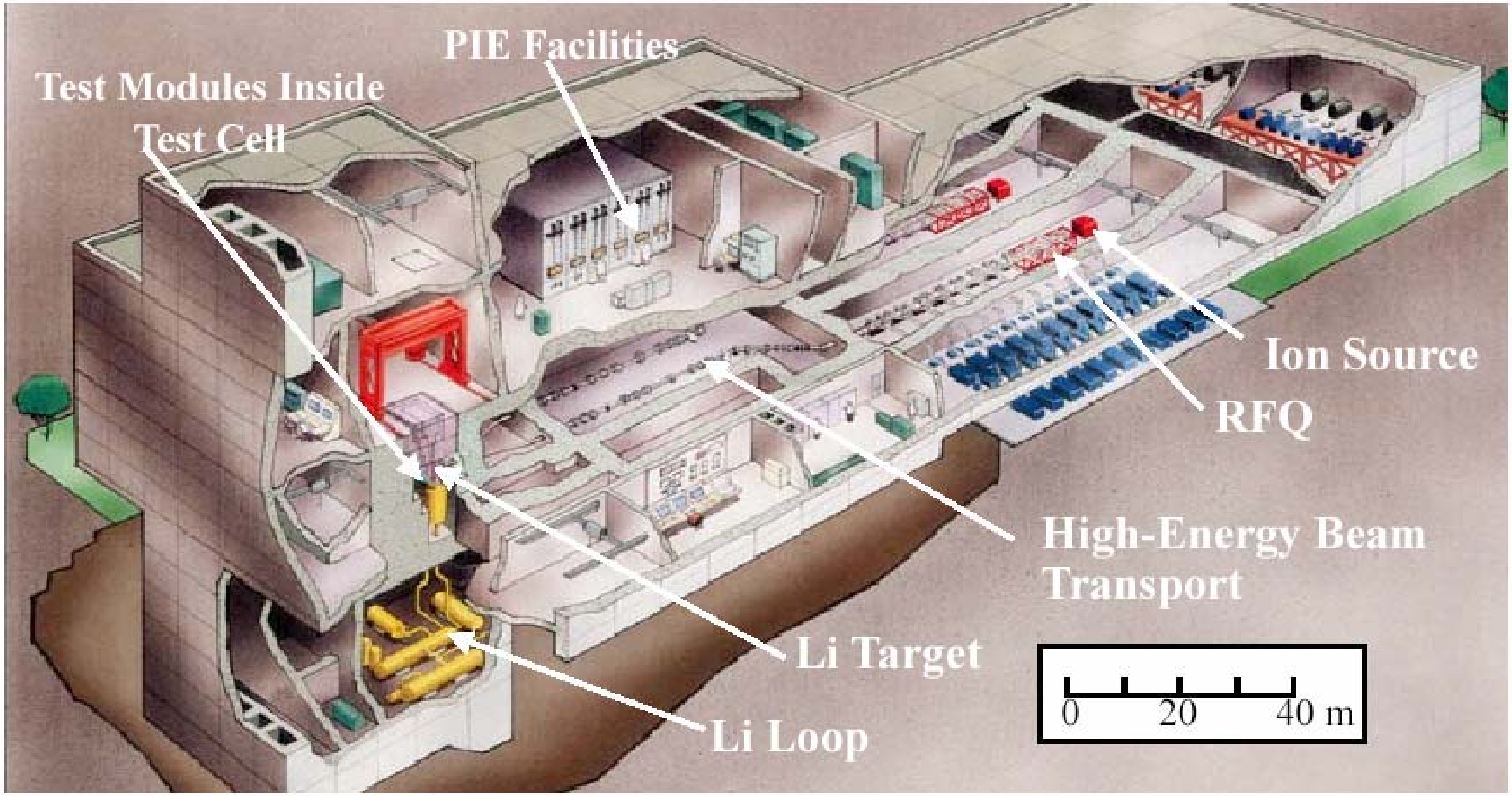
Test of supraconductors, materials



Broader approach

In parallel with ITER:

- International Fusion Materials Irradiation Facility (IFMIF)
- Theory / Computer centre
- Upgrade of JT60-U (Japan)



Next step: DEMO

Studies for the step after ITER has already started:

Goal:

- 1^{st} fusion power plant: 1GWe

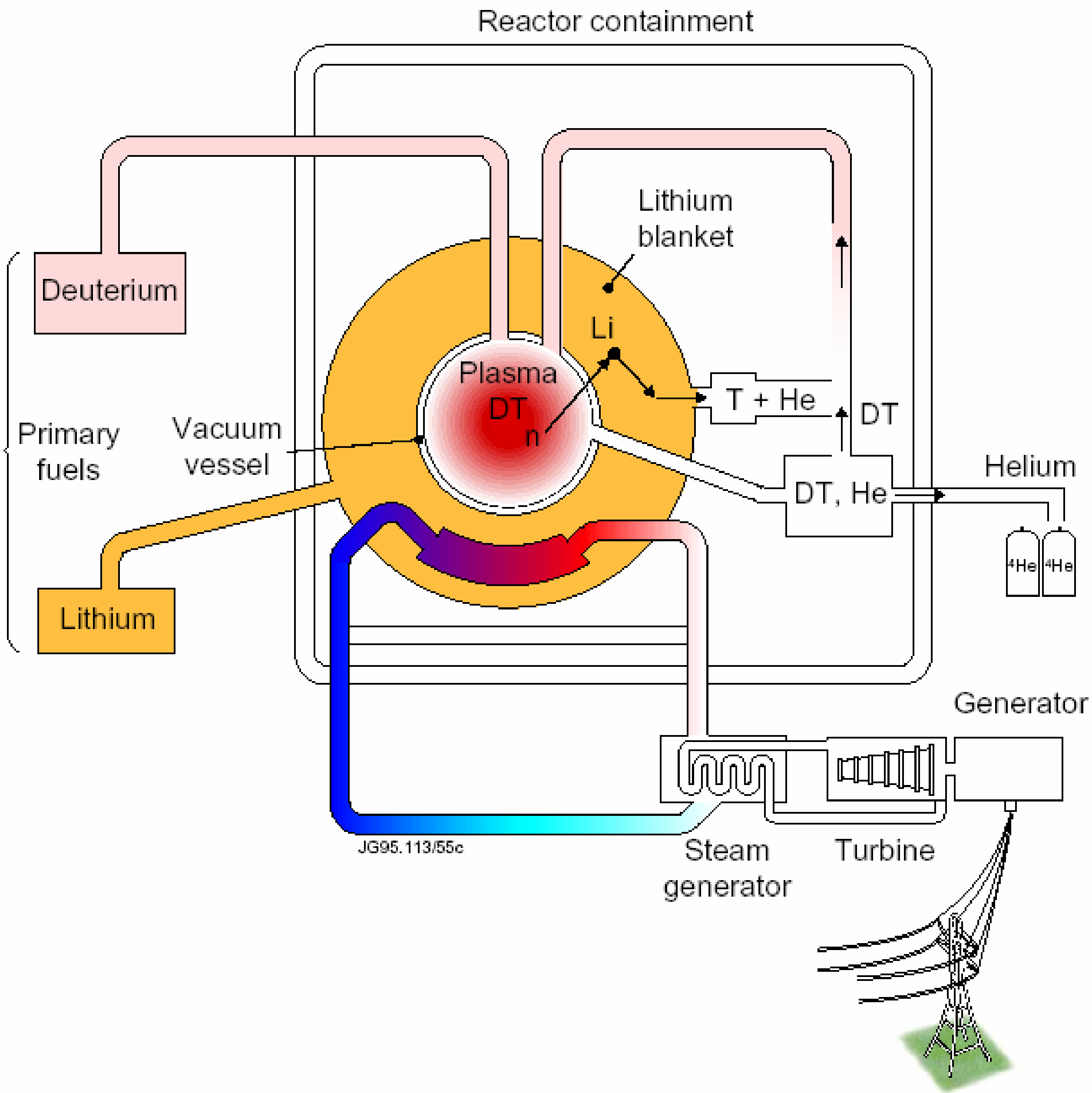
Characteristics

- Different sizes: Major radius between 6 and 10m
- Different scenarios

Organisation

- Construction might start before the end of ITER!
- How many DEMOs ???

Fusion Power station



Advantages of fusion energy

High energy density

- 1g D-T: 26'000 kWh (1g coal: 0.003 kWh)

Abundant fuel, available everywhere

- D ~ 1/6500 H
- Li ~17ppm in rocks

Environmental

- No CO_2
- No high level radioactive wastes

No risk of nuclear accident

No generation of weapons material

Conclusions

Fusion reactions power the stars

D-T reactions is the best candidate. Usage of Li for T breeding

The tokamak is the most advanced/promising device

Power ratio close to 1 has been obtained in JET

ITER is under construction to explore plasmas with high fusion power and improve techniques

DEMO will be the 1st fusion power plant

Fusion is an energy source in agreement with sustainable development