ITER

rendez-vous with a planetary challenge

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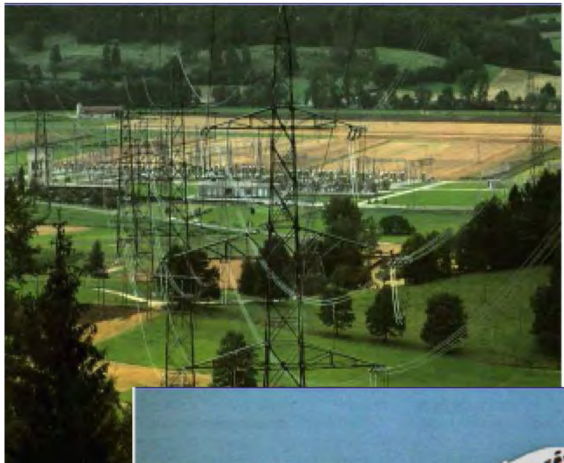
Outline

- Context of fusion energy research
- The basics of fusion energy – with apologies
- The road leading to ITER
- ITER in France
- ITER in operation

Our energy needs



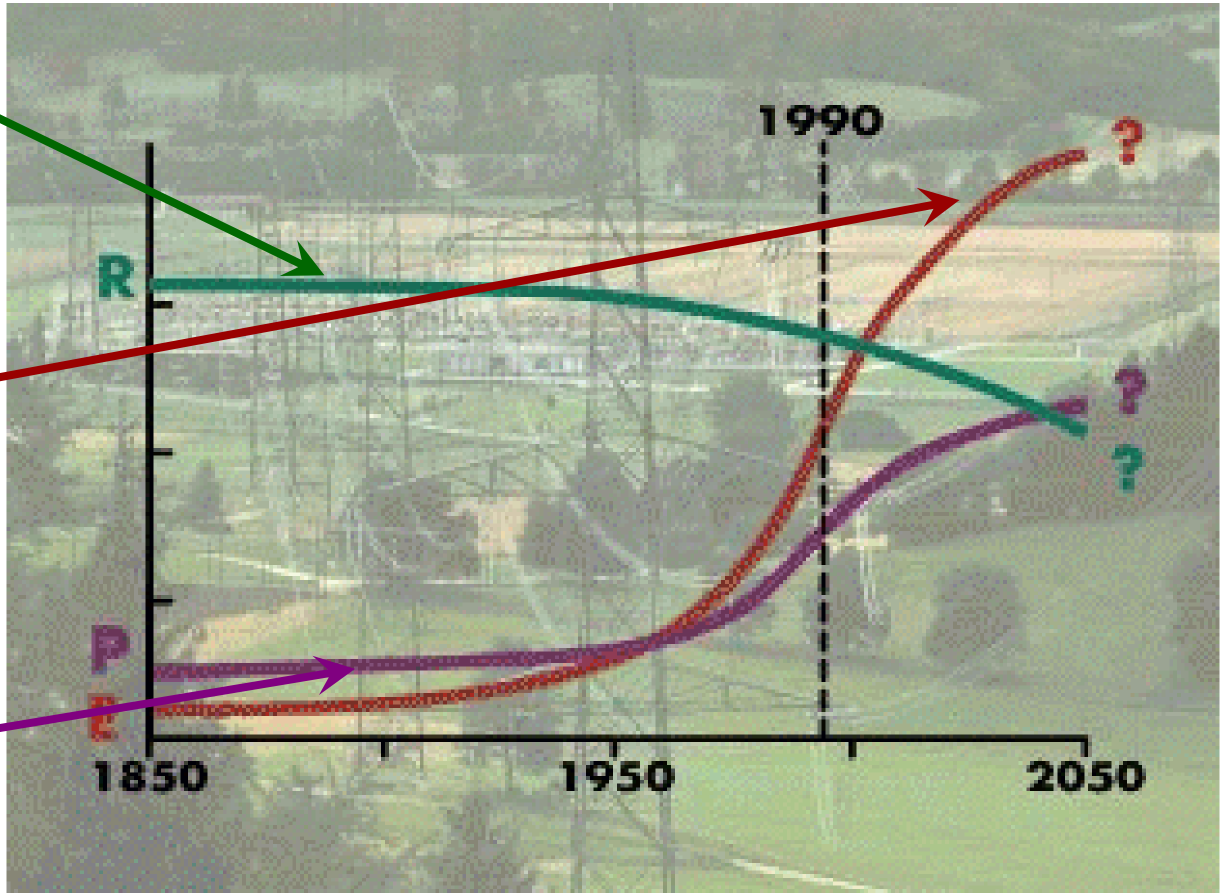


Population and energy resources

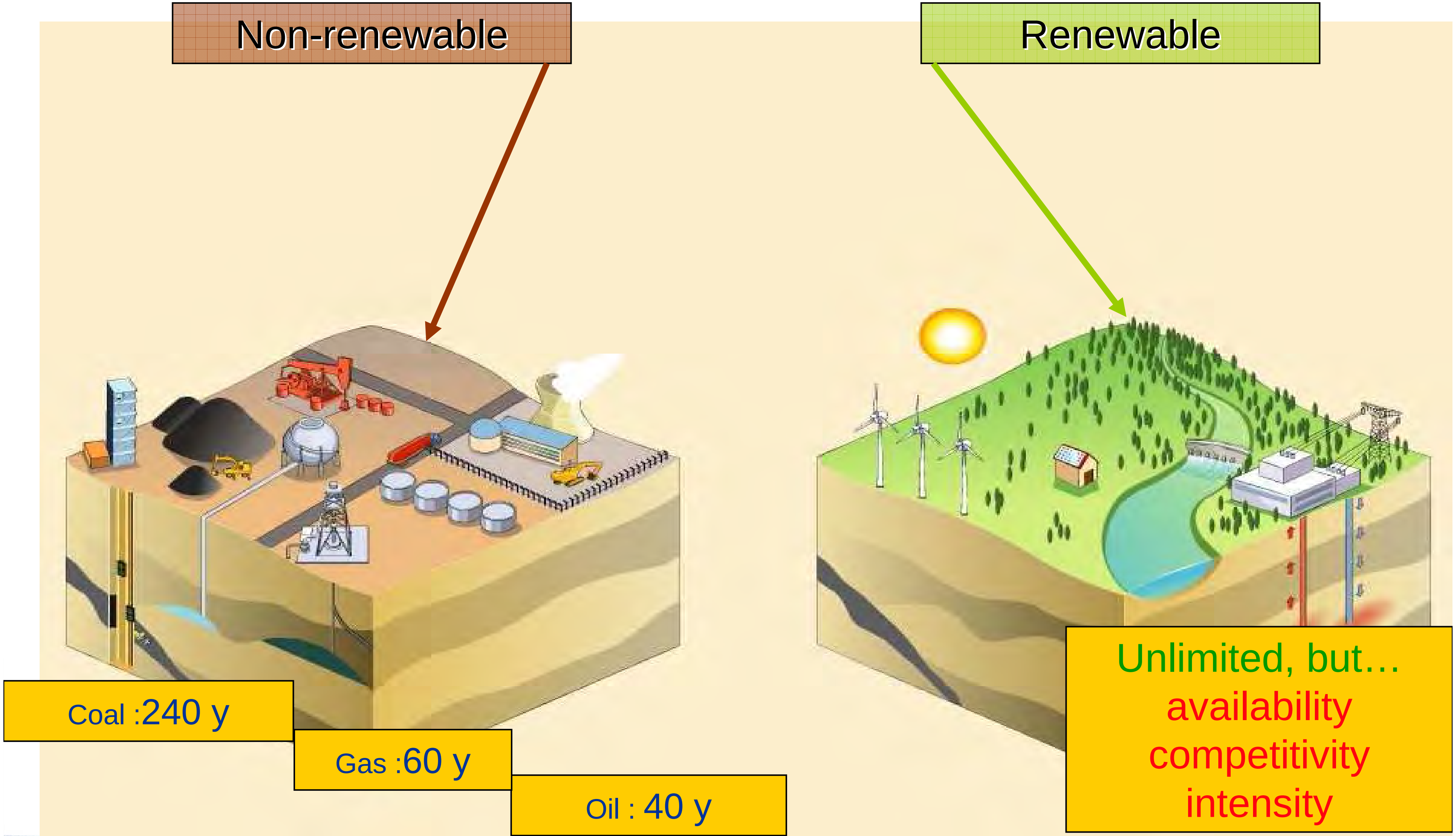
Fossile Resources

Energy Consumption

World Population



Different energy resources



Evolution of the fossile energy reserves

- Man (and woman) learned « with great wisdom » how to consume most of the planet's resources (CH, C, U…) in fewer than 6 generations

- 2000 man continues to believe in the market economy
- He is wrong …

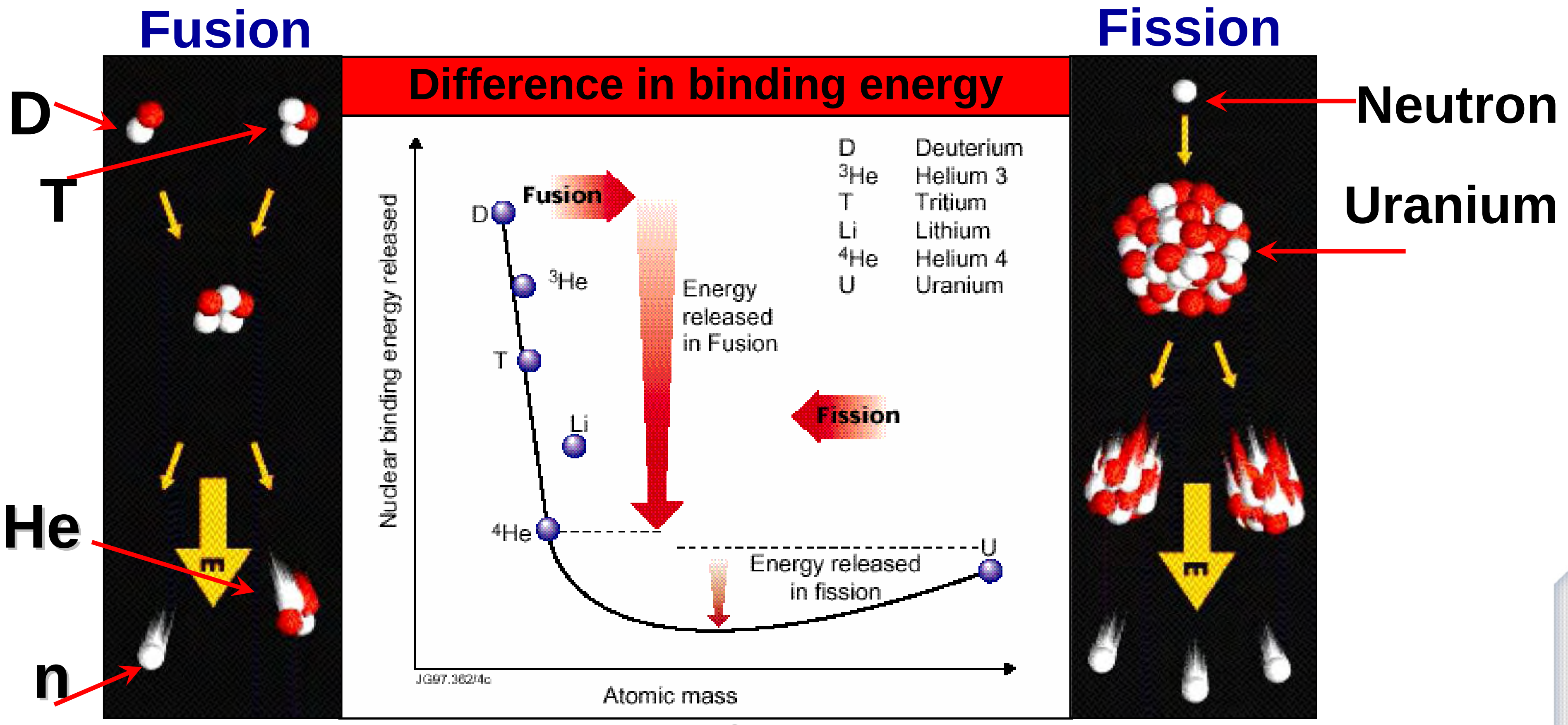
- The drop in availability will be much faster than the development took, since we are so good at consuming now…

- Consumption will finally fall with production…

- Solutions…
  - Coal… greenhouse effect ??
  - Uranium… fast-breeders (Germany…) ??
  - Renewables… yes but…
  - Any other ideas ??

Nuclear binding energy

- Nuclear mass ≠ sum of its components
- Missing mass ~ binding energy
  - $B = Z\,m_p + N\,m_n - M_{z,p}$



$D^+ + T^+ \rightarrow He^{2+}$ (3.6 MeV) + **n** (14 MeV)

$E = m c^2$

- The origin of fusion energy and fission energy is the change in mass of the fuel

  $\Delta m / m \sim 10^{-3}$

- The origin of chemical energy is also the change in mass of the fuel

  $\Delta m / m \sim 10^{-9}$

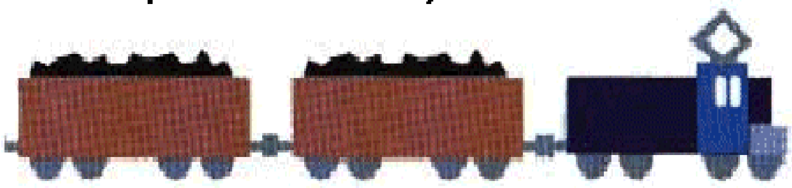
- This difference explains the HUGE difference in waste management (CO_2) when we use coal as an energy source. Fission can bury the waste, coal stations cannot yet do this

- A fundamental difference between fusion and fission
  - Fission reactions are statistical between competing channels. We cannot select benign final states, and we must live with Sr, I, Co etc
  - Fusion reactions are few, but create a fast neutron (14 MeV), and the presence of Tritium in the cycle must concern us

Annual fuel needs of a power station

CHARBON

200 trains avec 100 wagons chacun soit 400 km (2 x 10e10 tonnes)



x 200

PETROLE x 7

7 tankers géants (10 millions de barils)

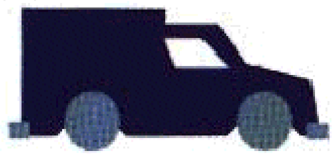
FISSION

8 poids lourds (150 tonnes)

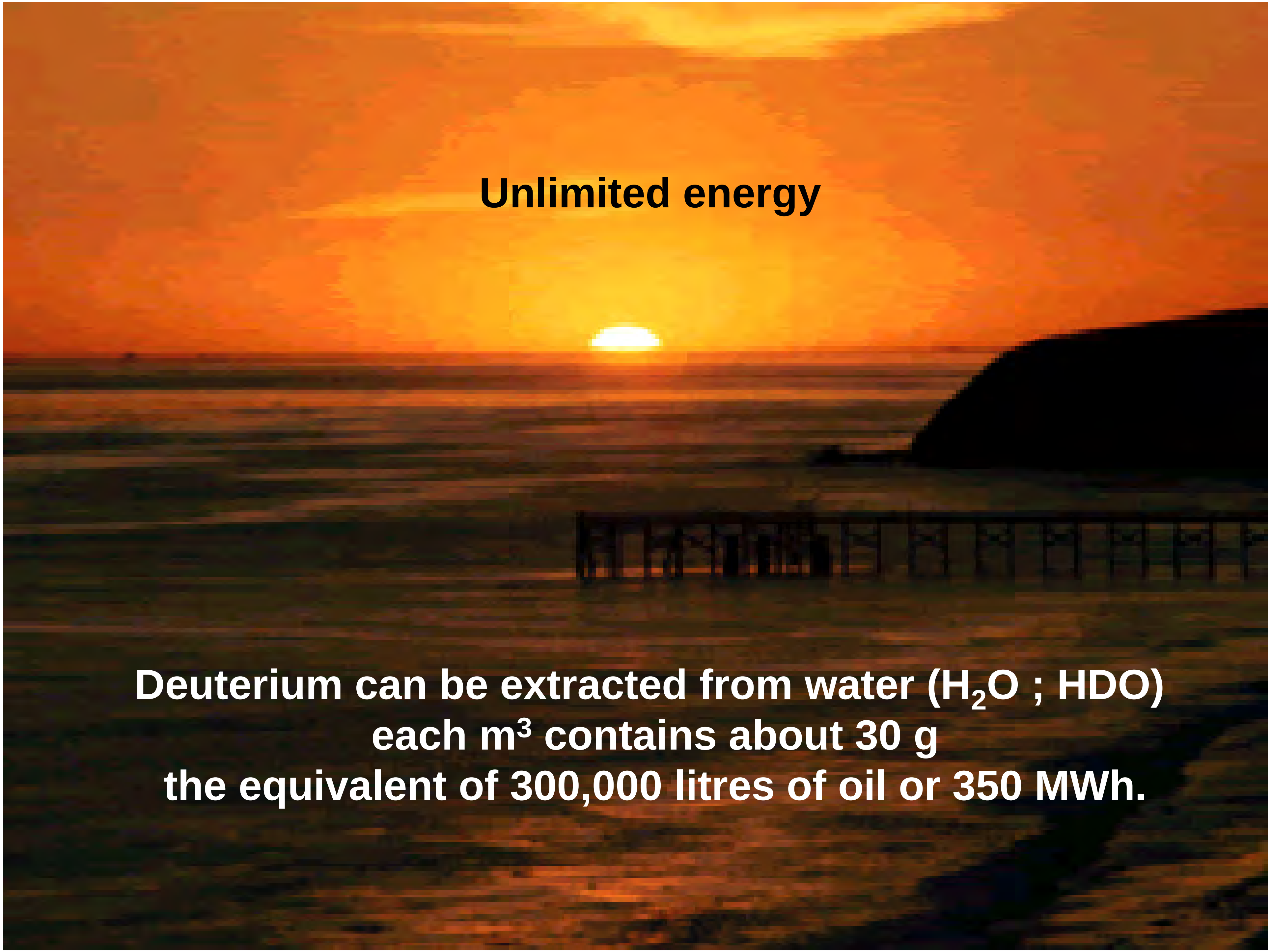
x 8

FUSION

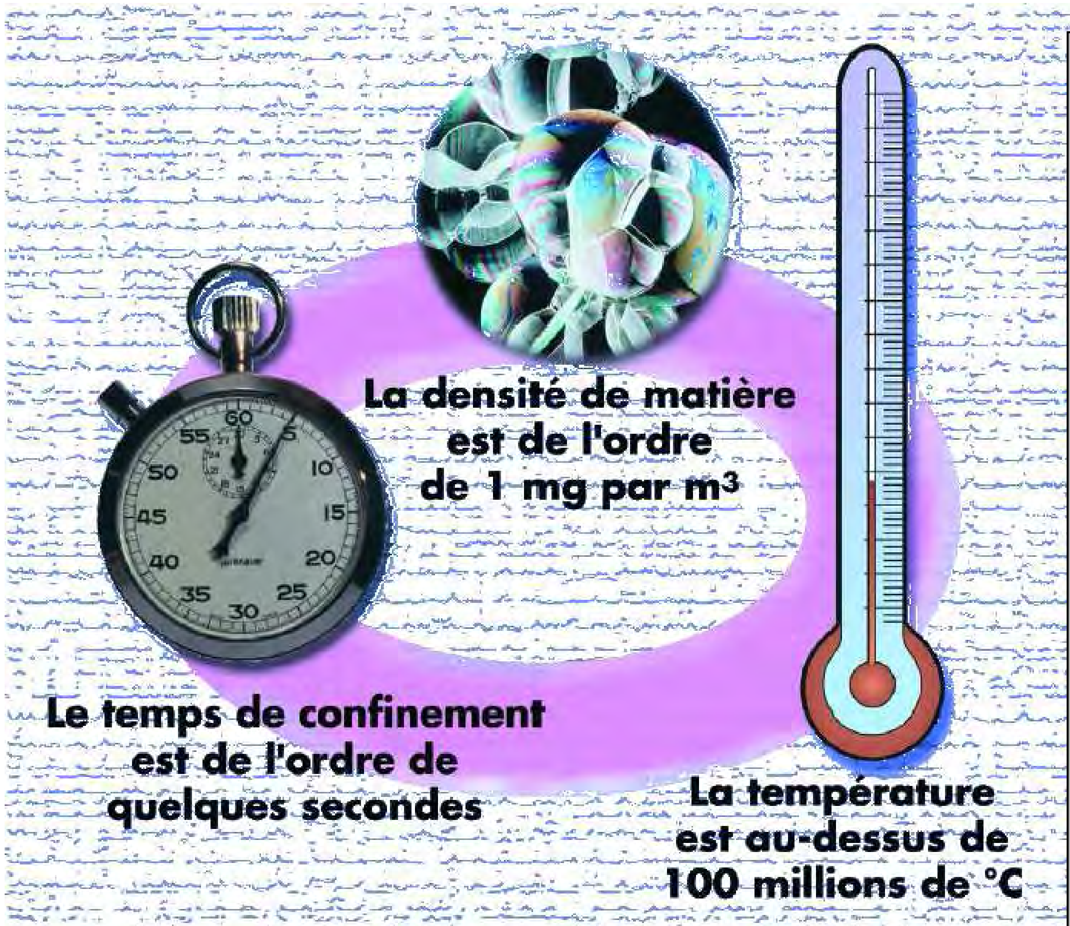
1 utilitaire (600 kg)

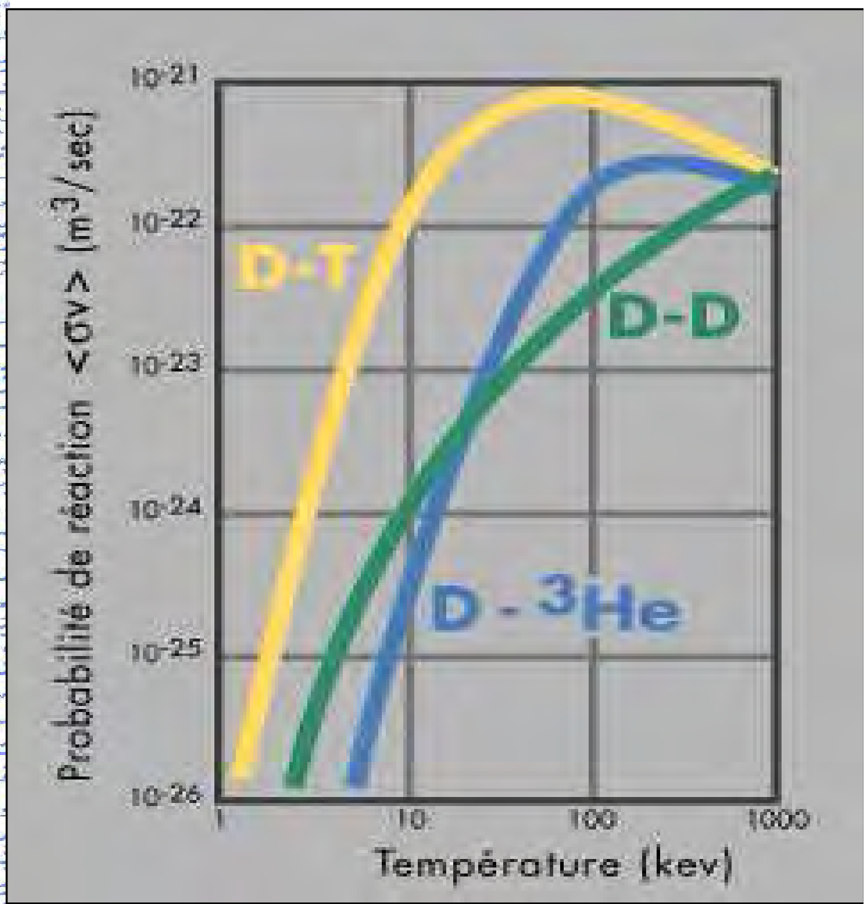


x 1


Unlimited energy
Deuterium can be extracted from water (H_2O ; HDO)
each m^3 contains about 30 g
the equivalent of 300,000 litres of oil or 350 MWh.

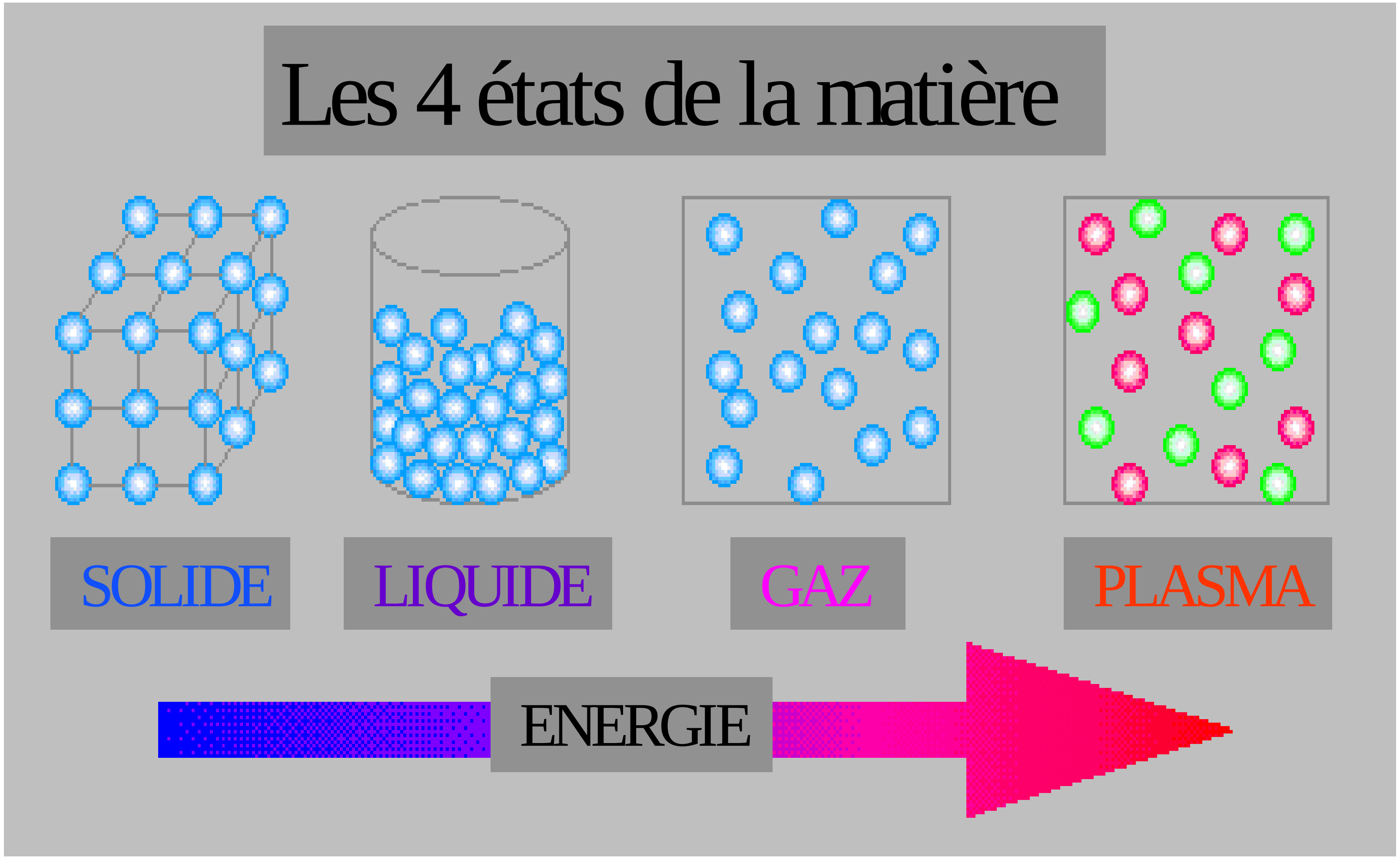
But… fusion requires extreme conditions



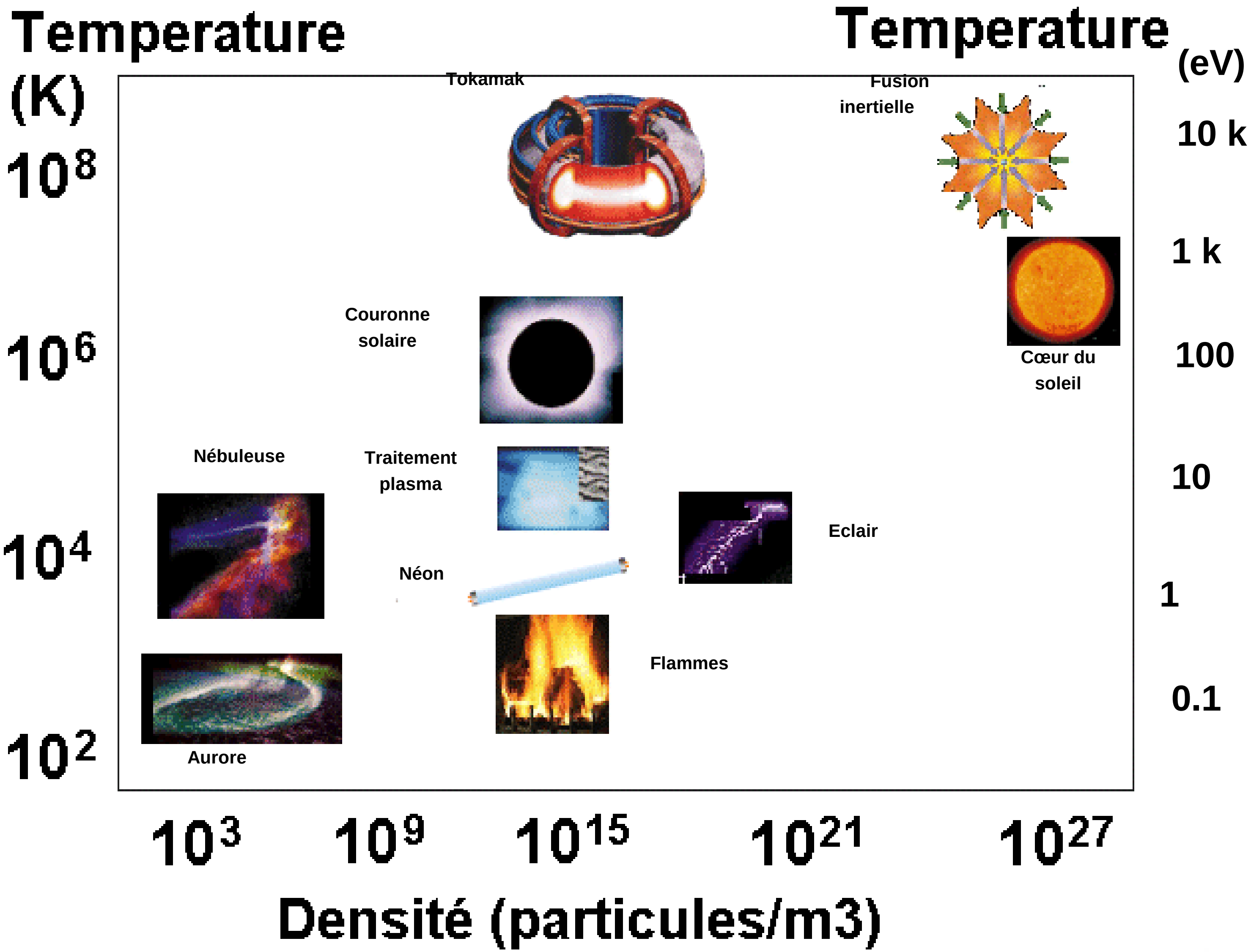


3 conditions must be satisfied in the plasma

Plasma: 4th state of matter



Plasma is 99% of the universe



« Plasma Physics »

- Plasma physics lies between engineering and physics
- Its origins lie in arcs, and in vacuum tubes

- Today plasma physics is everywhere, in nano-science, materials science, as well as in industrial processing

- Astrophysicists are also part of the field

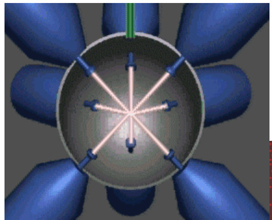
- Understanding 10^{21} charged particles has become a major numerical challenge, linking fluid modelling, statistics and electrodynamics

- Fusion reasearch is one of the driving key areas of plasma physics

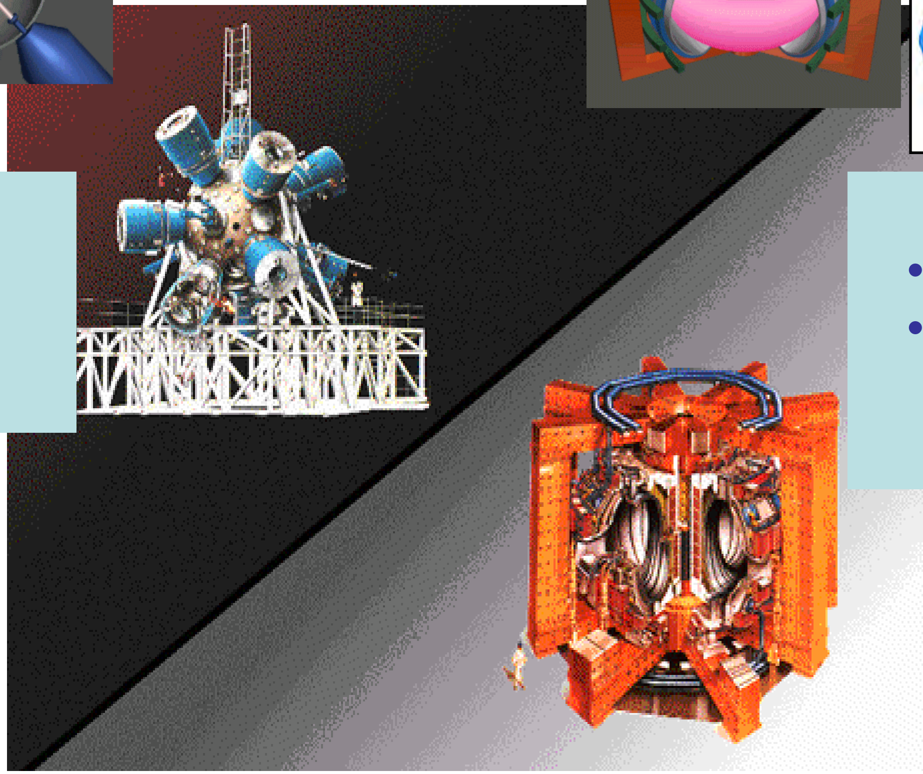
Controlled fusion on earth

1930 the nucleus, 1940 fusion, 1953 H-bomb…
54 years to harness it compared with a few years for fission – why ??

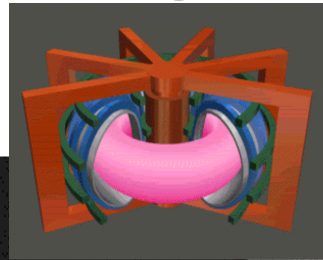
Inertial Confinement

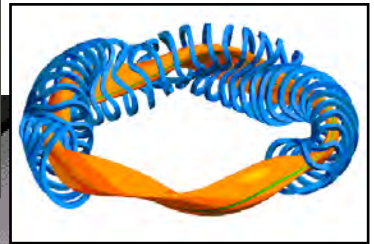


- Short pulses
- Overdense plasmas
- Military links



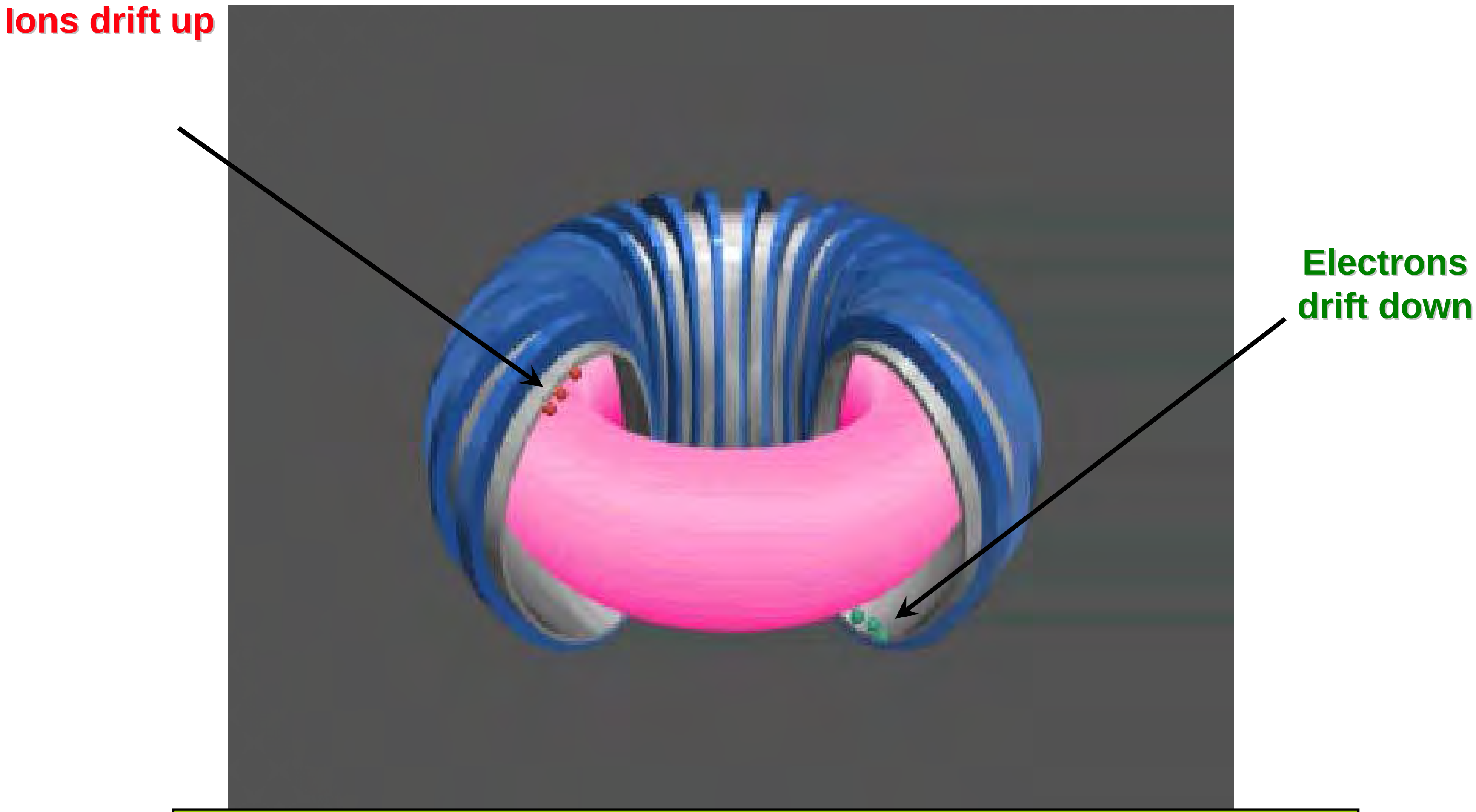
Magnetic Confinement





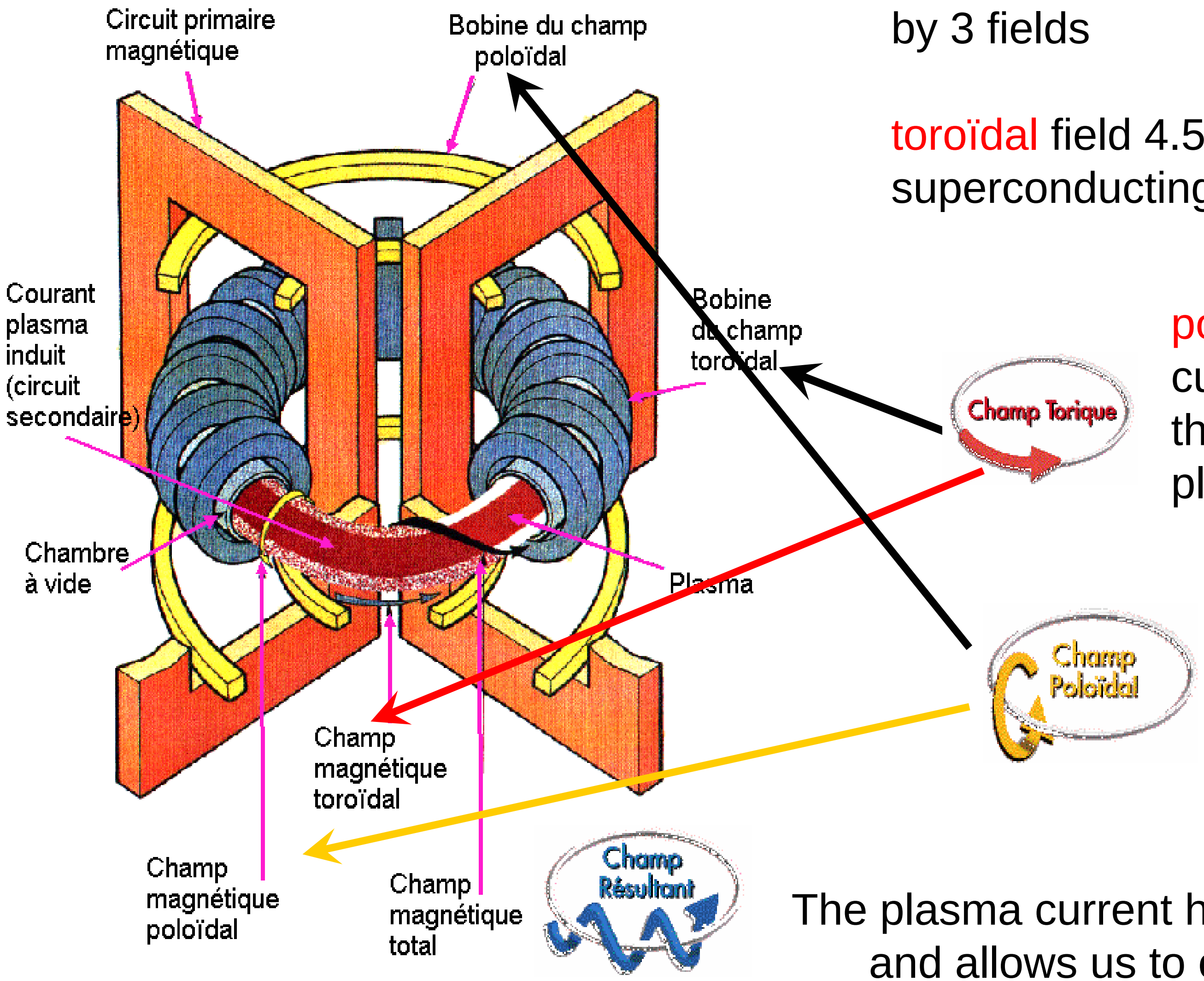
- Long pulses
- Lower density

Toroidal magnetic confinemet



Close field lines on themselves, but single particle drift obits destroy confinement

The basis of a simple tokamak



Confinement is provided essentially by 3 fields

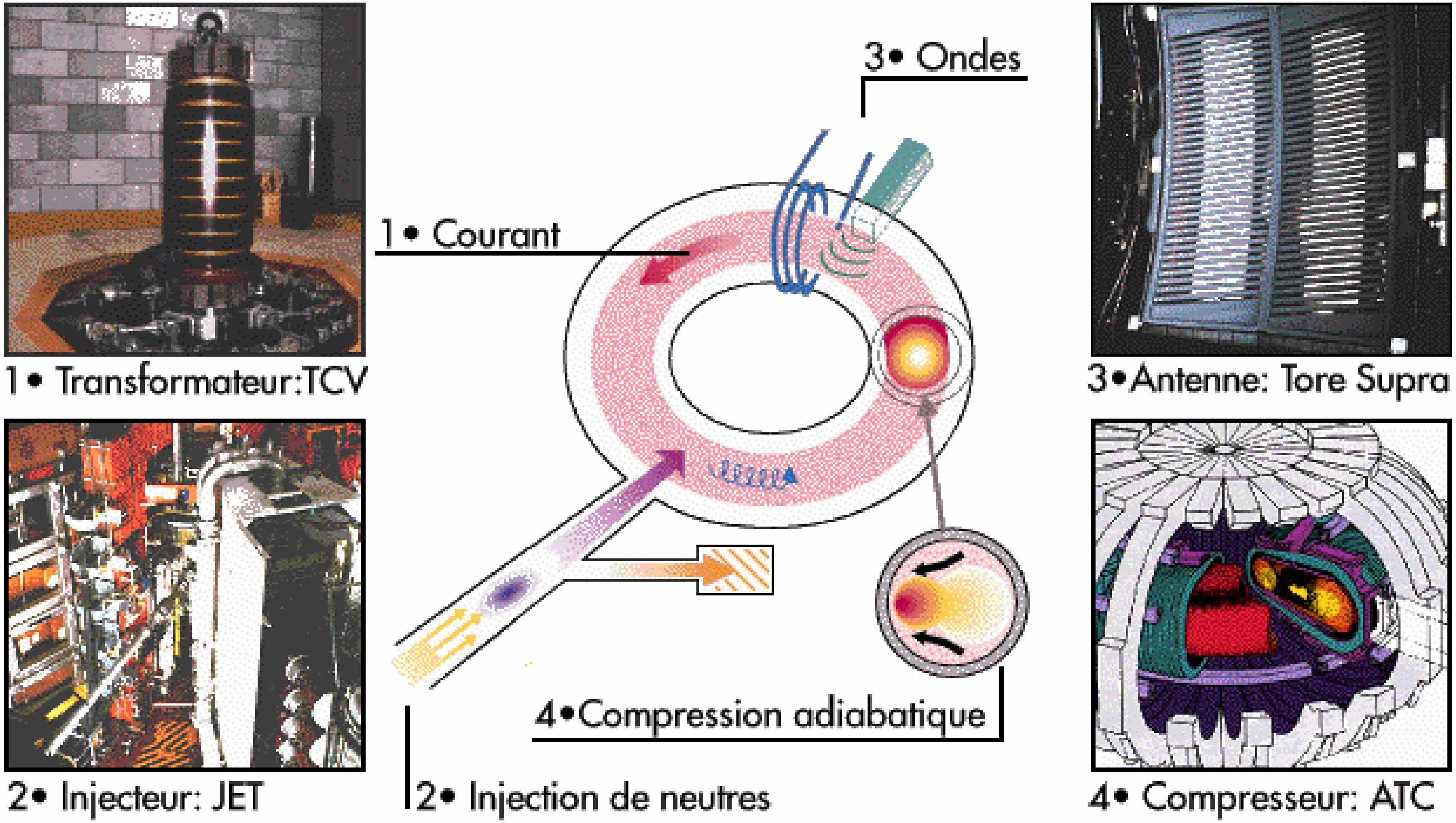
toroïdal field 4.5T, from superconducting coils

poloïdal field from a current flowing in the conducting plasma

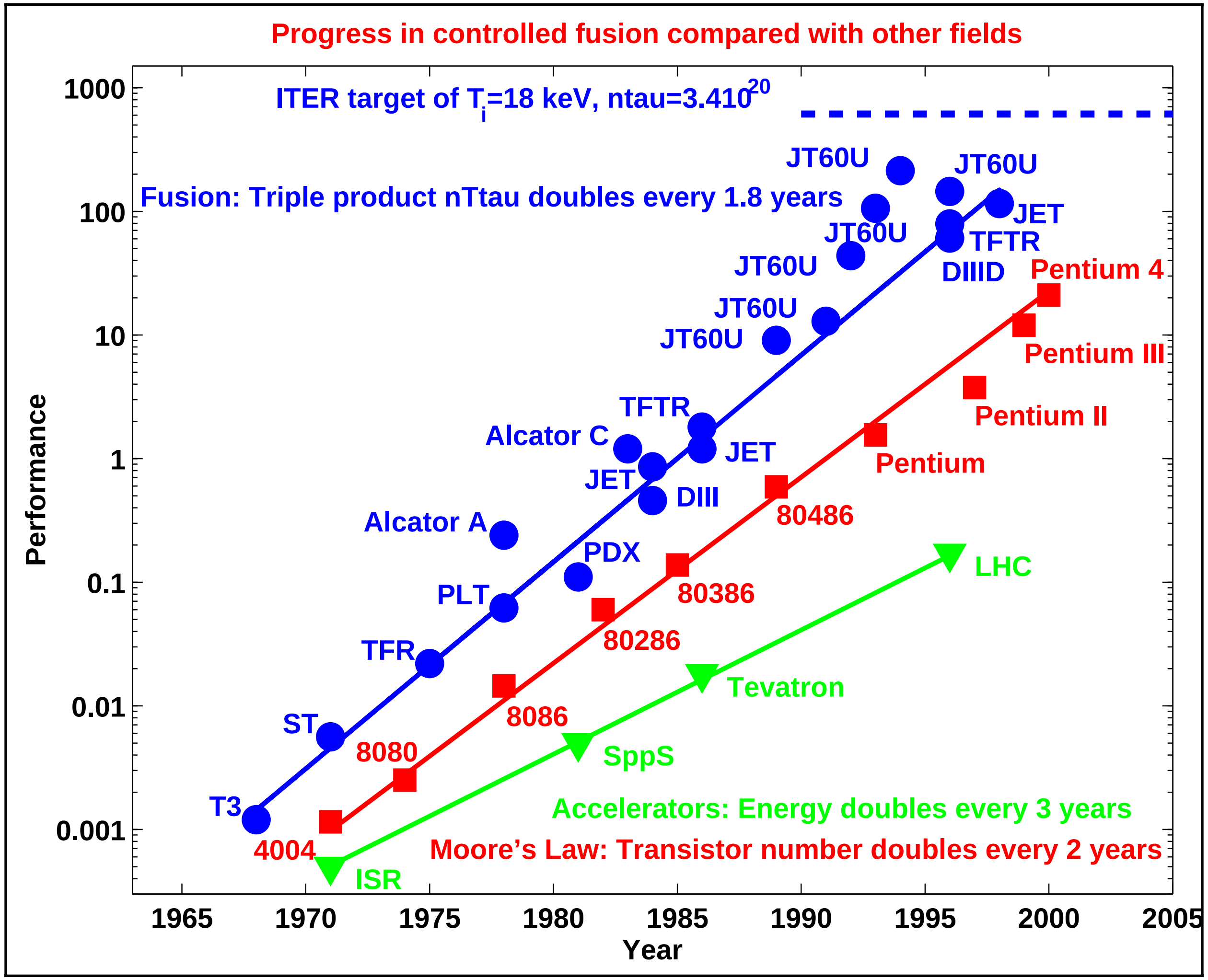
poloïdal field created by external currents

The plasma current heats the plasma and allows us to control it by JxB forces

Heating, aiming at 200,000,000 degrees



Progress in magnetic fusion

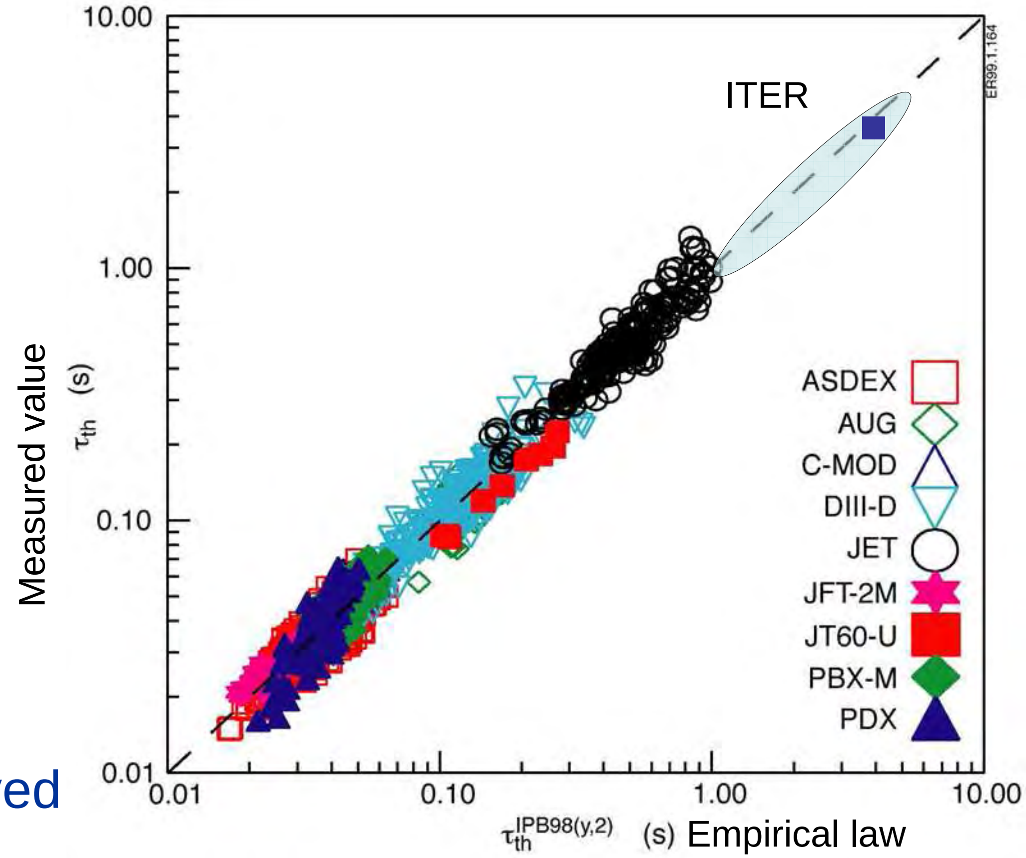


Result of international research

- Collaboration between historical partners:
  - EU
  - Russia
  - Japan
  - USA

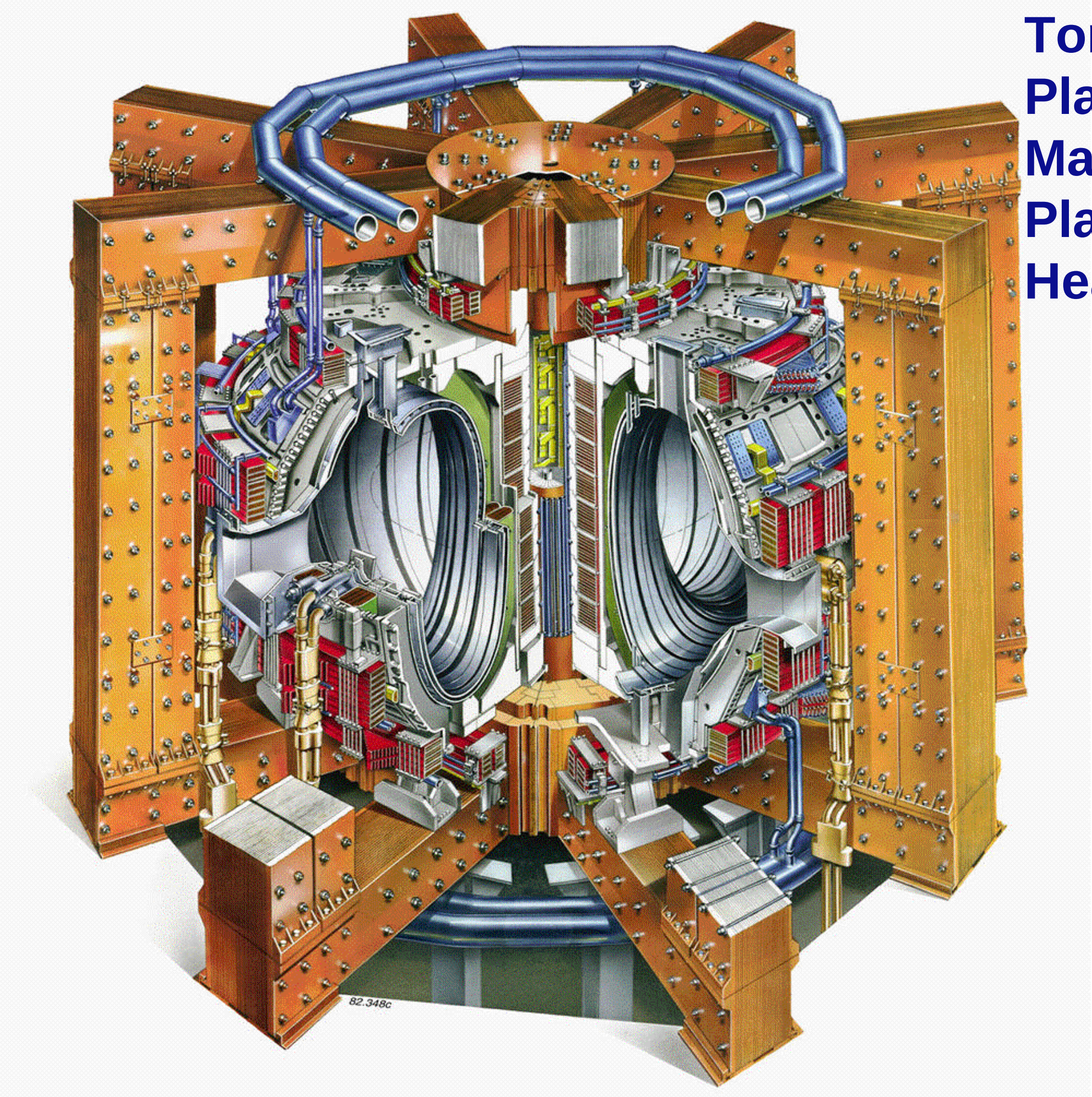
- And new partners
  - China
  - S. Korea
  - India

- Example: confinement is derived by regressing results from all tokamaks

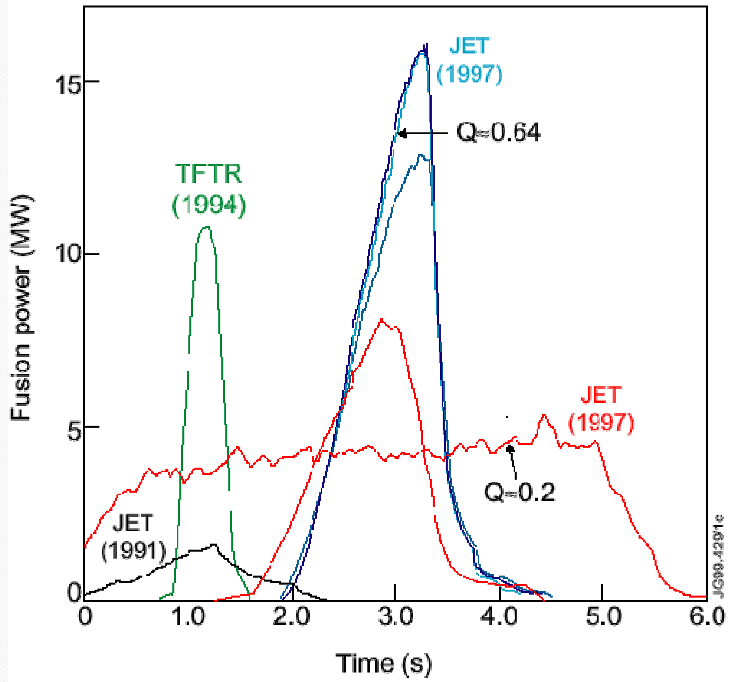


$$\tau_{E,th} = 0.0562\ M^{0.19}\ \kappa_a^{0.78}\ R^{1.39}\ a^{0.58}\ I_p^{0.93}\ B_T^{0.15}\ n_e^{0.41}\ P^{-0.69}$$

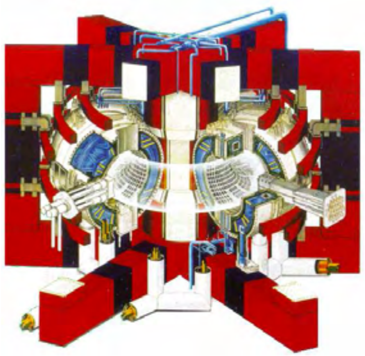
The EU flagship - JET



Toroidal field	**4 Tesla**
Plasma current	**7 million A**
Major radius	**3.1 m**
Plasma volume	**80-100 m^3**
Heating	**Neutrals, RF**



We had to be ambitious…

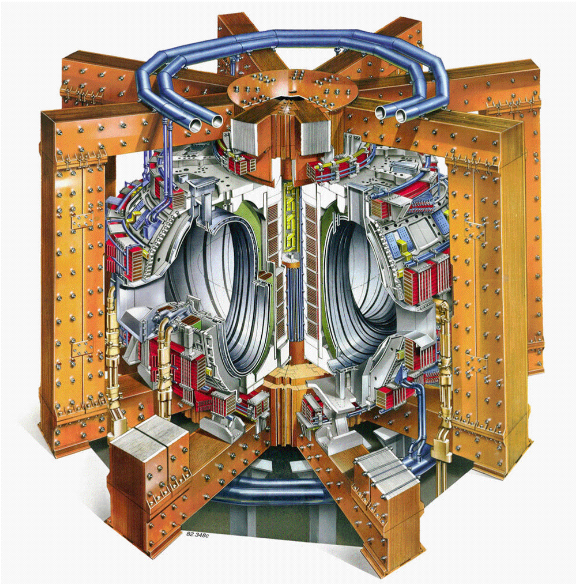


Tore Supra

V_{plasma} 25 m^3

P_{fusion} ~0

t_{plasma} ~400 s

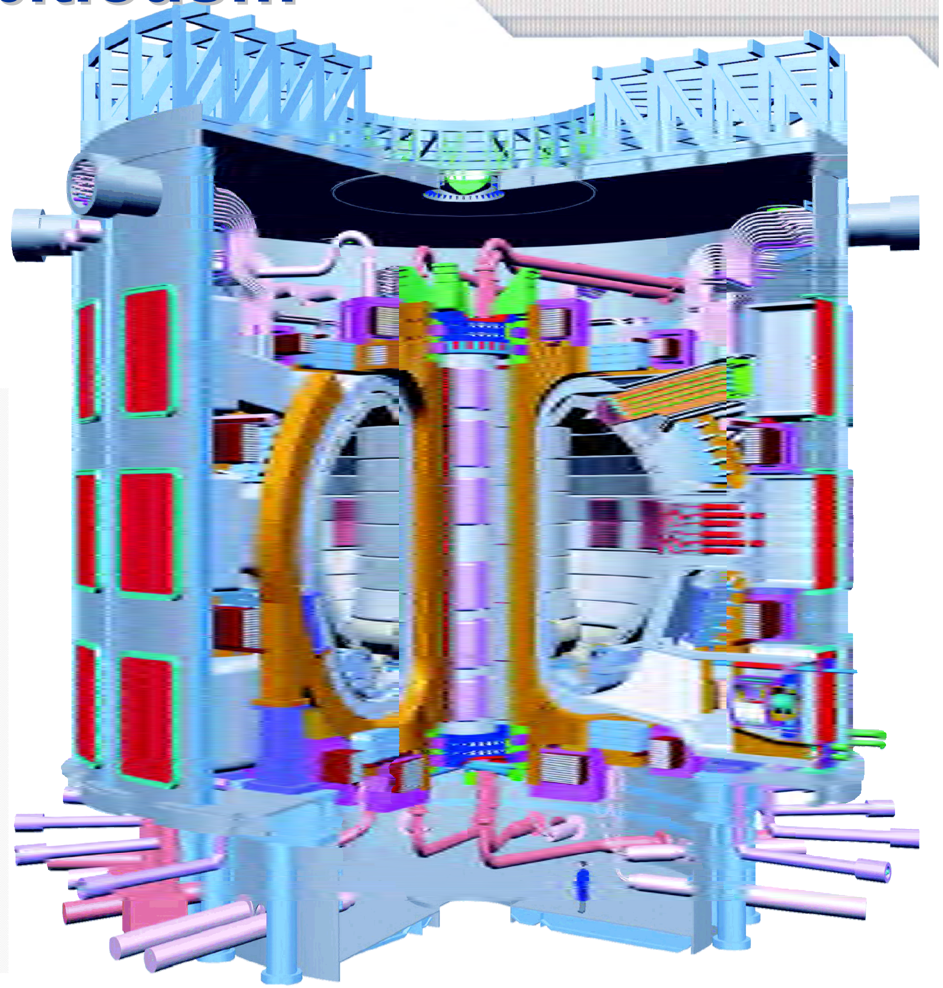


JET

V_{plasma} 80 m^3

P_{fusion} ~16 MW 2s

t_{plasma} ~30 s



ITER

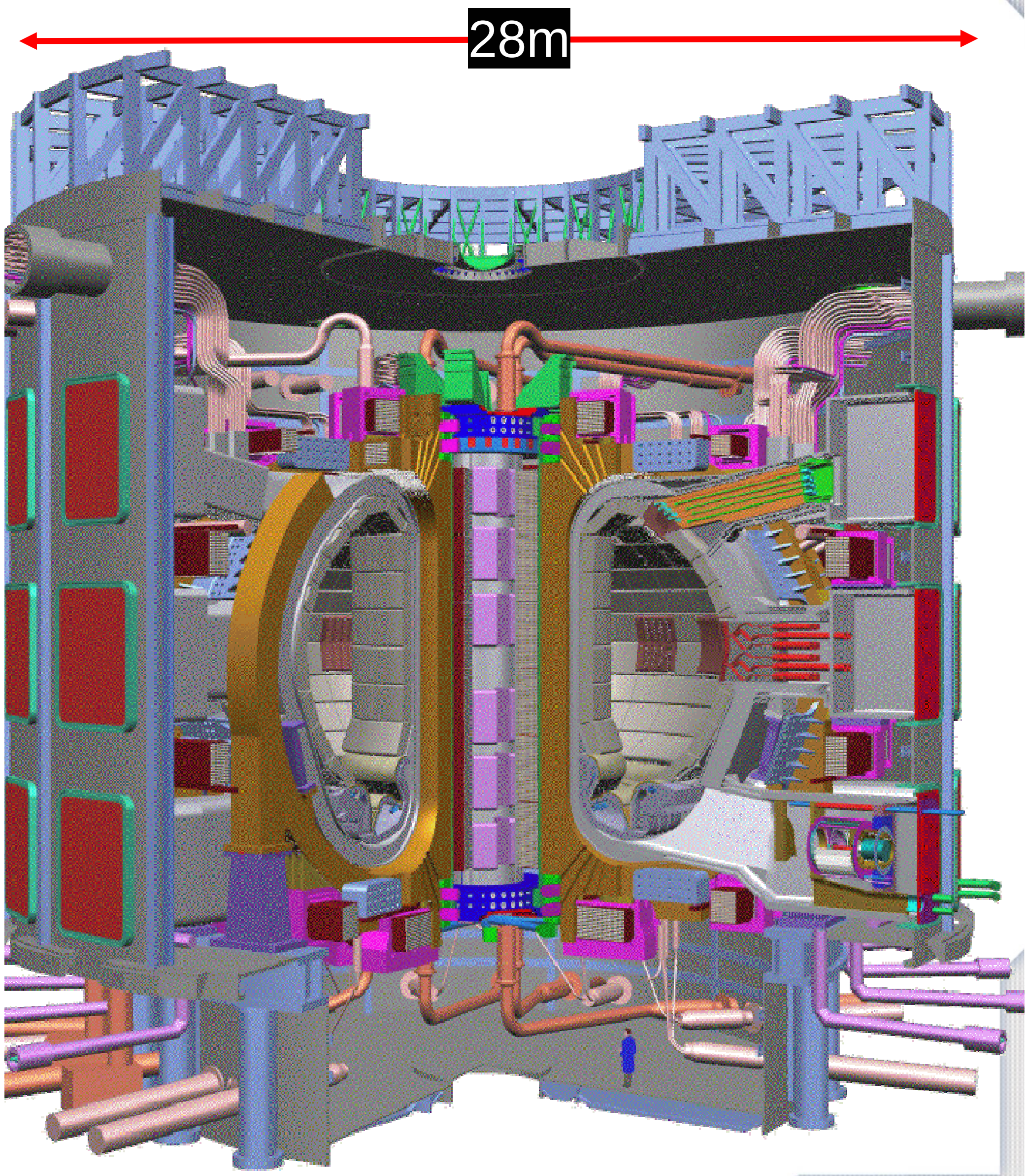
V_{plasma} 830 m^3

P_{fusion} ~500 MW 500s

t_{plasma} ~400 s

ITER – some facts

Fusion power	500MW
Heating power	73 MW
Pfus / Pheat	Q>10
Neutron wall load	0.57 MW/m^2
Major radius	6.2 m
Minor radius	2.0 m
Plasma current	15 Megamp
Toroidal field	5.3T
Plasma volume	837 m^3
Pulse length	300 - 5000 s
PF SC coils	925+6*130 t
TF SC coils	18*312 t
Vacuum vessel	9*575 t
Load assembly	40,000 t



ITER – some technical challenges

- SC coils with crossed fields and dynamical forces, AC losses, unprecendented quantities to be made
- First wall power loading, we have developed handling up to 20MW/m2
- First wall material – 2 choices
  - Low Z (Be, C) higher pollution, low radiation. C traps Tritium as hydrocarbons, requiring removal techniques
  - High Z (W) lower pollution, higher radiative loss. Little experience.
- High vacuum quality in a large vacuum volume and surface area
- Optimisation of plasma performance
  - Partly understanding/modelling, partly feedback automation
- Guarantee safety and licensing in a one-of-a-kind facility
- Specific domain challenges
  - Provide efficient high performance plasma heating
  - Provide active and passive measurements of plasma parameters

ITER en EU

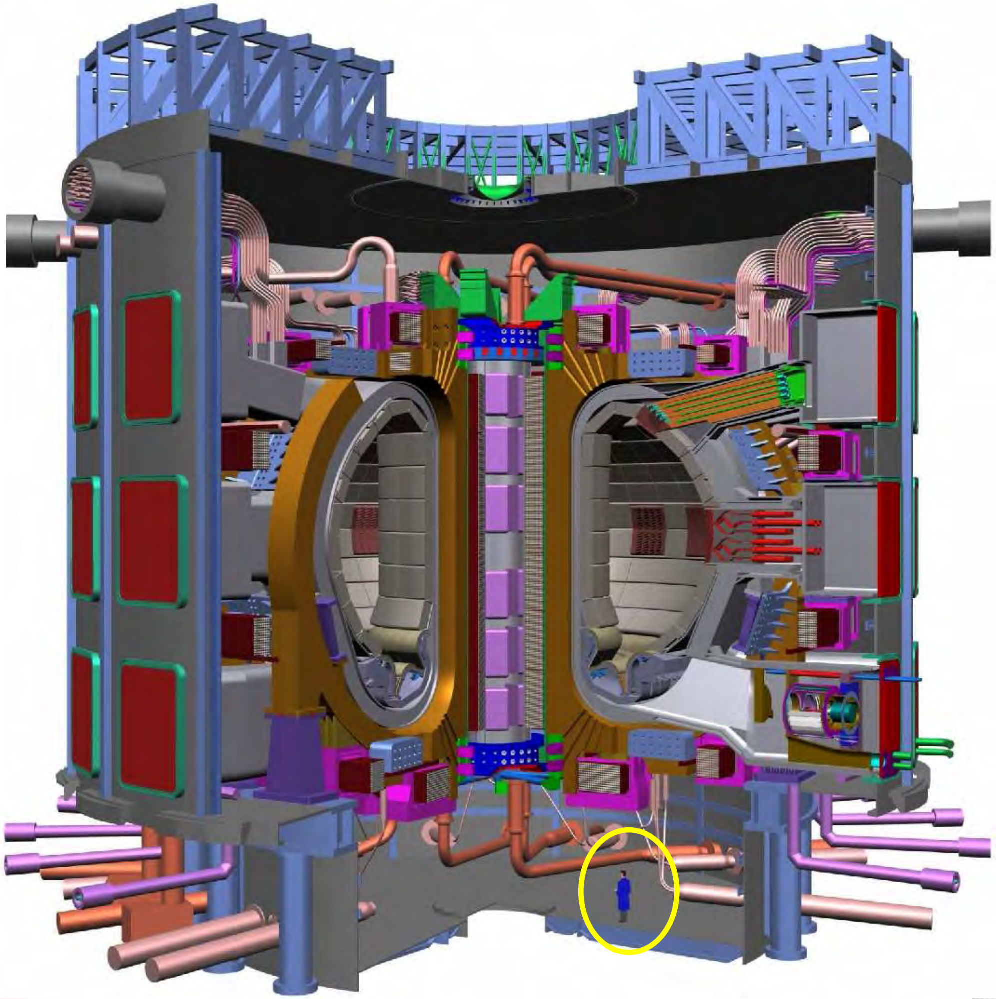
10 billion Euros to build and operate

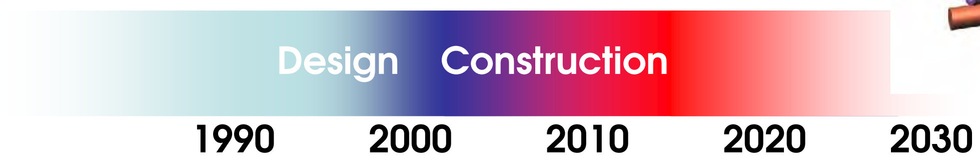
10 years to build

Startup 2016

18 buildings

180 hectares being cleared





ITER : indicative cost

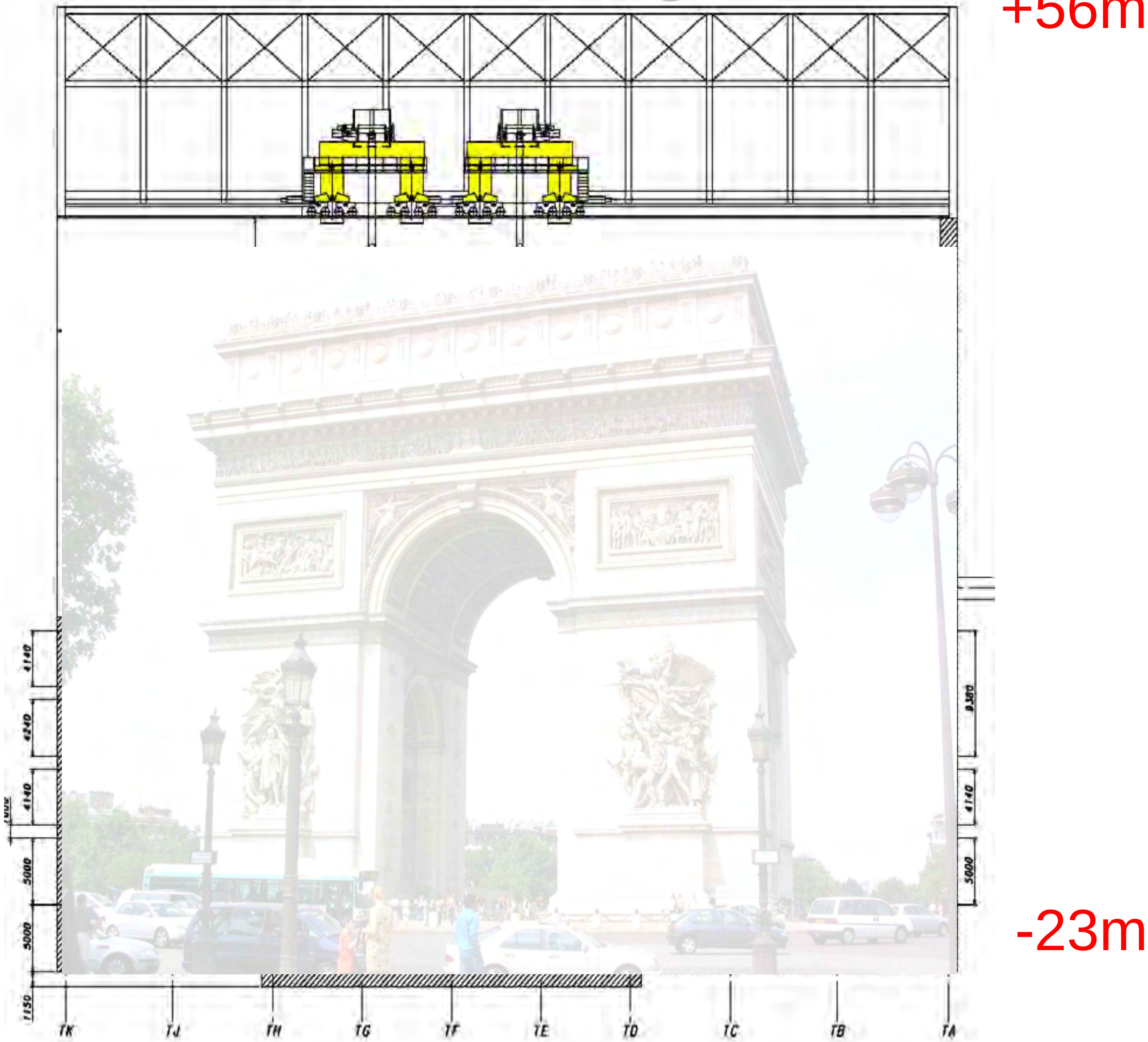
- Construction (10 year)
  - Investment 3960 M€
  - Management and services 610 M€
  - **Total 4570 M€**

- Exploitation (per year over 20 years)
  - Exploitation costs 240 M€
  - Provision for dismanteling 27 M€
  - **Total 267 M€**

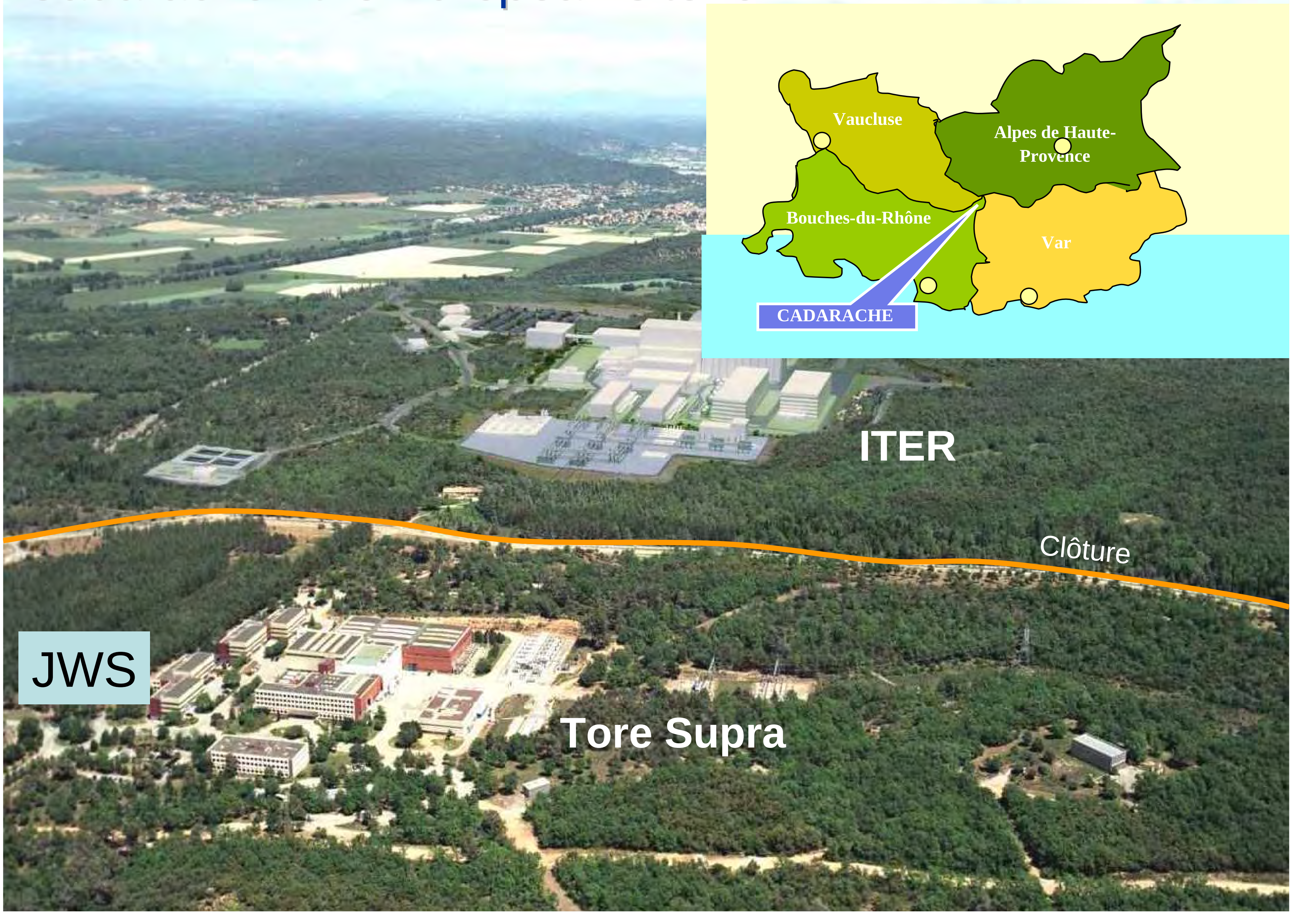
- **Total investment ~ 10 G€**

- Splitting: EU (45%), others 6 * 9%

Is ITER so huge …. ?



Cadarache : the European site for ITER



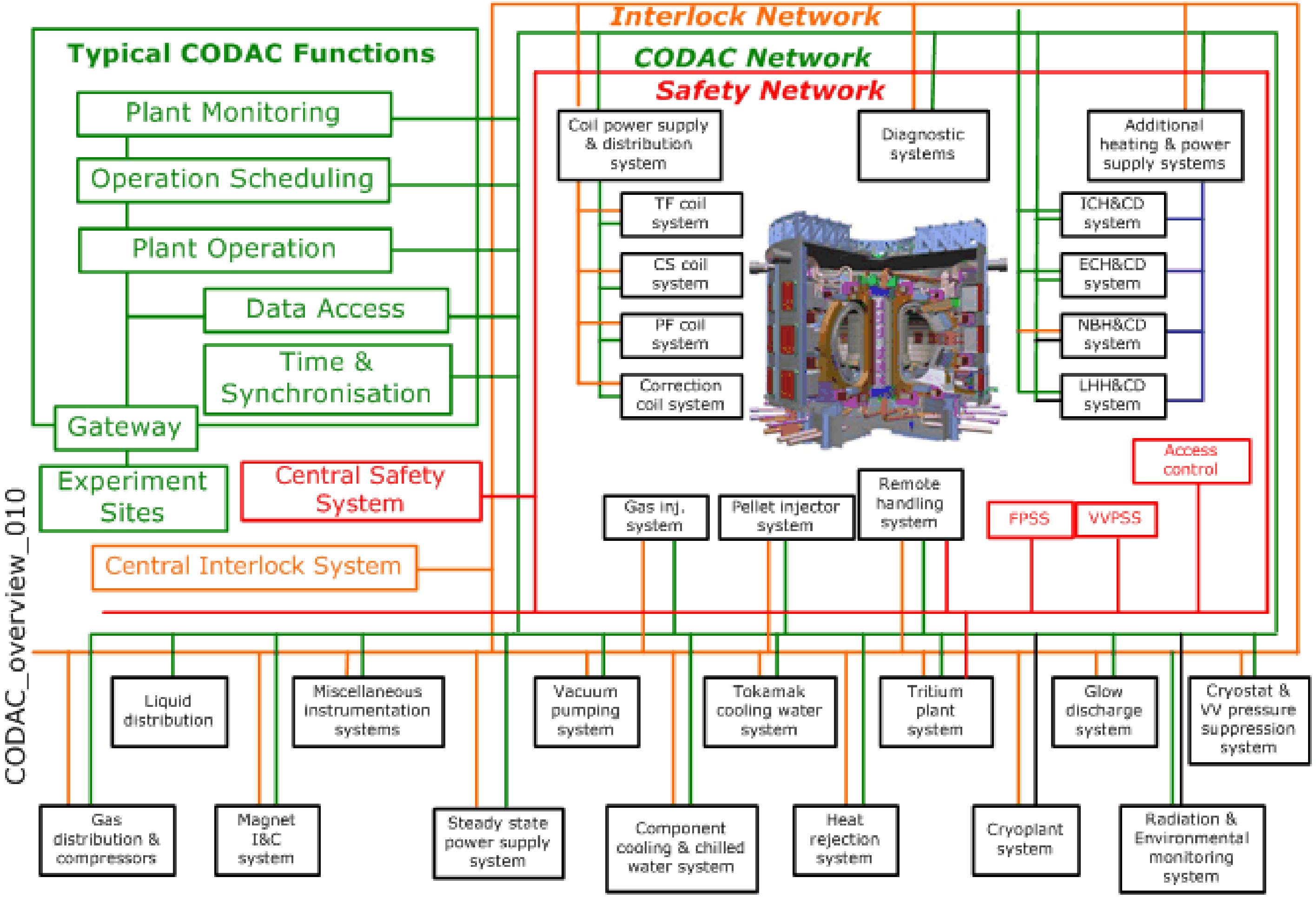
Some information on the data systems

- COntrol, Data Access and Communication provides:

  - Slow controls
  - Fast feedback
  - Data storage, archiving
  - Data access for analysis
  - Operation
  - Scheduling
  - Safety, interlocks

  - High availability – almost no down time for 35 years….

Plant Systems seen from CODAC

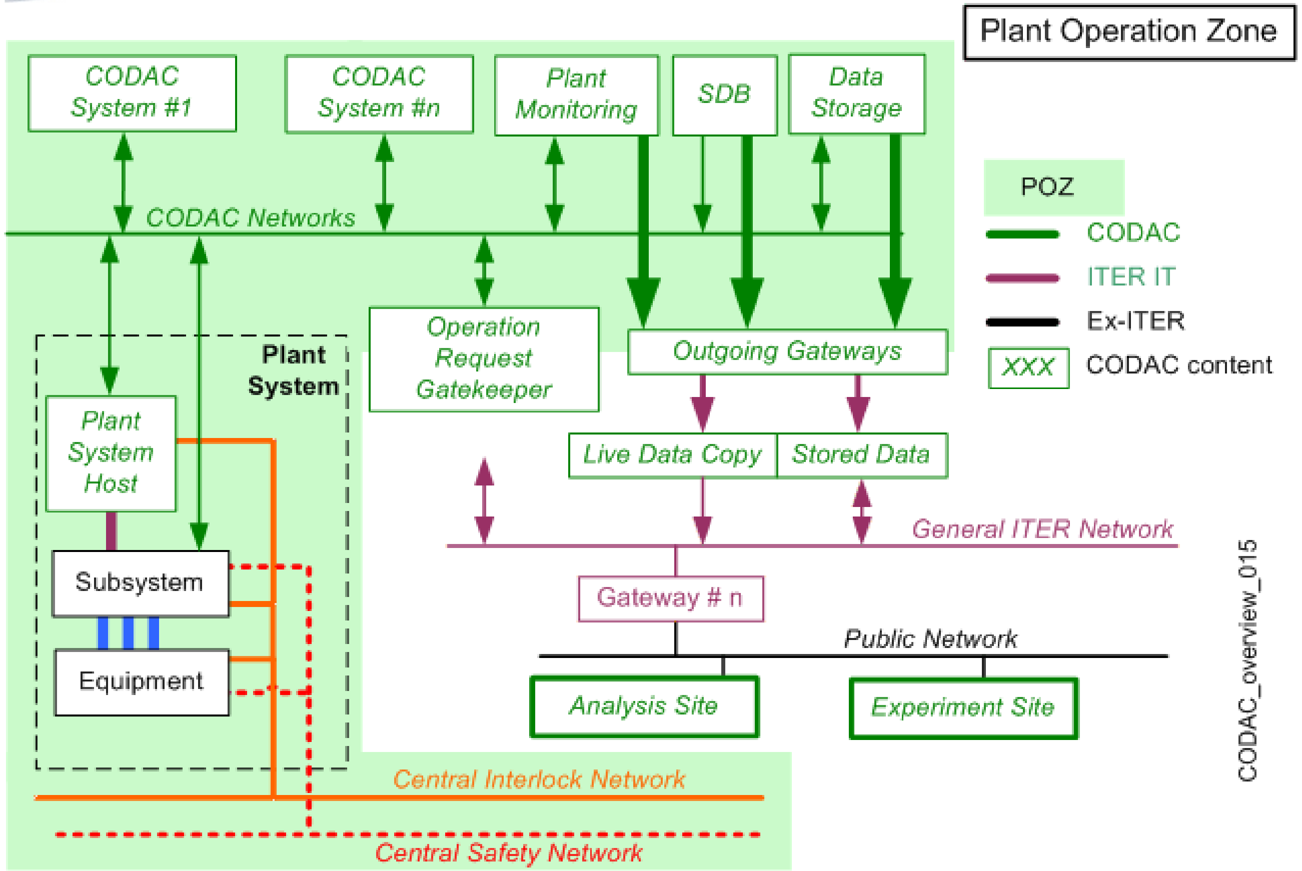


All the 60-90 "technical systems"

Connected by networks:
- Operation
- Interlocks
- Safety

Block of "CODAC" Systems which are software

Plant Operation Zone



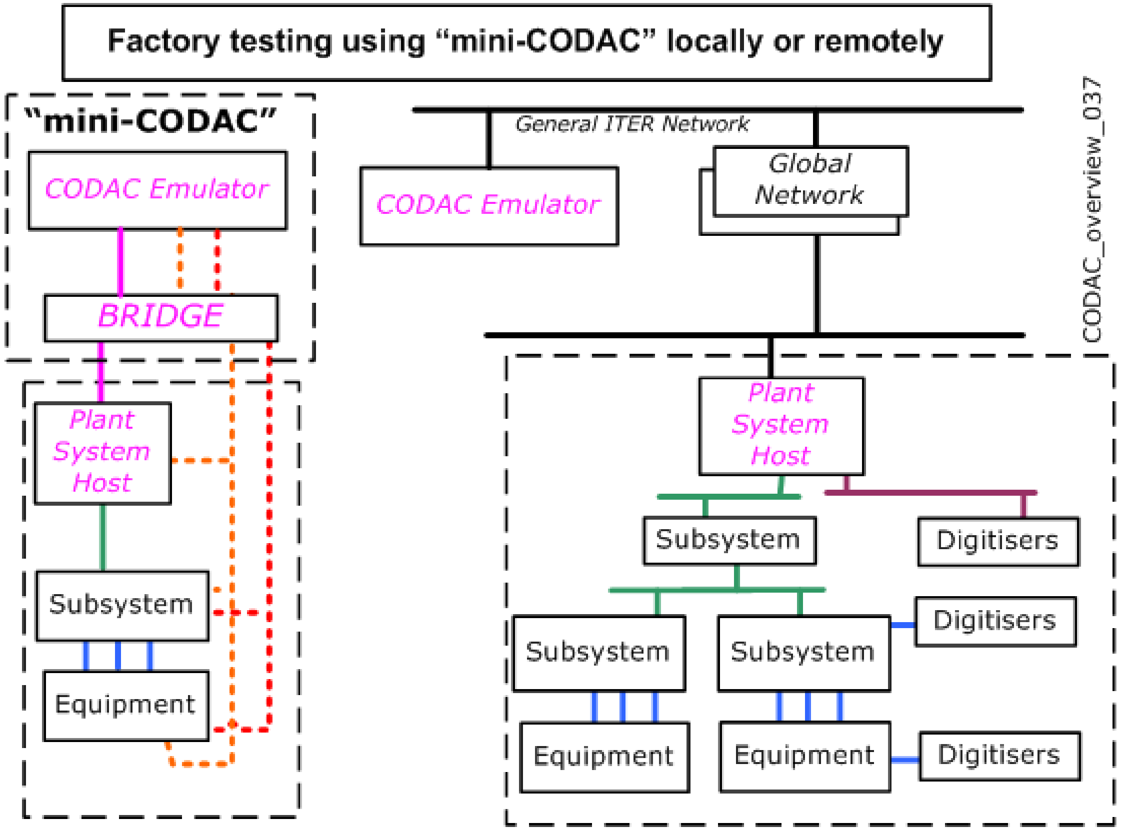
- The Plant Operation Zone "operates" ITER
- It is highly protected and can function isolated
- Live data are exported from the POZ to Experiment Sites
- Cadarache is also one of these Experiment Sites
- Inside the POZ are
  - CODAC Systems
  - Plant Systems
  - Operation networks
  - Interlock network
  - Safety network

Factory development

- Suppliers develop their self-description using CODAC tools
- The Plant System Host (IPC) is "free issue" for full compatibility

- Each system self-description is factory-accepted before shipping
- CODAC System functionality is deployed in a "Mini-CODAC" to help factory development

- An industrial case is identified

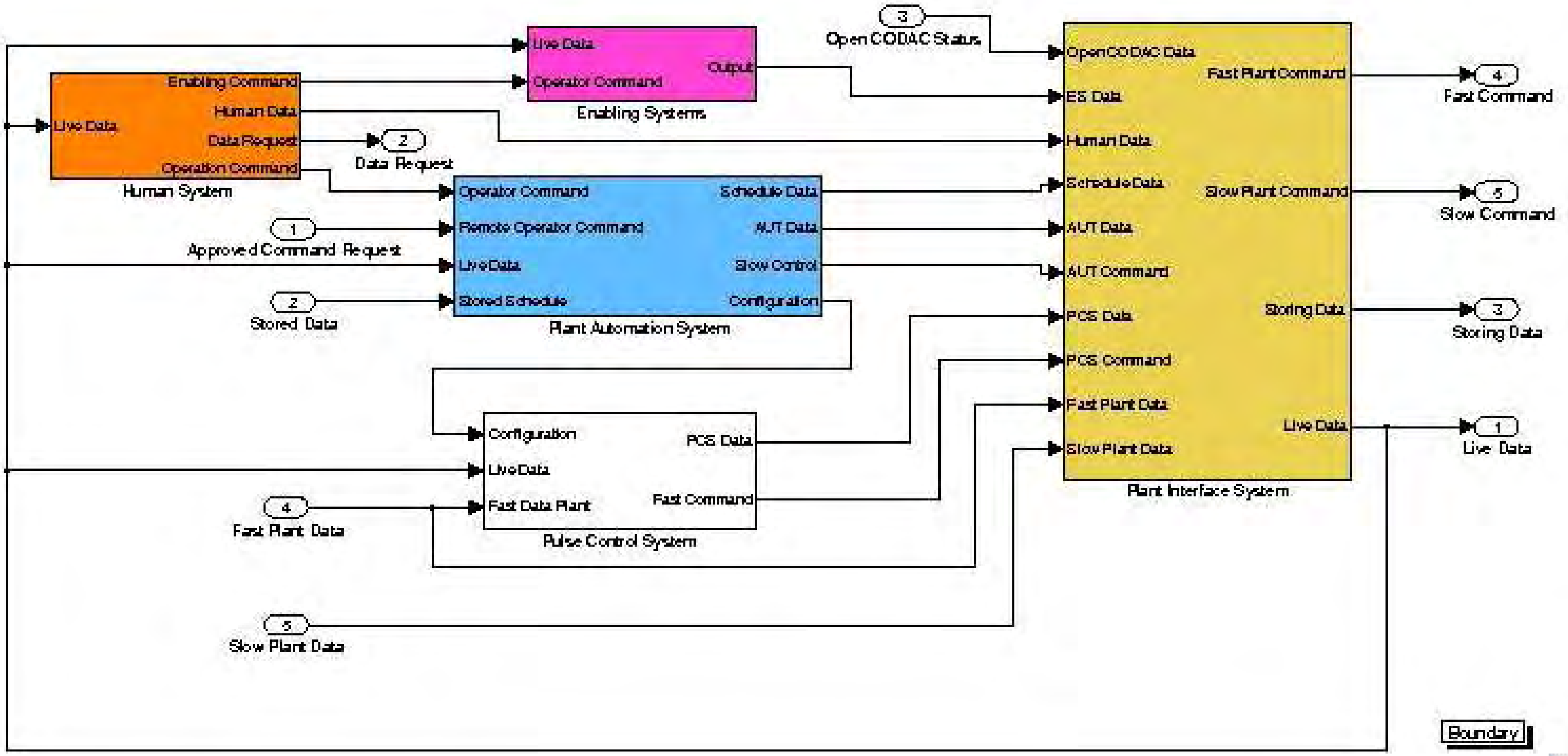


- "Mini-CODAC" tests all CODAC interfaces and functionality at the factory, where the competence is, in case of difficulties
- CODAC monitors the evolution of the Plant System Host functionality during development, to identify delays or difficulties early *guarantees integration*

CODAC evolution

- Conceptual design
  - Complete mid-2007
- Engineering design of CODAC Systems
  - 2007-2009
- Retrofitting CODAC design approaches to installations
  - Existing experiments
  - ITER test-stands
- Developing a full prototype to be maintained during operation
  - Flexibility, full functionality, no QA “ideas test bed”
- Developing a production environment
  - QA, functionality, performance, availability
- Developing the factory testing using “mini-CODAC”
- Developing a full simulator using the CODAC Plant System data

Example of data flow – POZ CODAC



- *Thank you for your attention…*