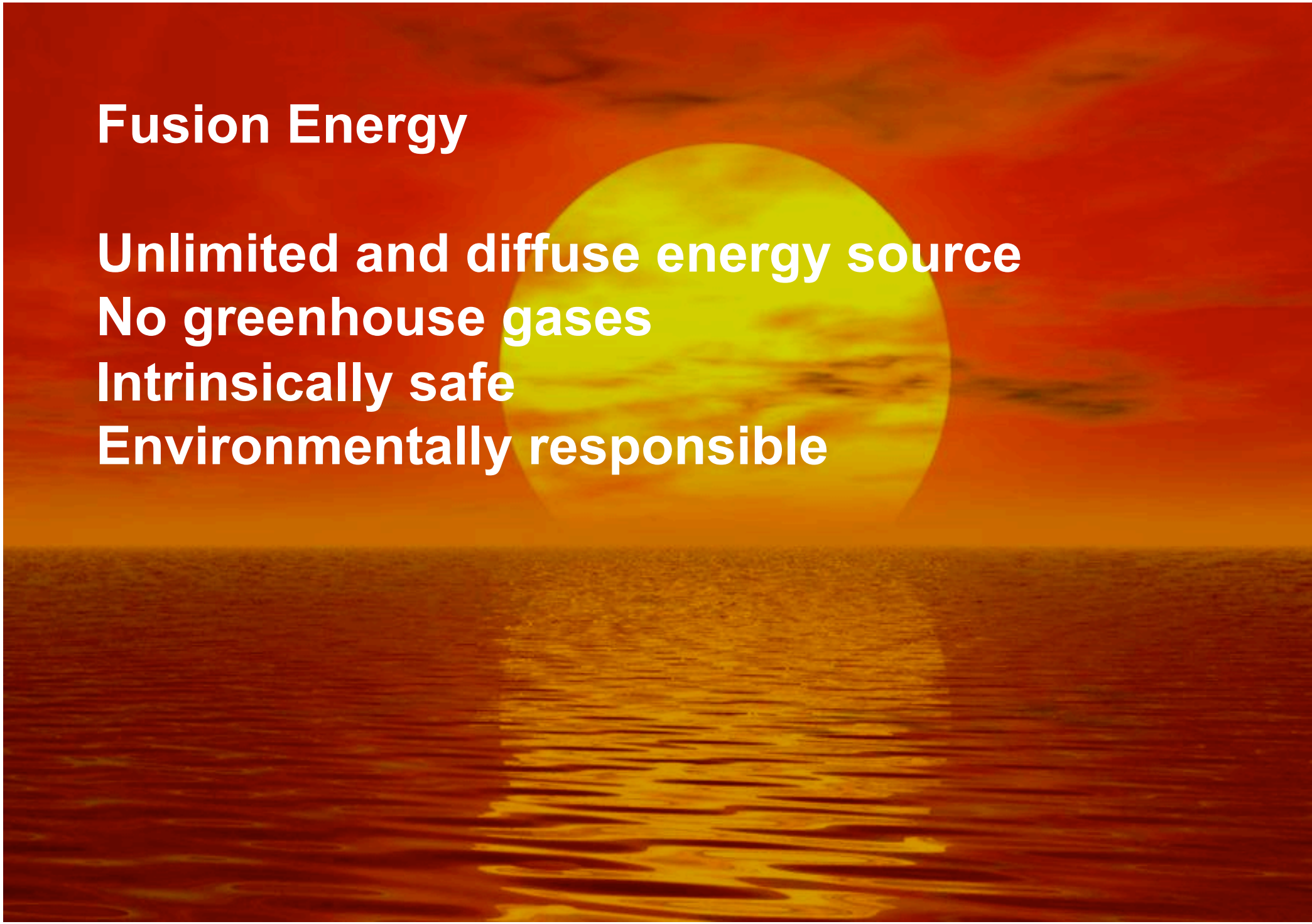
Fusion resarch for ITER
What can we learn from JET

Working Group on Energy
Dresden

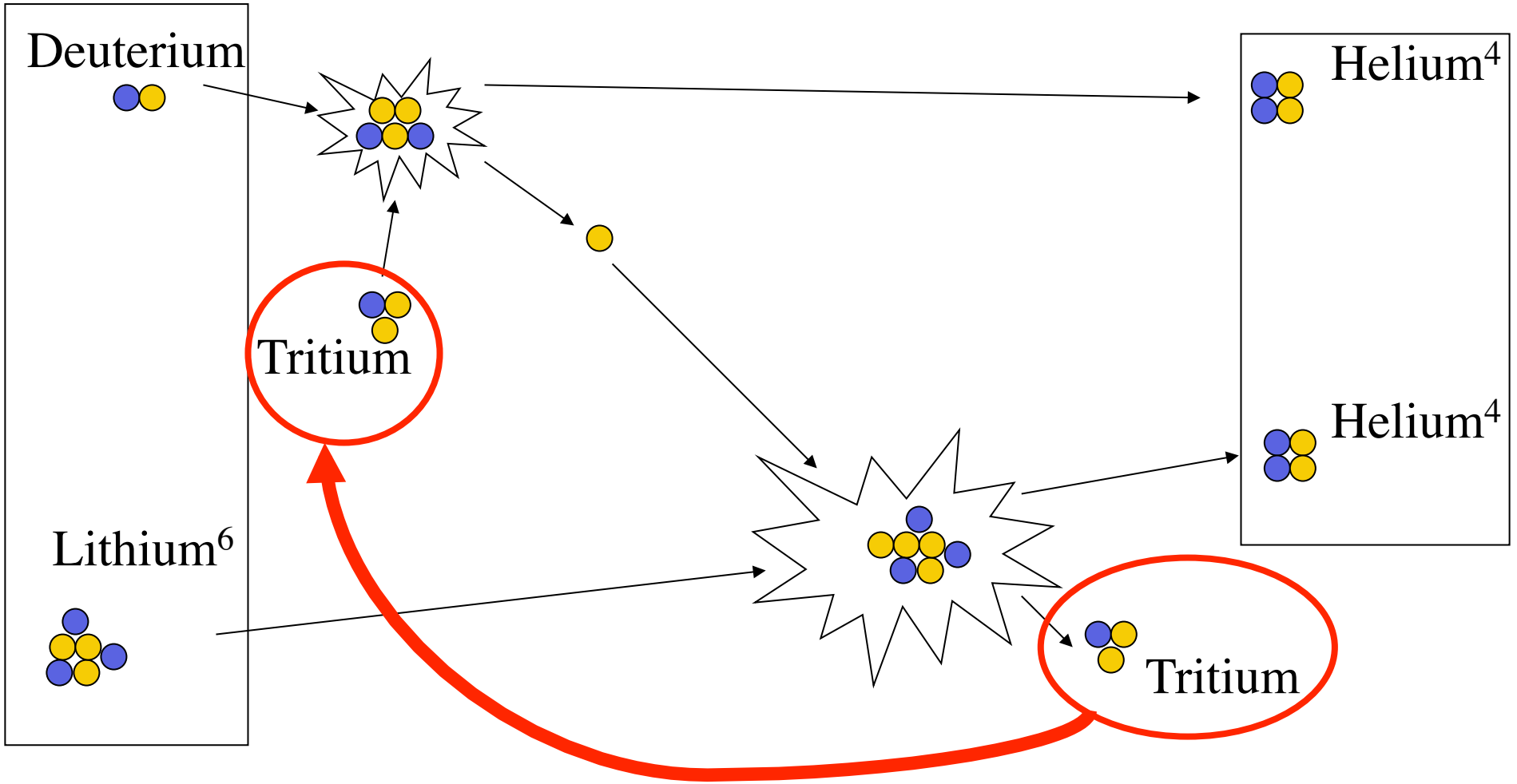
Francesco Romanelli
European Fusion Development Agreement
EFDA Leader and JET Leader
14 March 2011

Outline

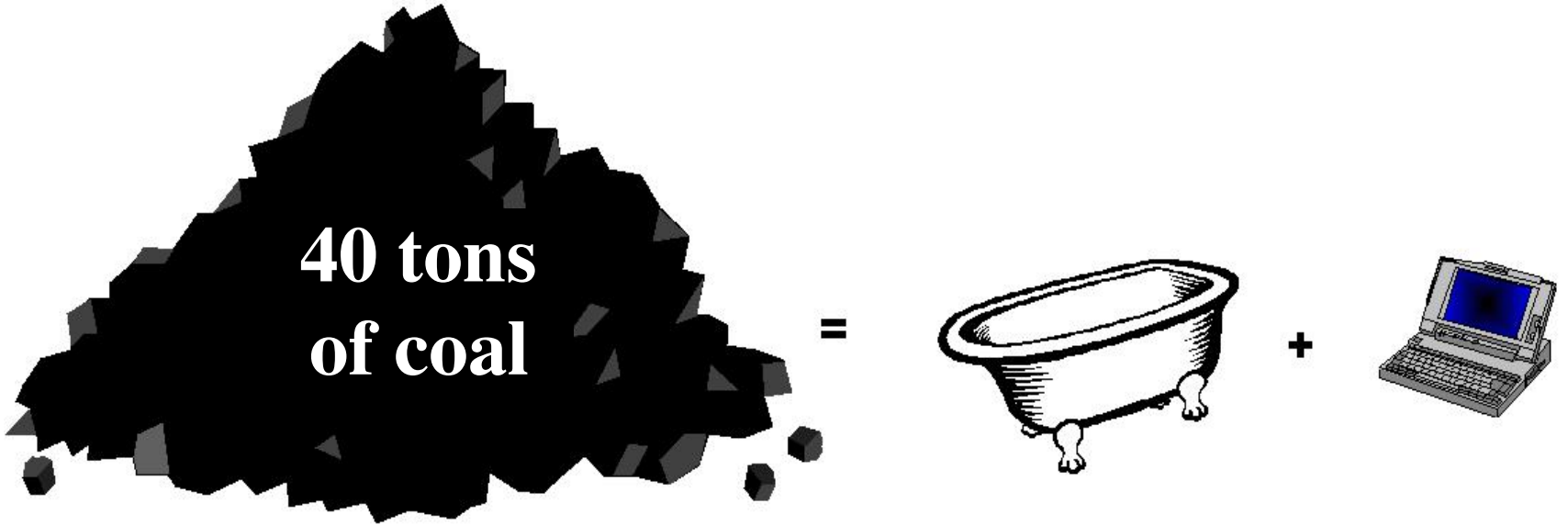
- Background on Fusion
- The fusion challenges
- The path to the fusion Power Plant


Fusion Energy
Unlimited and diffuse energy source
No greenhouse gases
Intrinsically safe
Environmentally responsible

No nuclear waste produced by the primary reaction
No greenhouse gases

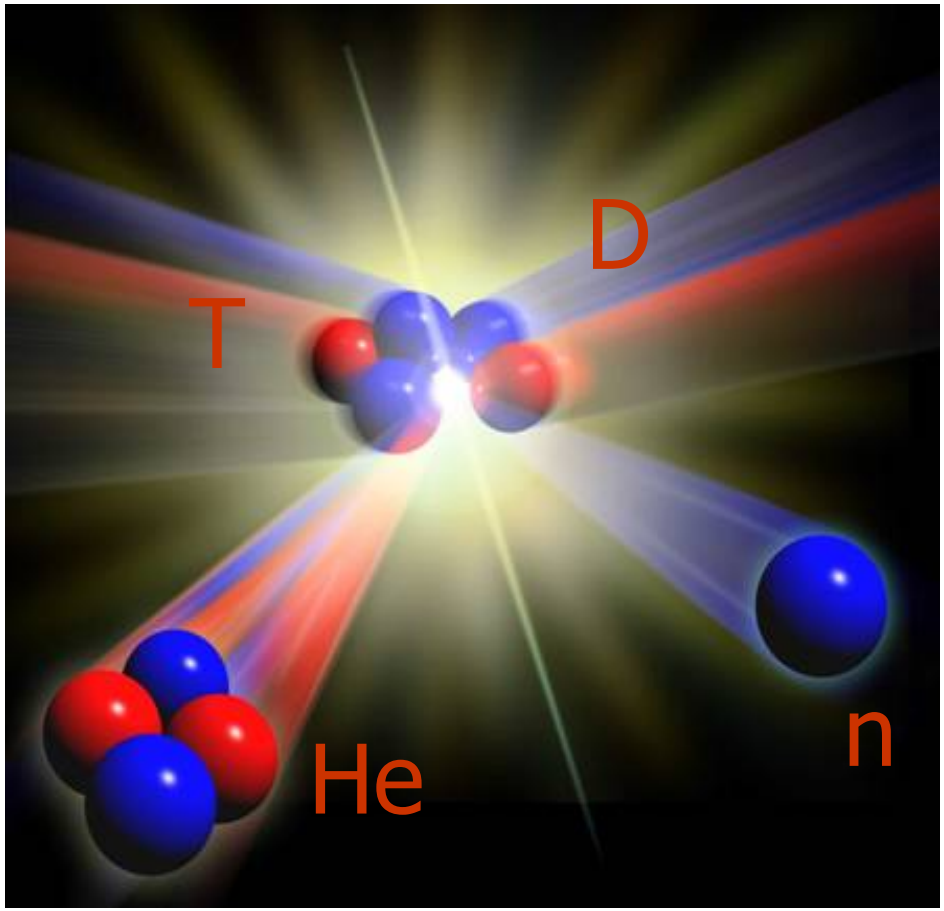


Electricity consumption for 30 years by a single EU person.



45 liters of water + a computer battery

How to make fusion?

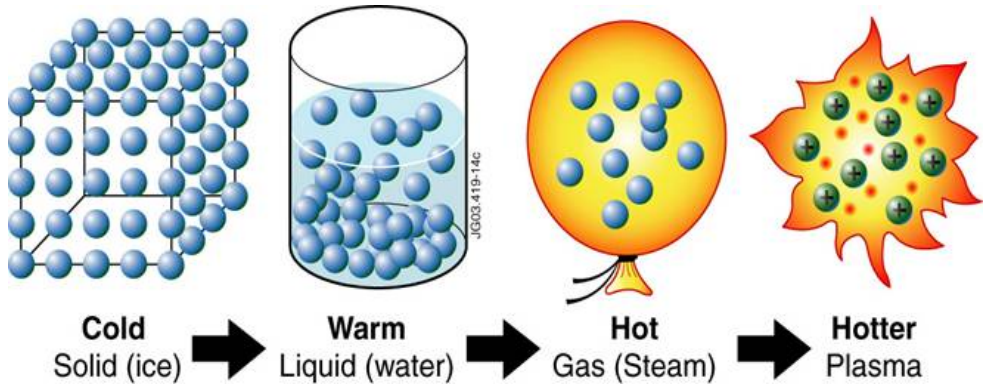


Reacting nuclei are charged

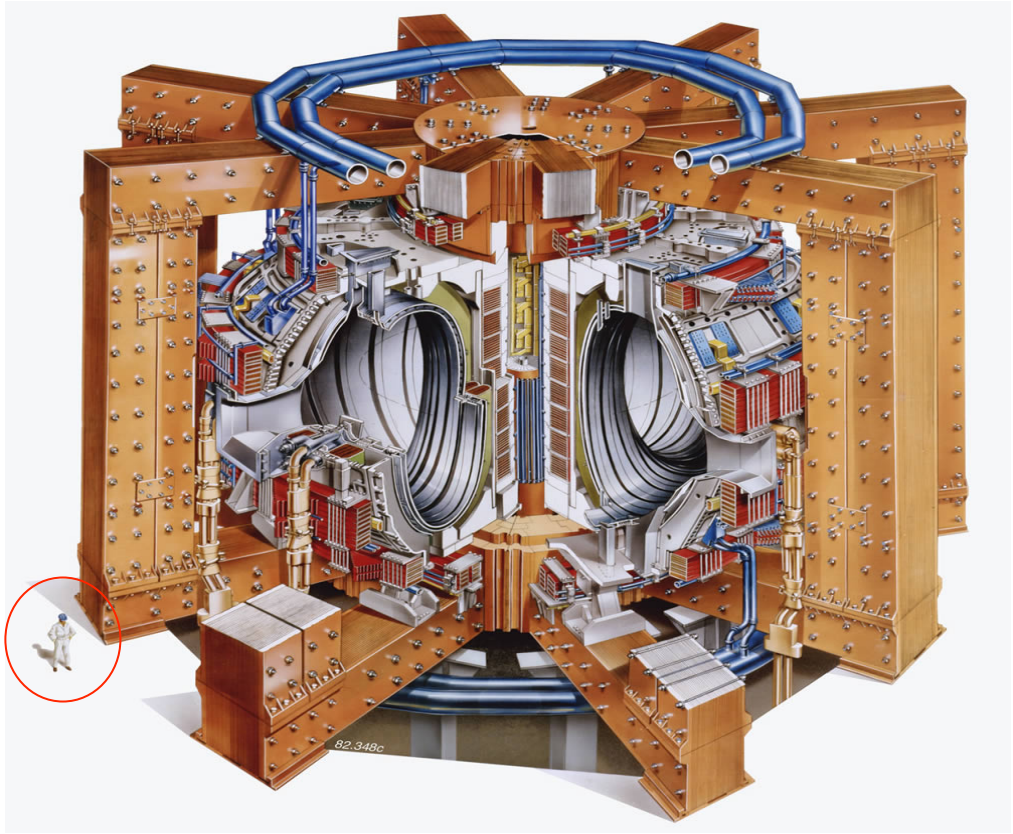
⇒ they repel each other

Heat nuclei up to 200Million ^{o}C

Matter is in the *plasma* state



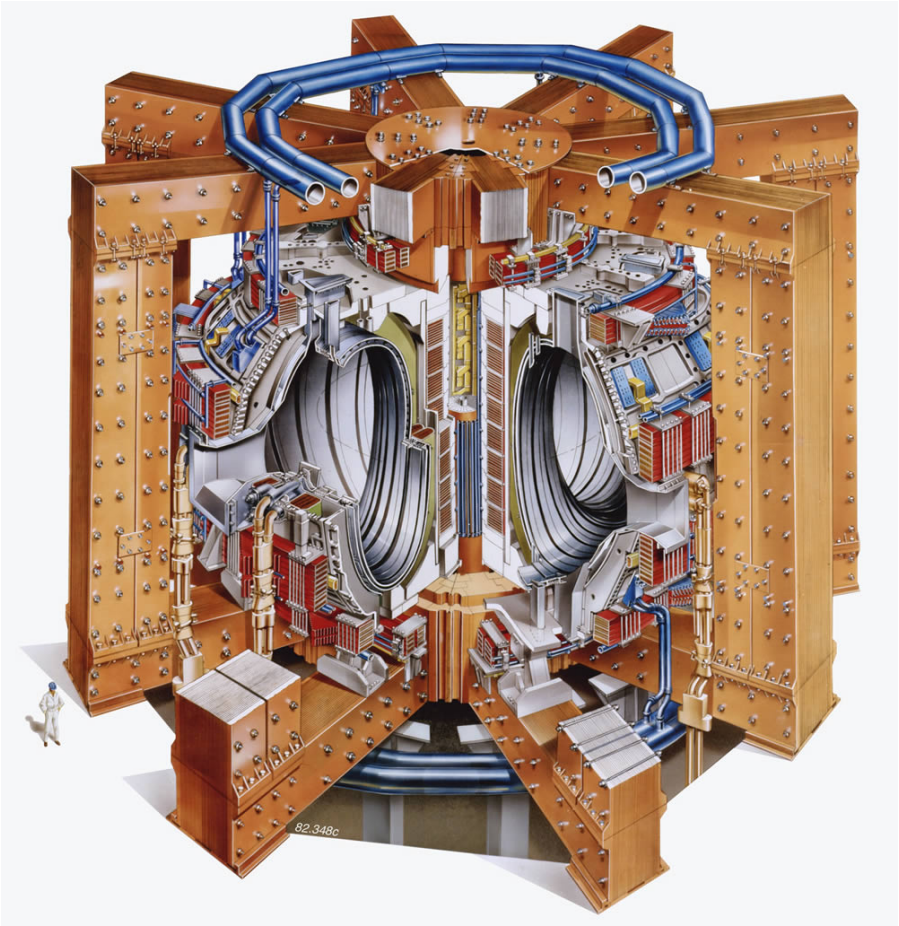
How to confine a plasma?



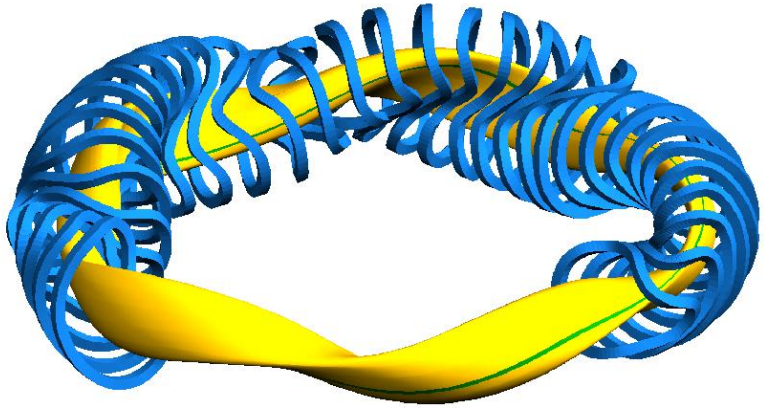
Joint European Torus (JET)

- **Intense magnetic field** (100000 x the earth magnetic field)
- **Toroidal shape**
- In addition:
  - External heating methods
  - Advanced diagnostic systems

How to confine a plasma?

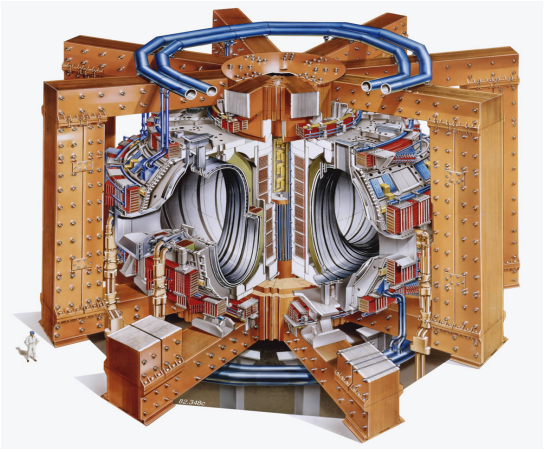


Joint European Torus (JET)

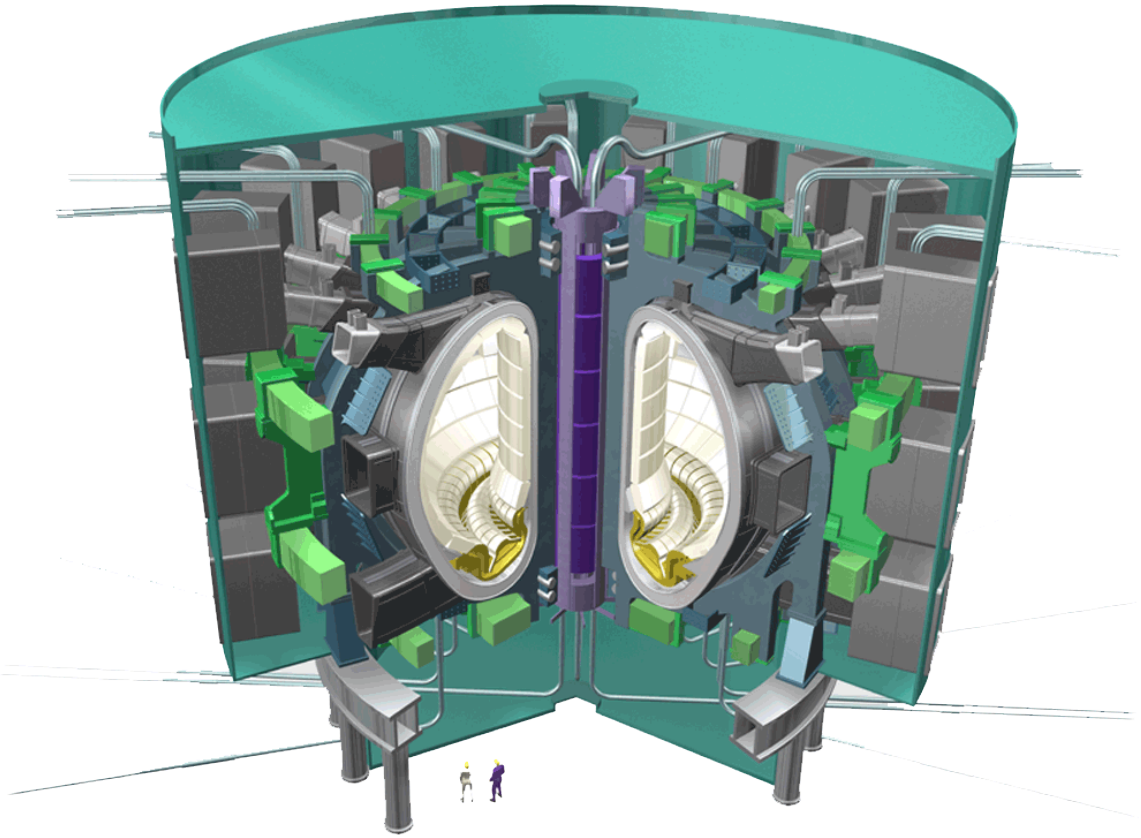


W7X

How to confine a plasma?

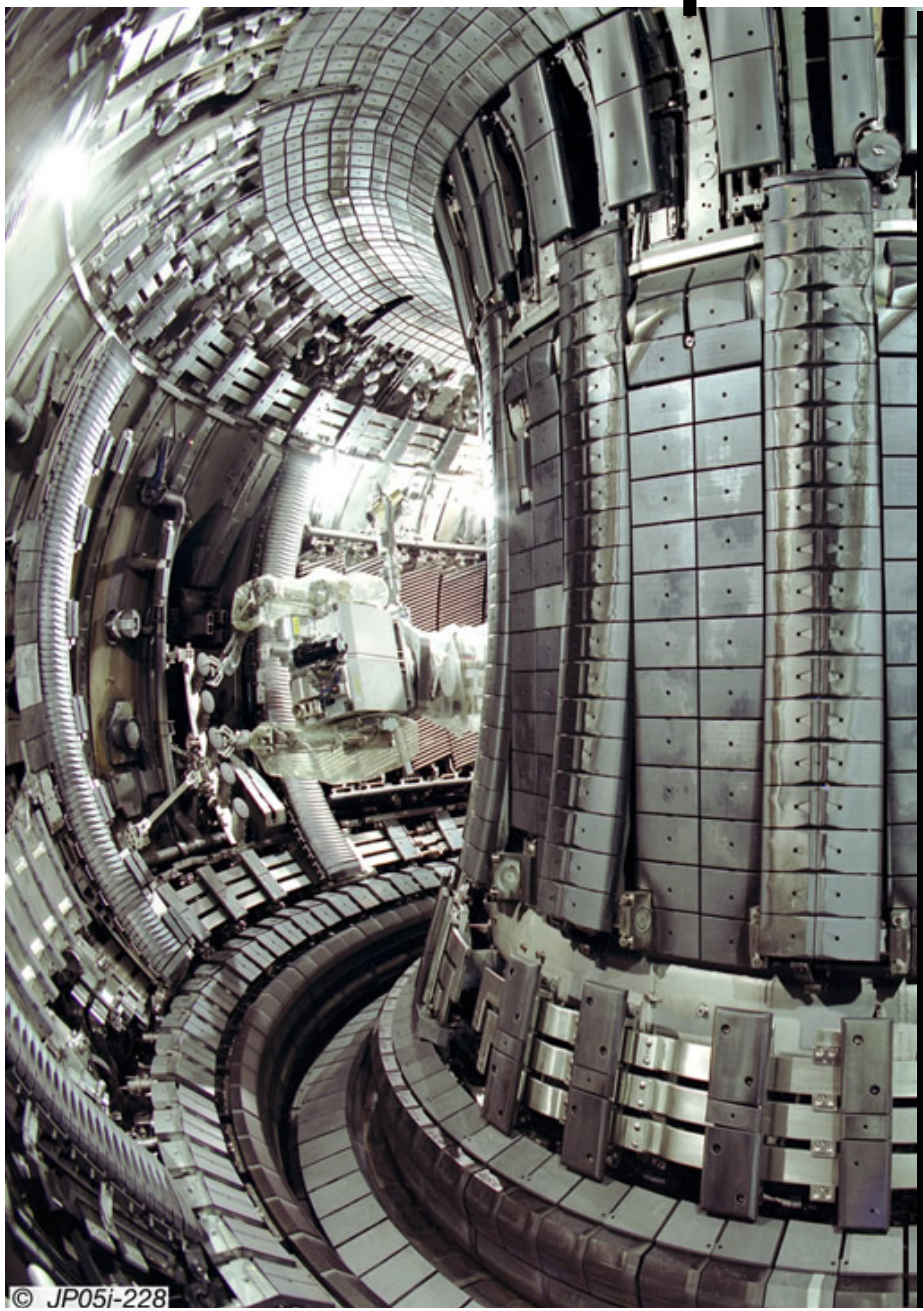


Joint European Torus (JET)



ITER

The Joint European Torus (JET)



Fusion power has been produced on JET

25MW of auxiliary power to heat the plasma

Challenge 1: Confine a plasma

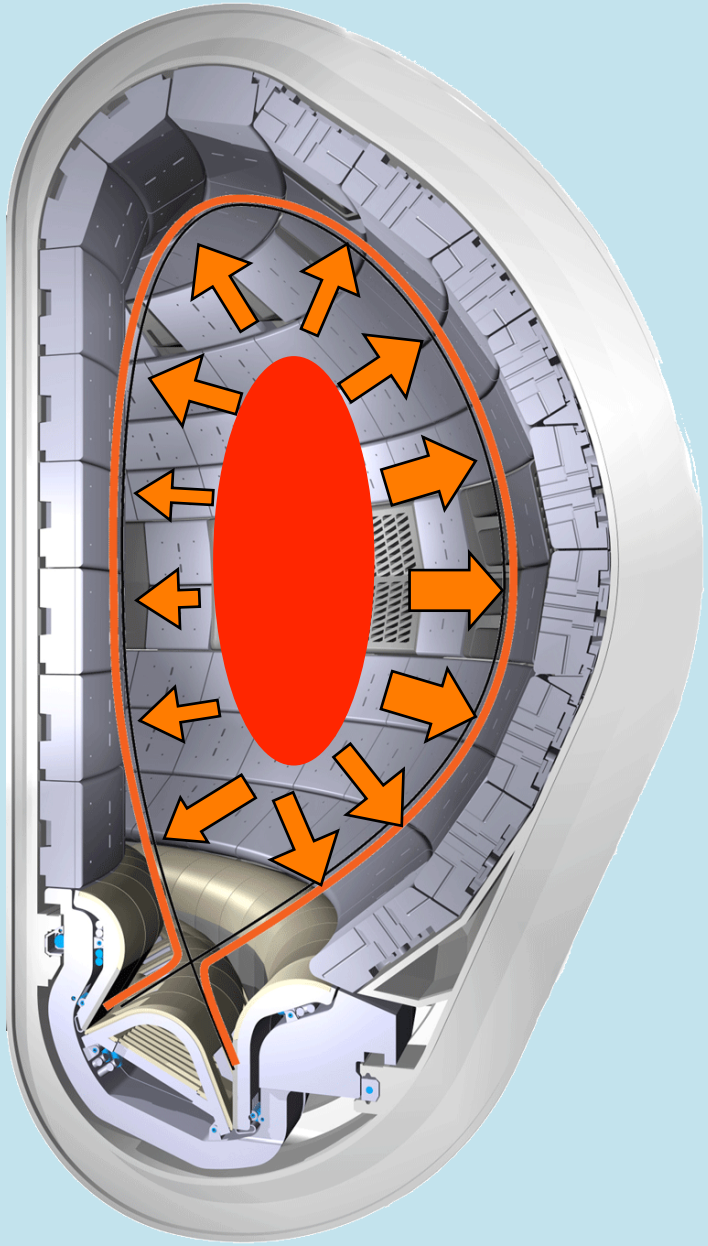
Achieved!

What do we need to make a power plant?

Challenge 2: Reduce the energy losses

Code: **GYRO**

Authors: Jeff Candy and Ron Waltz

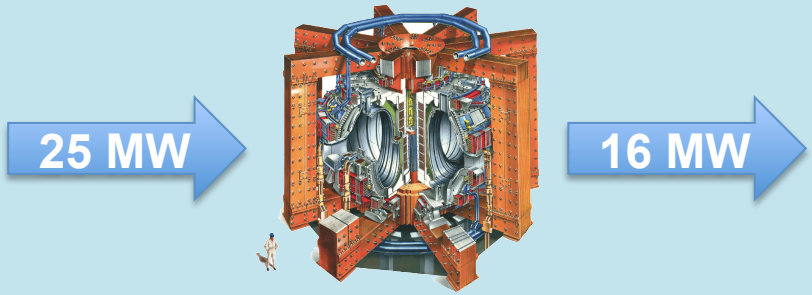


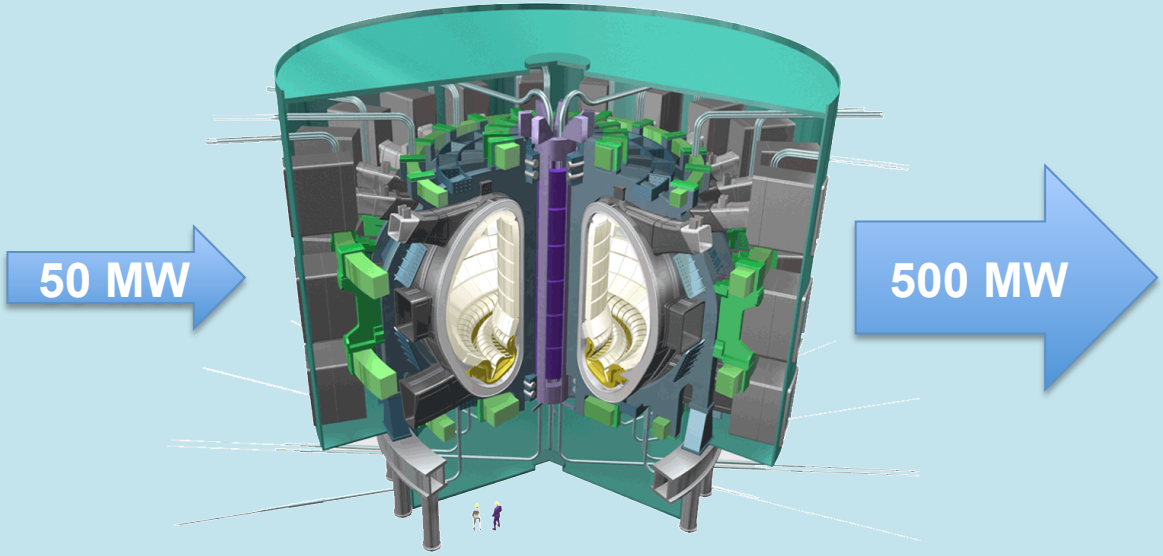
Challenge 2: Reduce the energy losses

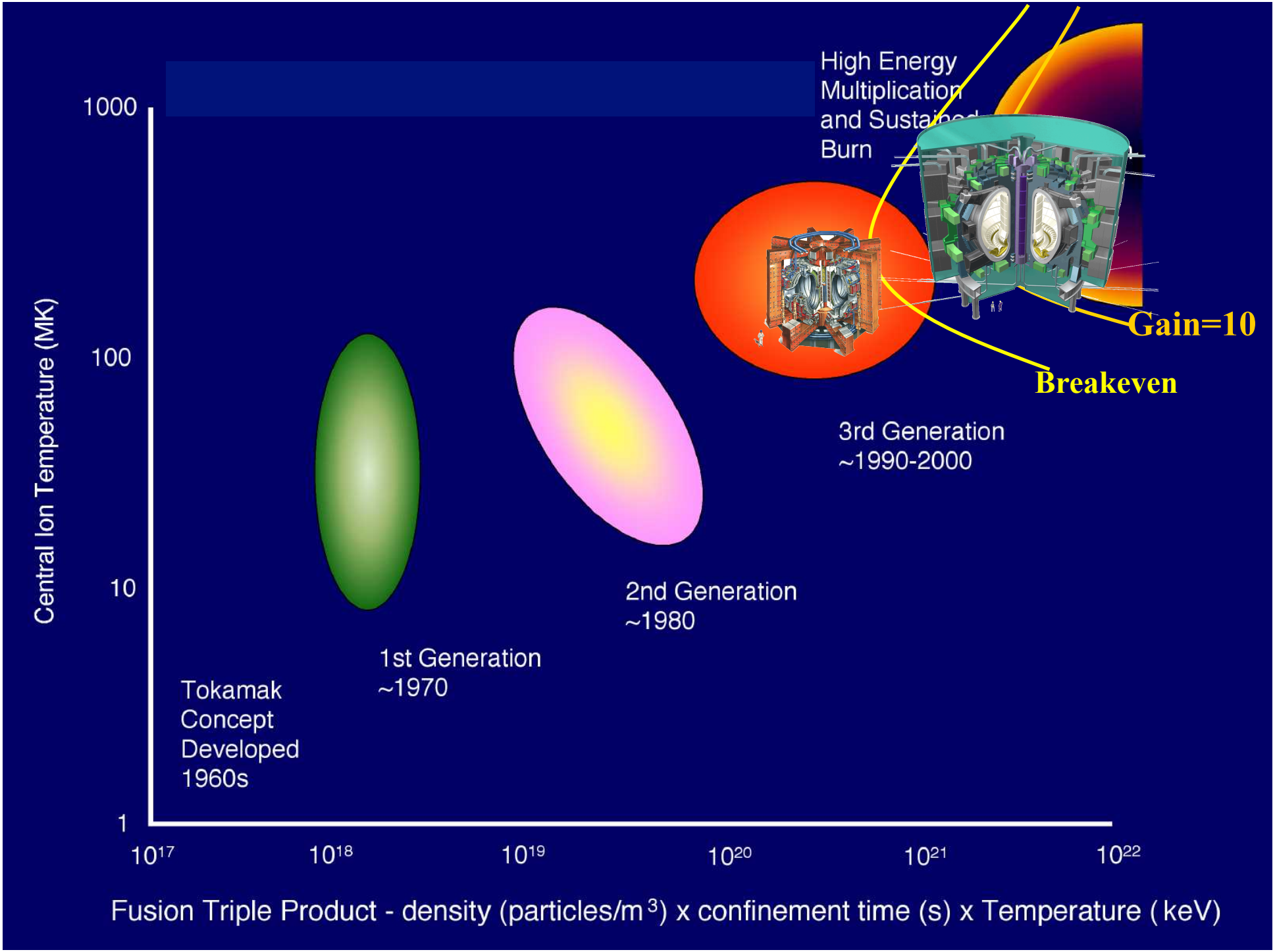
- Energy losses increase at most as the radius R of the device
- Fusion power increases as the volume ($\approx R^3$)

MAKE LARGER DEVICES

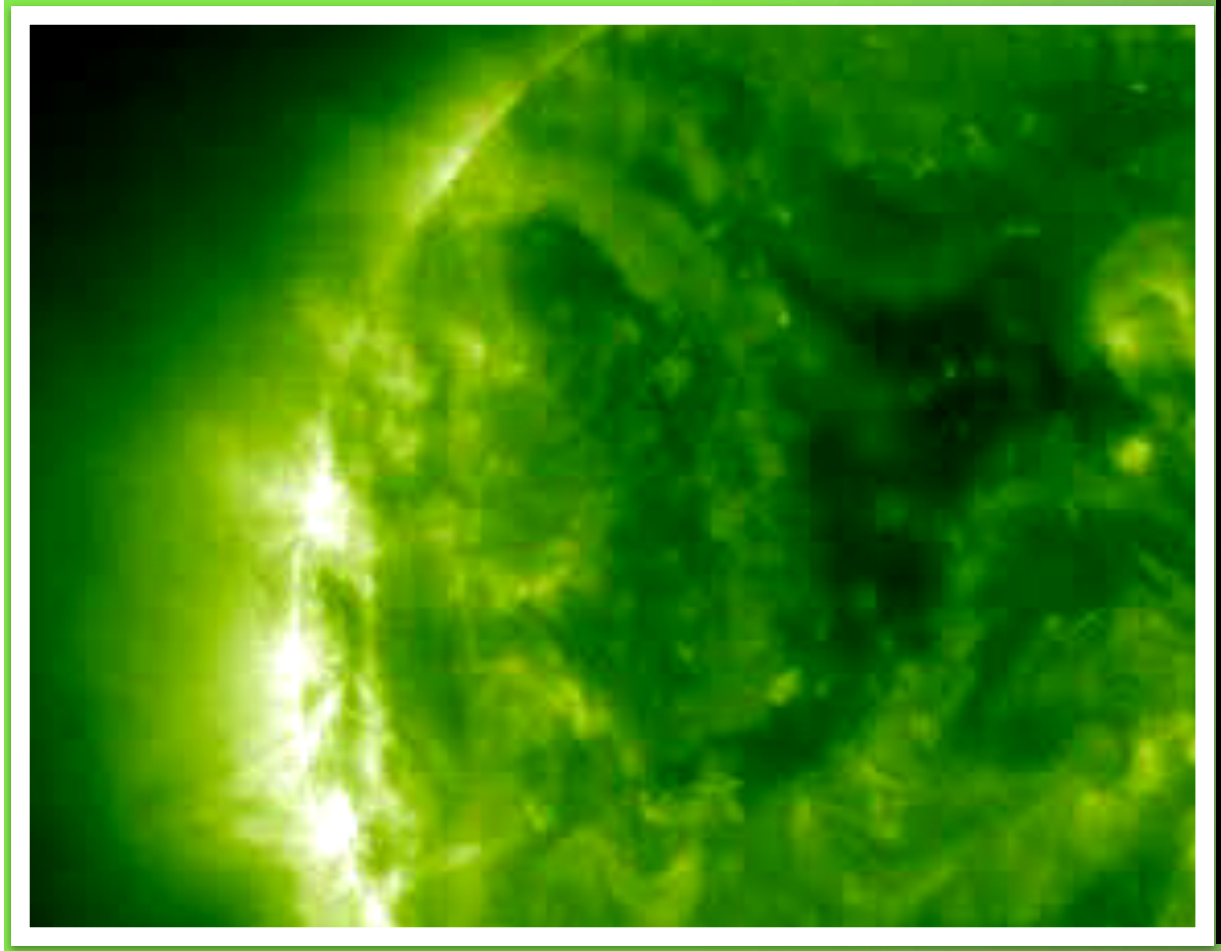
Challenge 2: Reduce the energy losses

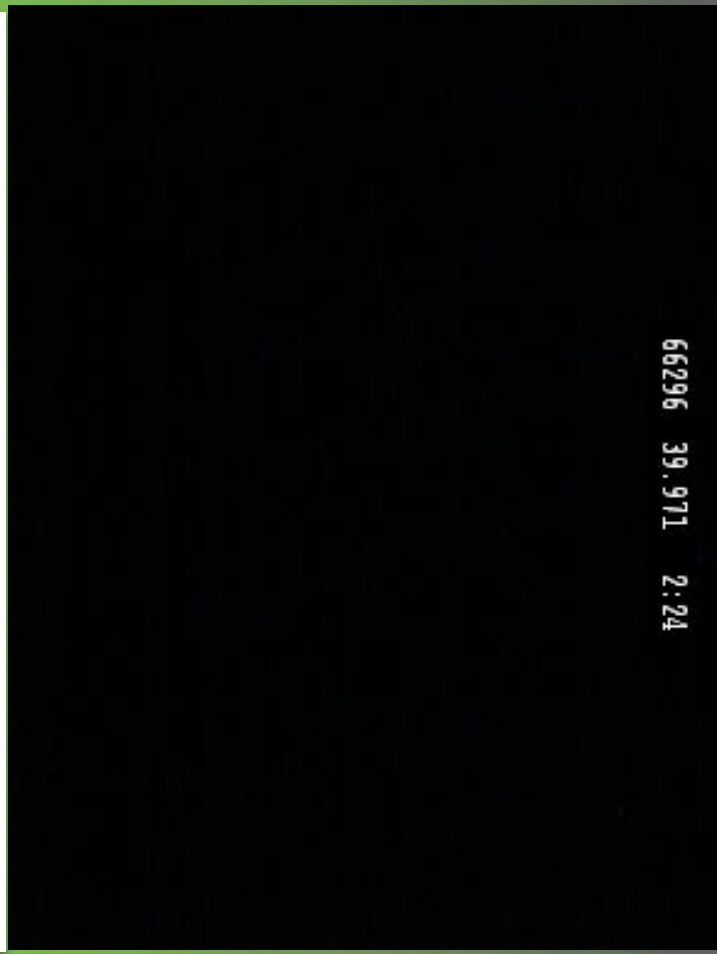





High Energy
Multiplication
and Sustained
Burn
Gain=10
Breakeven
3rd Generation
~1990-2000
2nd Generation
~1980
1st Generation
~1970
Tokamak
Concept
Developed
1960s
1000
100
10
1
Central Ion Temperature (MK)
10^17
10^18
10^19
10^20
10^21
10^22
Fusion Triple Product - density (particles/m^3) x confinement time (s) x Temperature (keV)

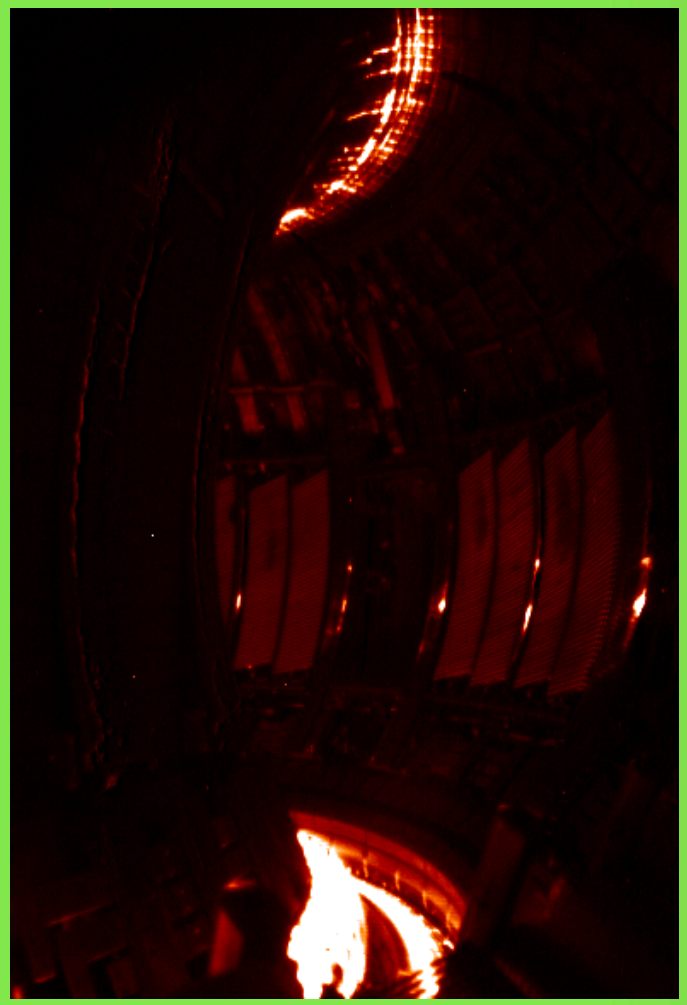
Challenge 3:
Control plasma instabilities

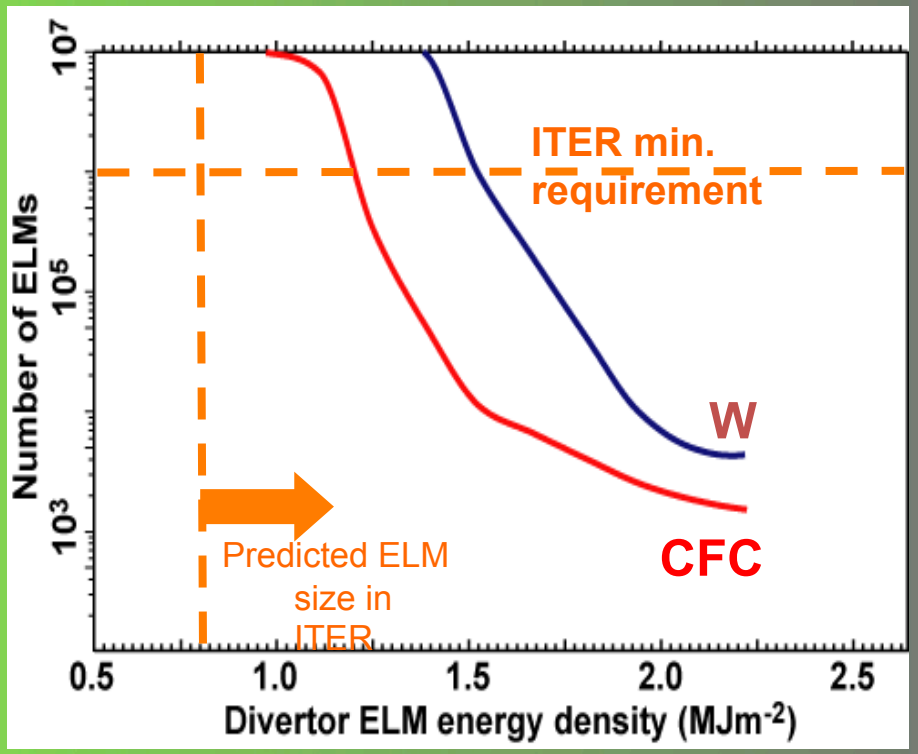




Challenge 3: Control plasma instabilities

- Edge pressure gradient lead to *Edge Localised Modes* (ELMs) that expel particles and produce large transient thermal loads

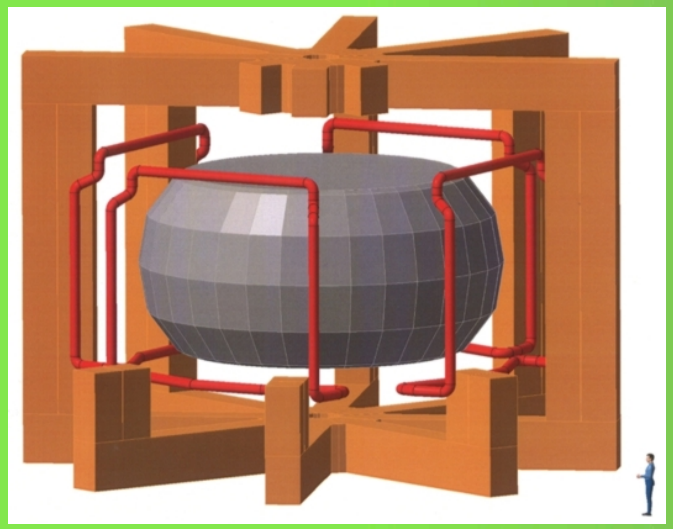


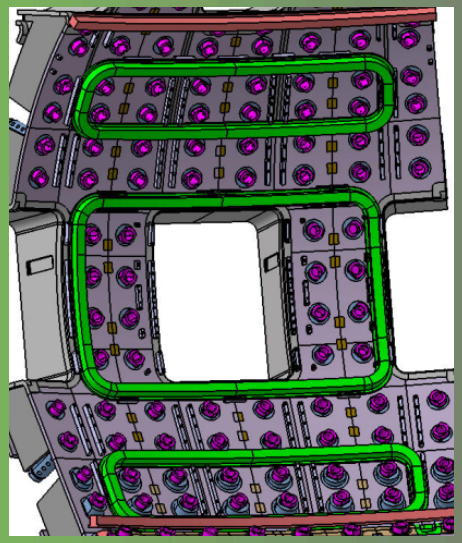


In ITER ELM loads of 1MJm^{-2} correspond to ELM losses <1% of energy stored in the plasma

Challenge 3: Control plasma instabilities

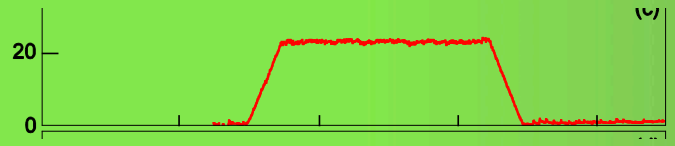
JET



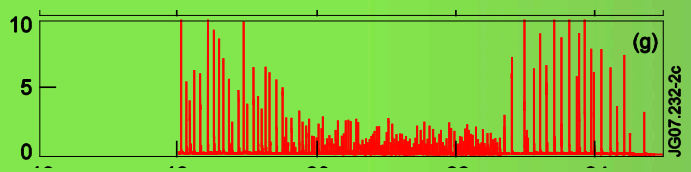


ITER

Coil current

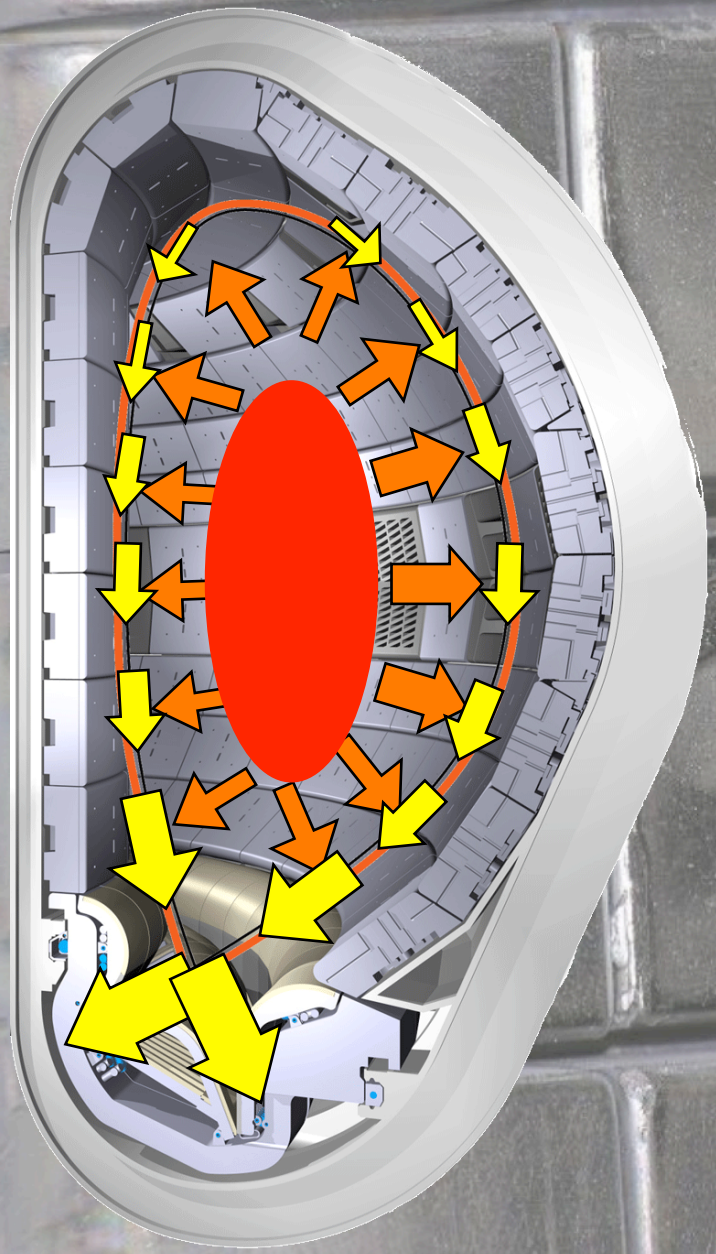


ELM amplitude

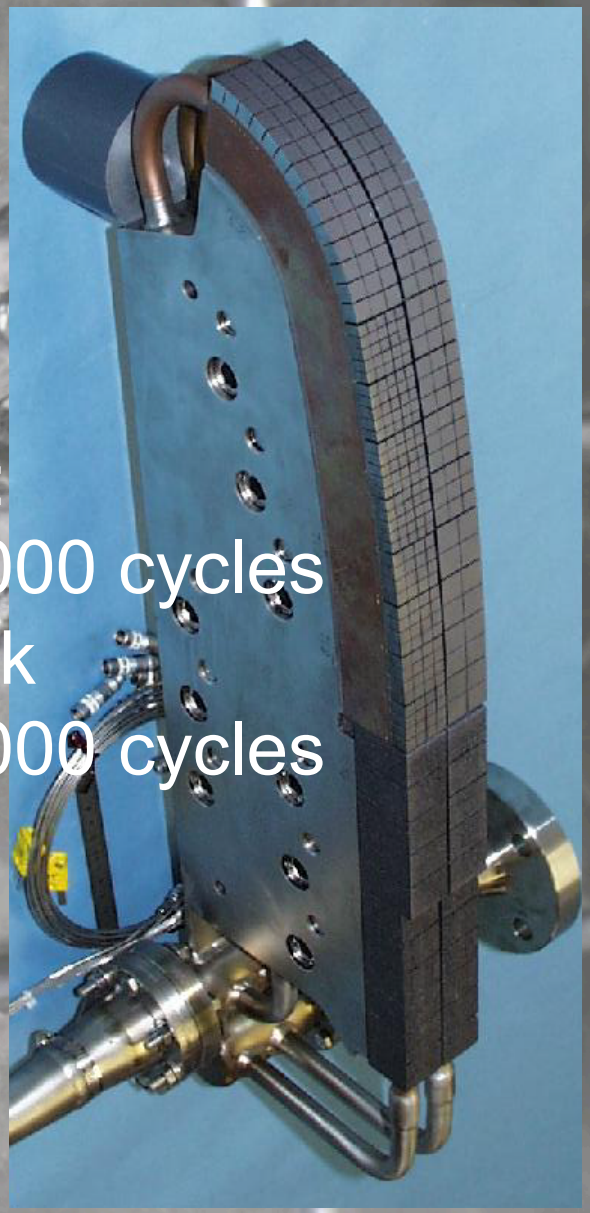


time

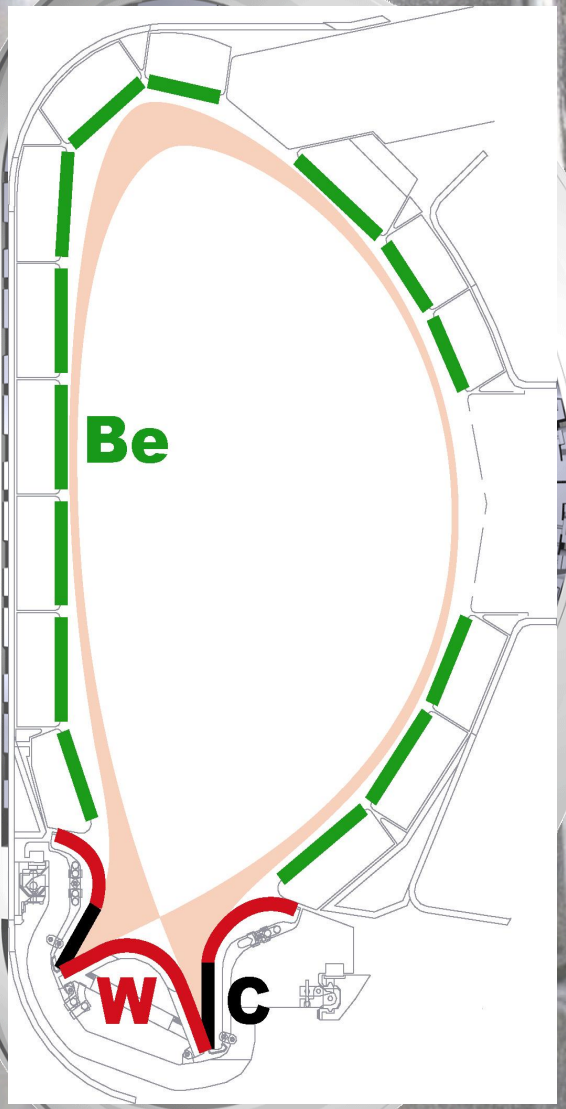
Challenge 4: Develop heat resistant materials



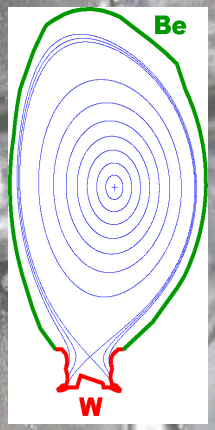
W macrobrush:
15 MW/m^2 x 1000 cycles
CFC monoblock
20 MW/m^2 x 2000 cycles



Challenge 4: Develop heat resistant materials



ITER



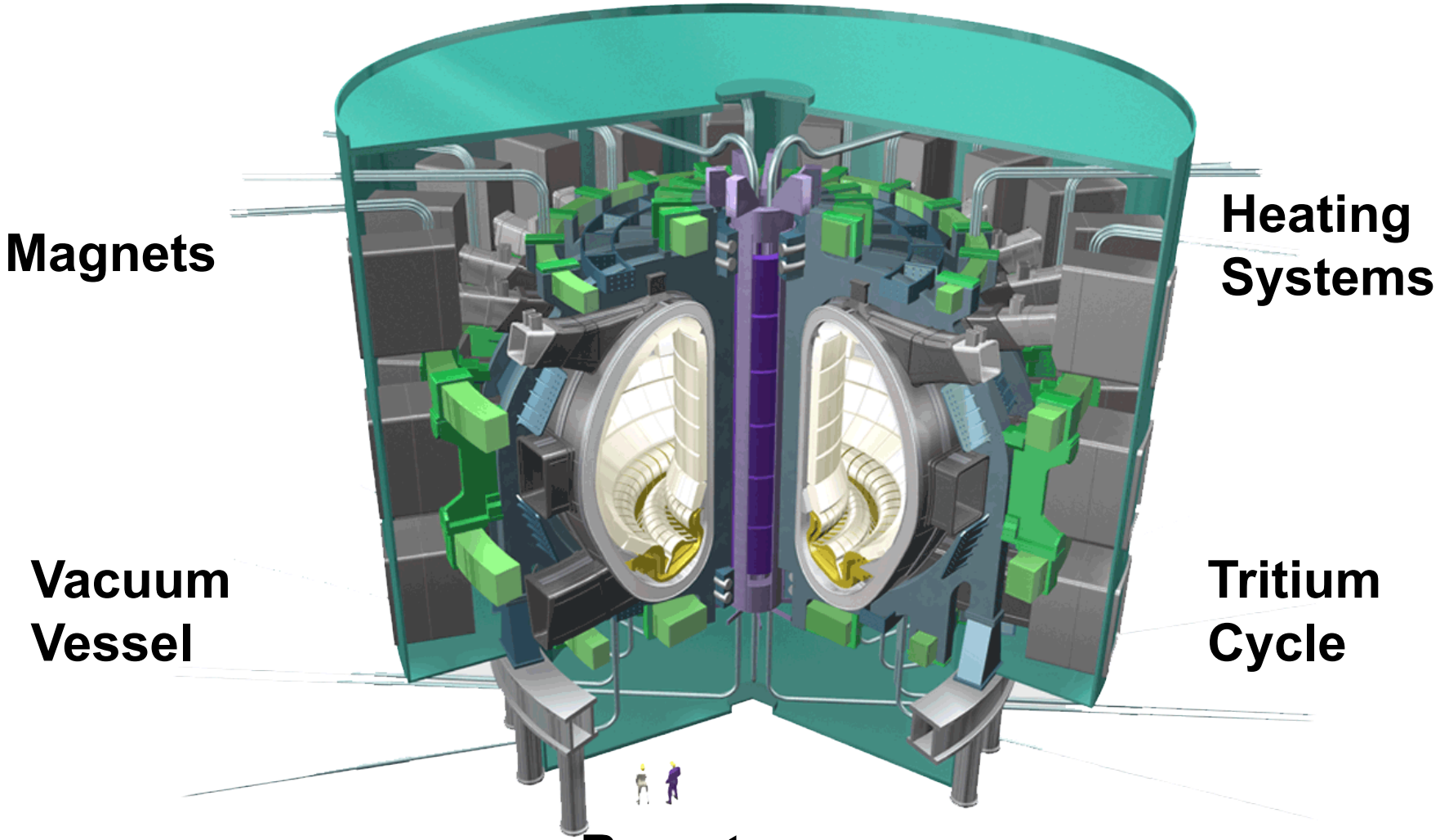
JET

Challenge 4: Develop heat resistant materials

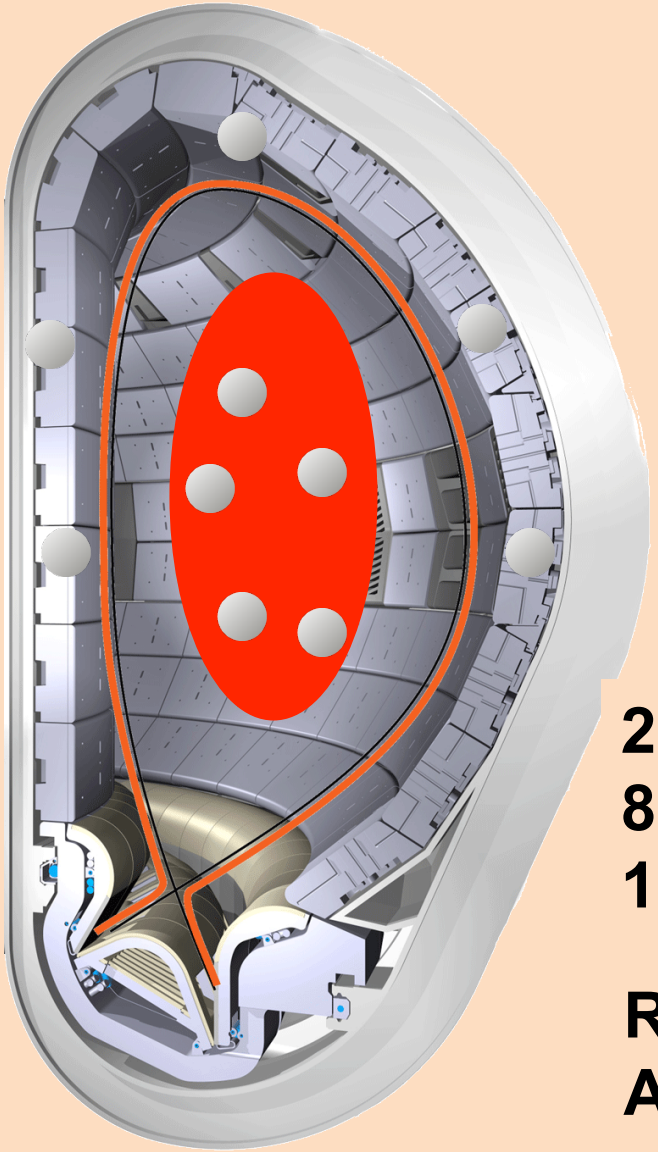
W or W-alloys foreseen for plasma facing components in reactor to avoid erosion problem

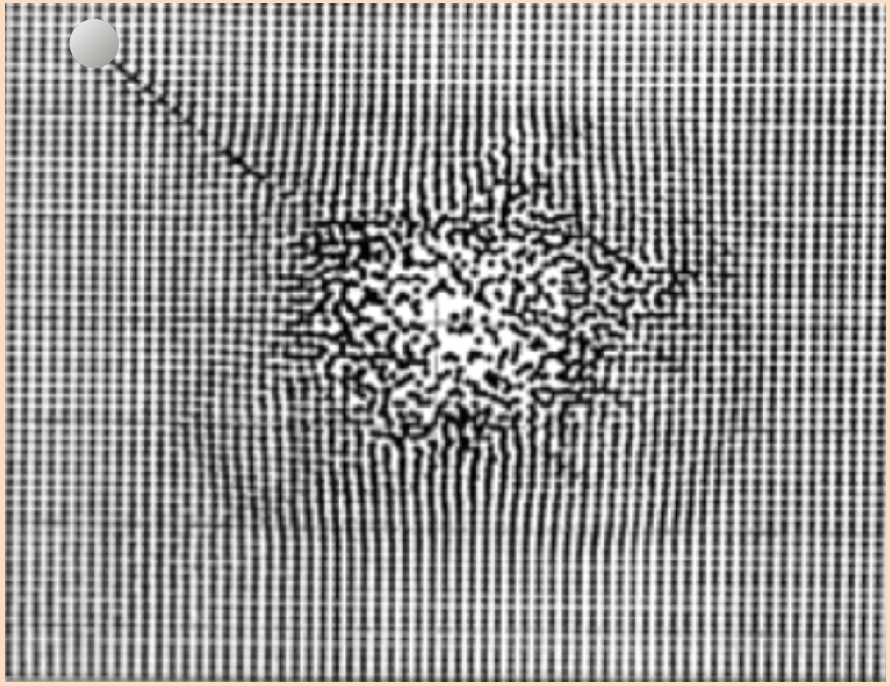
Additional R&D required if Helium is used as coolant instead of water

Challenge 5: Deal with complexity



Challenge 6: Deal with neutrons bombardment





2 displacements per atom (dpa) in ITER
80 dpa in a DEMO reactor
150 dpa in a fusion plant

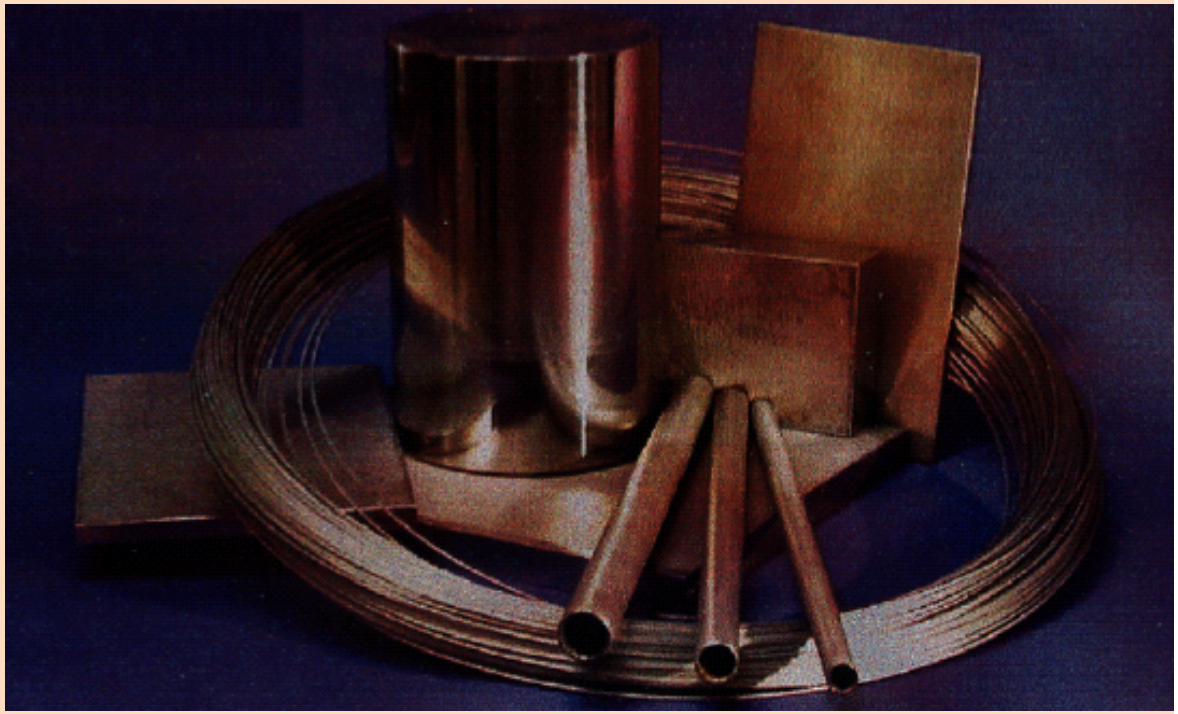
Reduction of structural properties
Activation

Not a problem for ITER but must be solved for DEMO reactor!

Challenge 6: Deal with neutrons bombardment

Existing candidate:
Low activation EUROFER
Selected range of temperature (300/550°C)
Tested in fission reactors up to 60 dpa

Advanced materials
ODS steels (650°C)
SiC/SiC (≈1000°C)



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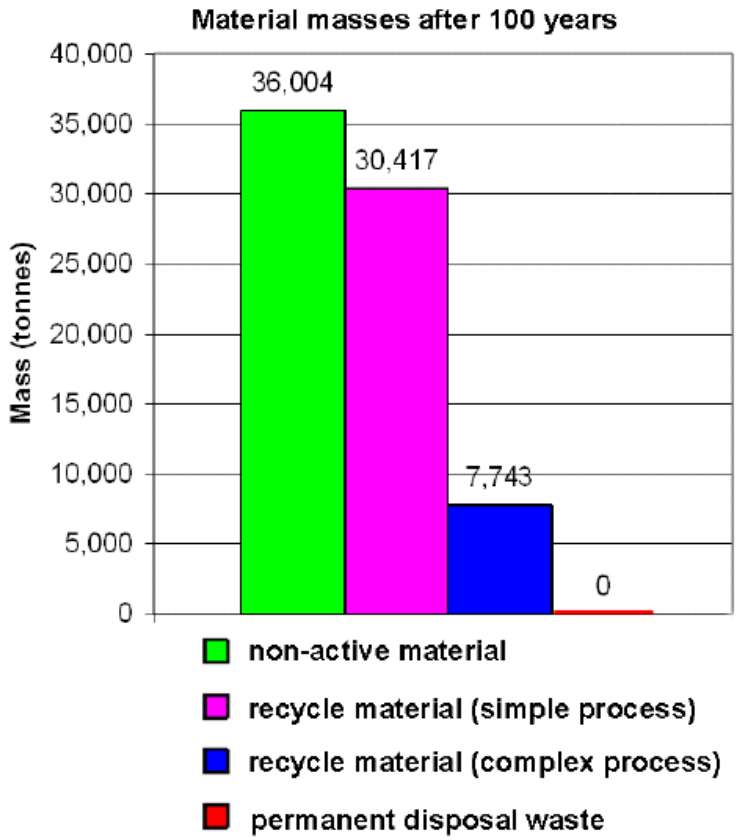
Advanced materials
ODS steels (650°C)
SiC/SiC (≈1000°C)

Activation falls 10000 times after 100 years
No need for permanent waste repository

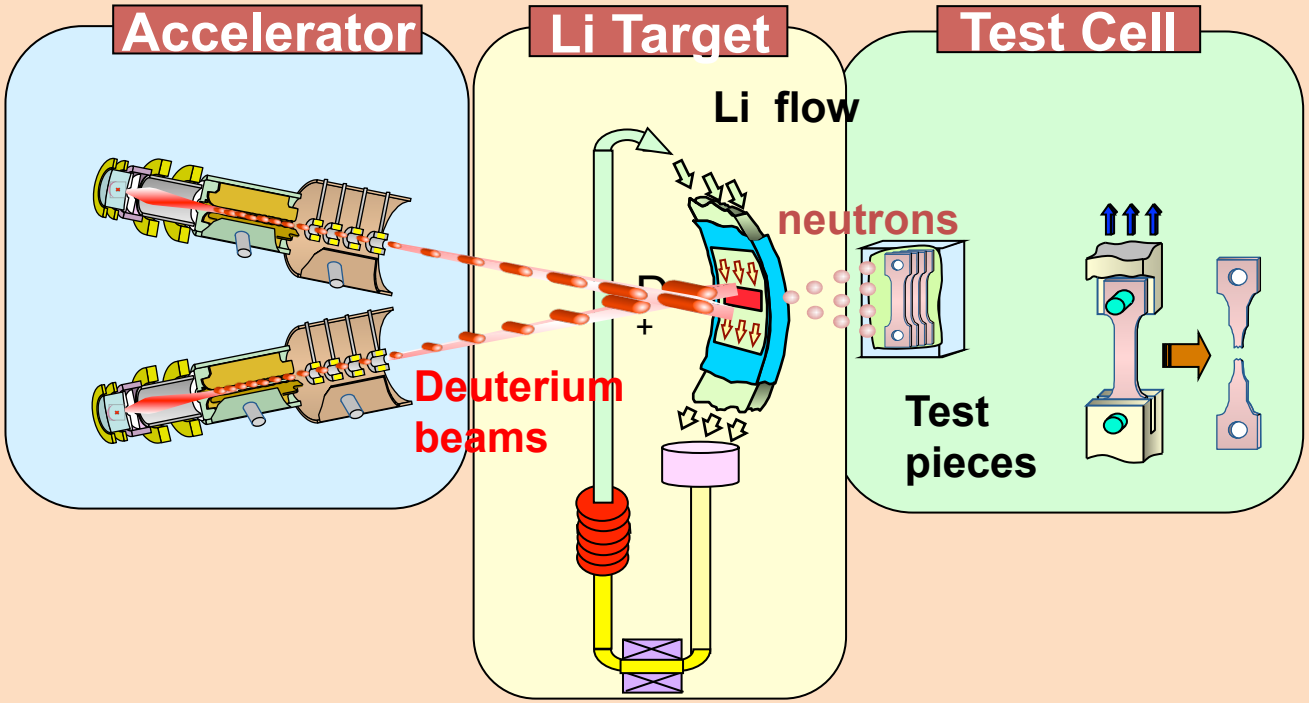


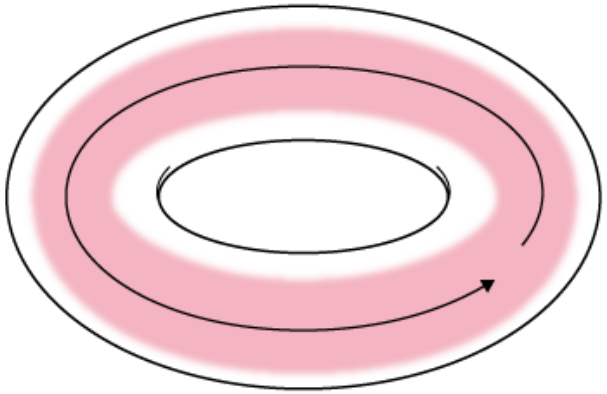
Challenge 6: Deal with neutrons bombardment

QUALIFICATION OF MATERIALS FOR DEMO REACTOR REQUIRES A DEDICATED FACILITY PRODUCING THE RELEVANT NEUTRON SPECTRUM

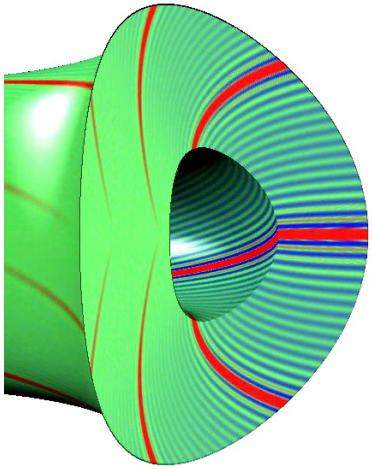
⇓

INTERNATIONAL FUSION MATERIAL IRRADIATION FACILITY (IFMIF)

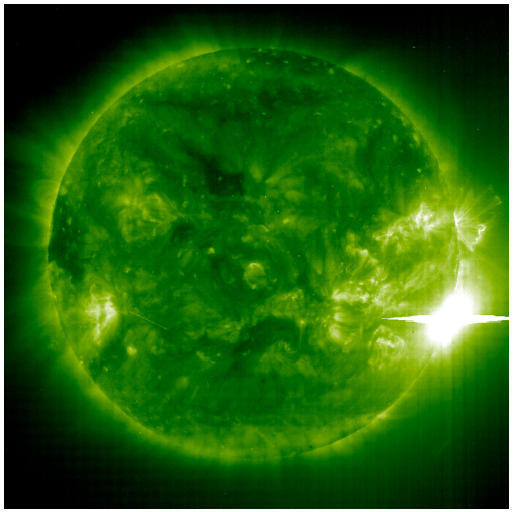




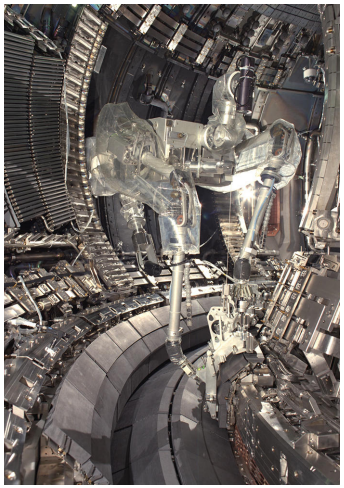
Confinement: done



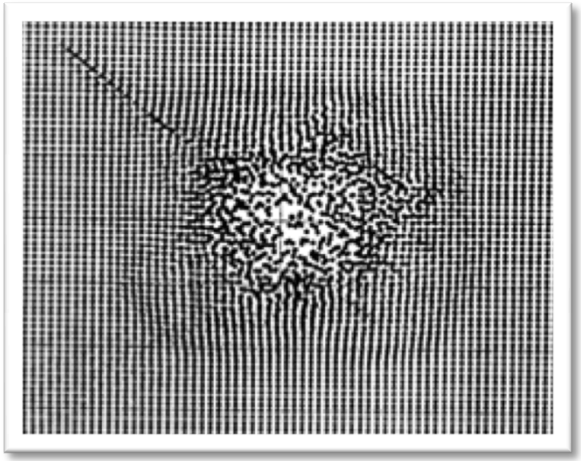
Turbulence: ITER



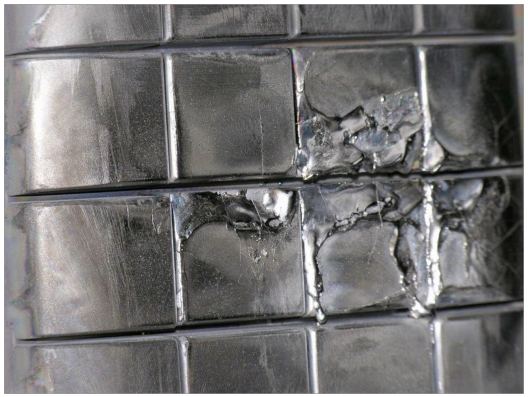
Instabilities: ITER



Complexity: ITER



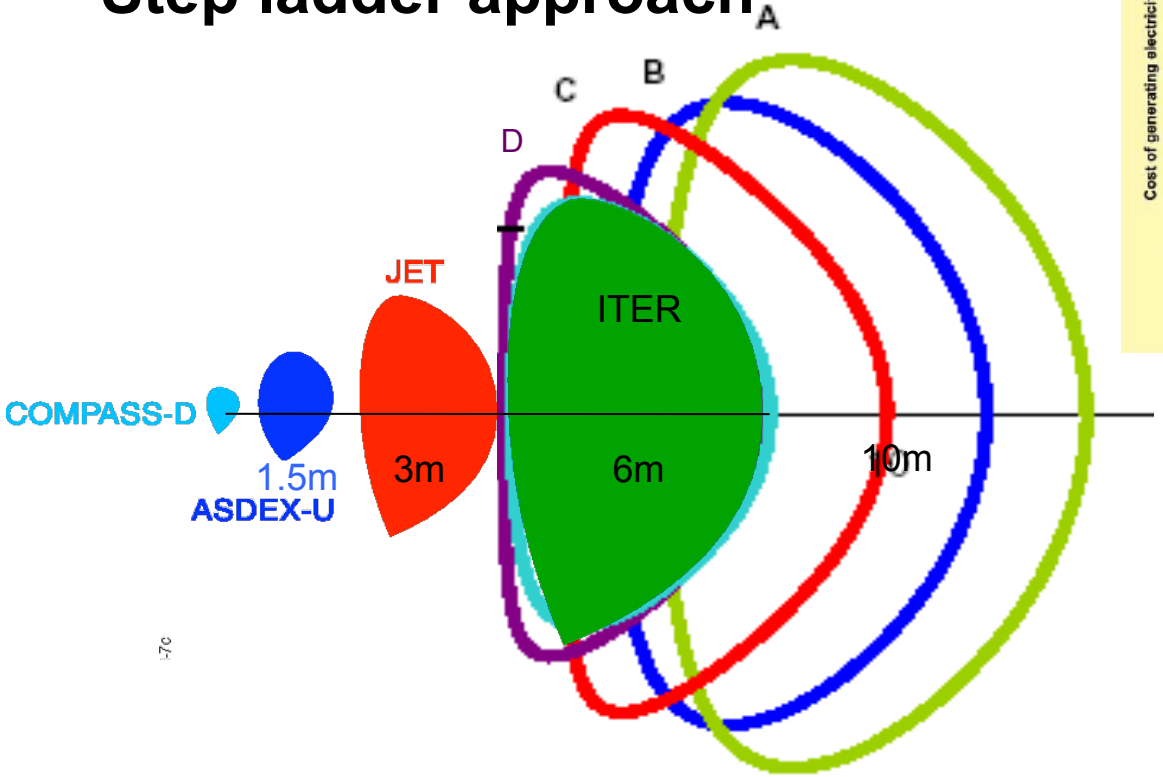
Neutron resistant materials: IFMIF

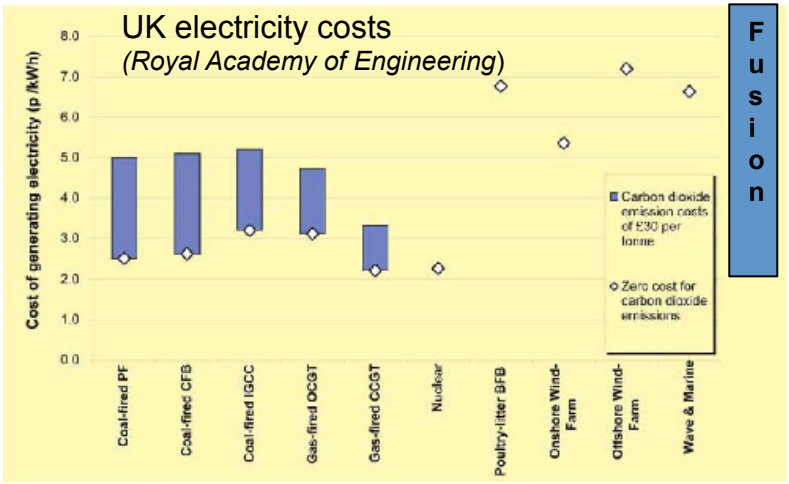


Heat resistant materials: ITER

Fusion Power Plant

Step ladder approach



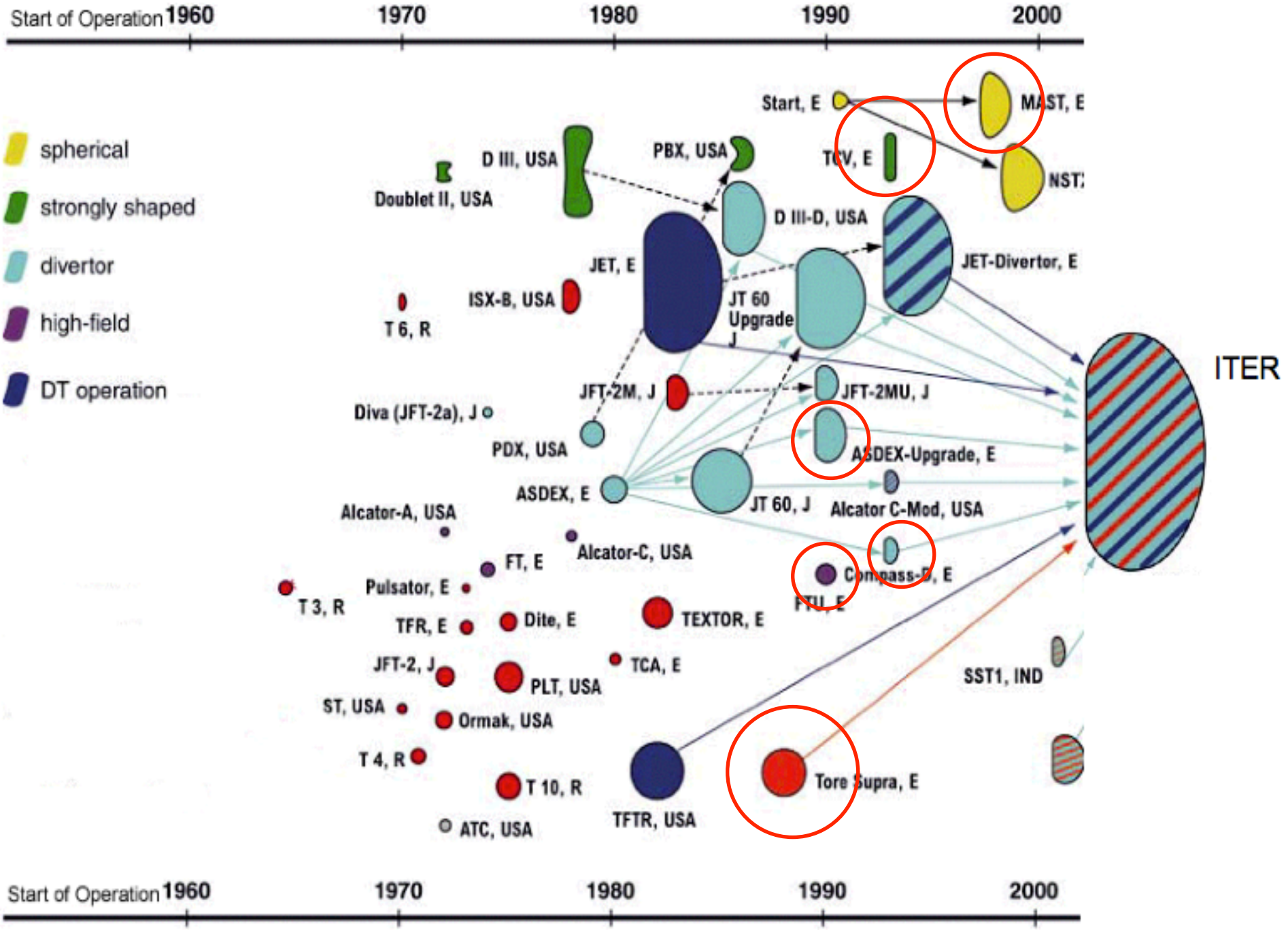


Cost of electricity from fusion expected to be competitive with other sources (IEA Levelised Cost Approach)

ITER is a moderate extrapolation from JET (x2)

The Power Plant (1.5GWe) expected to be a moderate extrapolation from ITER (x1-1.5) depending on the assumptions on physics and technology solutions (A=conservative; D=advanced)

EFDA Power Plant Conceptual Study


Start of Operation
1960
1970
1980
1990
2000
spherical
strongly shaped
divertor
high-field
DT operation
Start, E
MAST, E
NST
TCV, E
D III, USA
PBX, USA
Doublet II, USA
D III-D, USA
JET, E
JET-Divertor, E
ISX-B, USA
JT 60 Upgrade J
T 6, R
JFT-2M, J
JFT-2MU, J
Diva (JFT-2a), J
PDX, USA
ASDEX-Upgrade, E
ASDEX, E
JT 60, J
Alcator C-Mod, USA
Alcator-A, USA
Alcator-C, USA
FT, E
Pulsator, E
T 3, R
TFR, E
Dite, E
TEXTOR, E
JFT-2, J
TCA, E
PLT, USA
SST1, IND
ST, USA
Ormak, USA
T 4, R
T 10, R
TFTR, USA
Tore Supra, E
ATC, USA
ITER

Coordinated approach to fusion research has addressed the challenges of fusion and developed and tested the solutions to be demonstrated in ITER.

EFDA is now launching a coordinated effort to the R&D for a fusion DEMOnstration reactor.