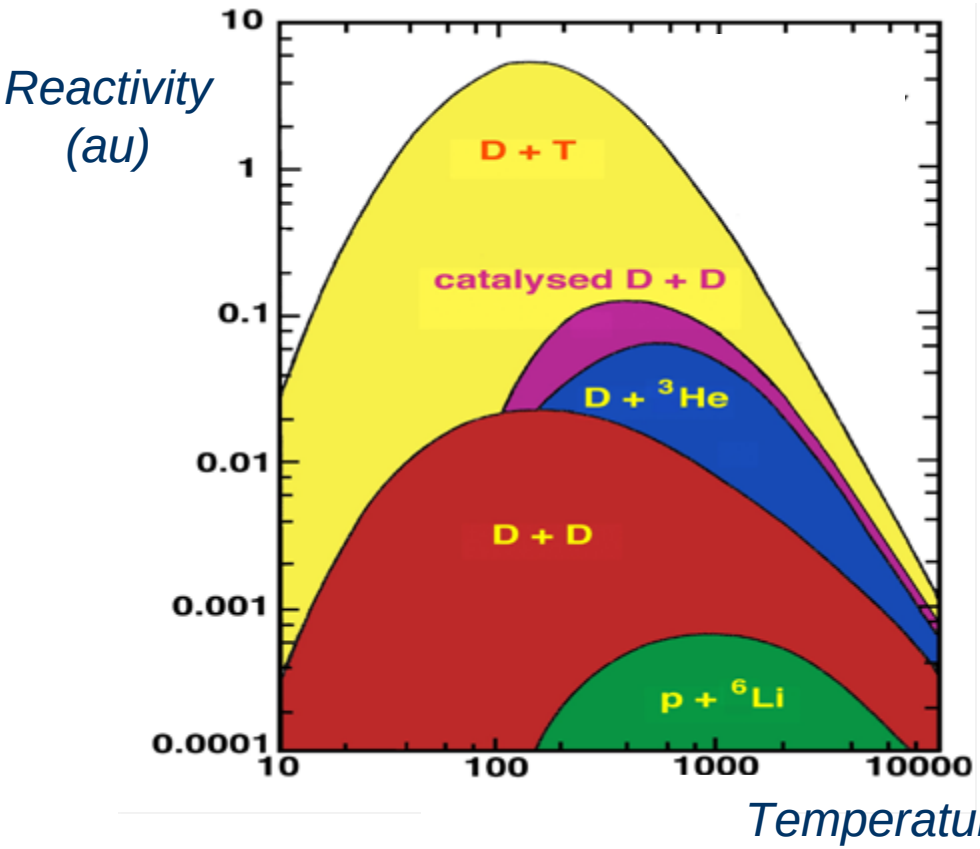

SOME LIKE IT HOT

Some like it hot…



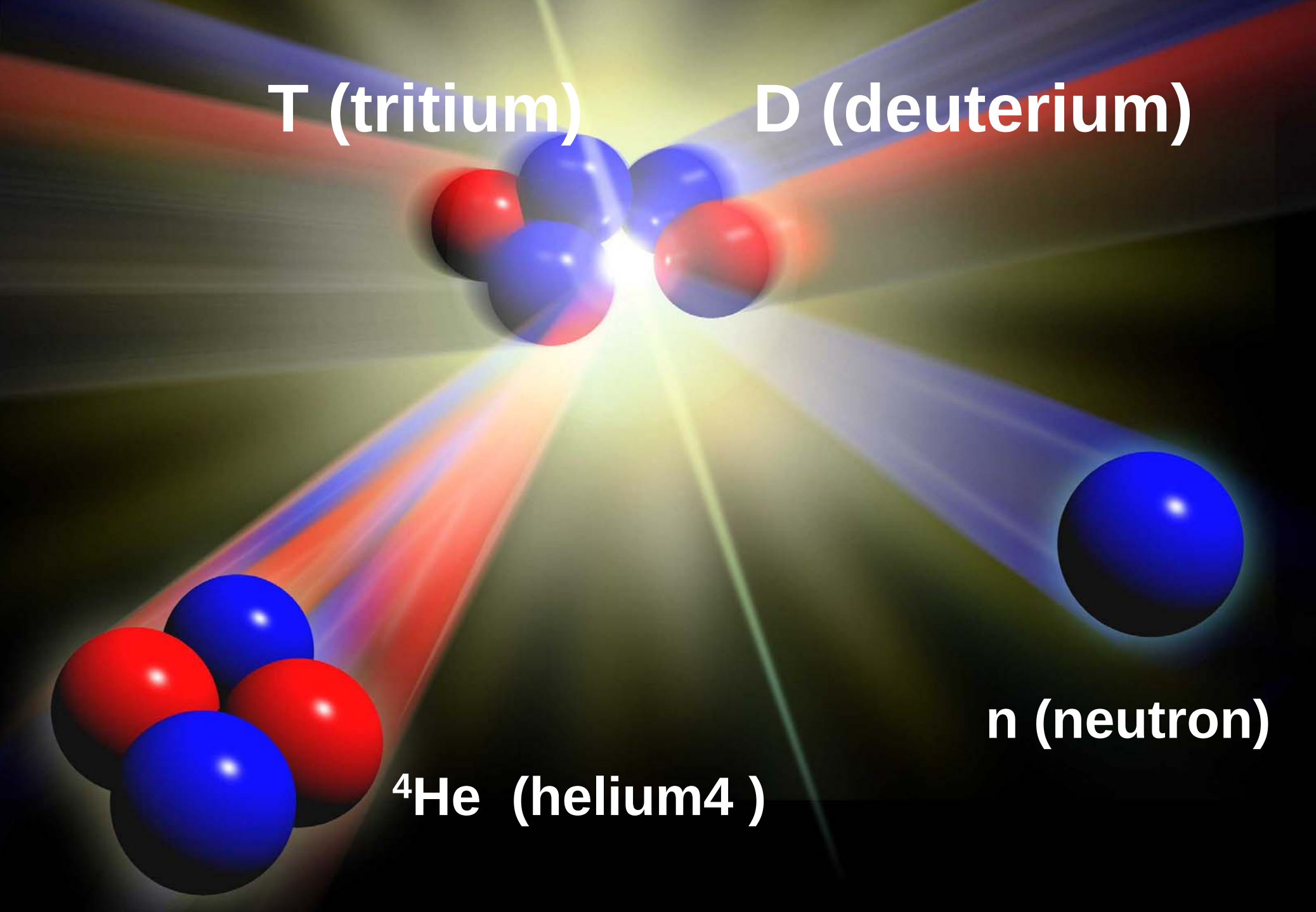
$$P\ (W/m^3) = n_1\ n_2\ \text{reactivity}\ E_{fusion} \sim\ p^2$$

deuterium / tritium

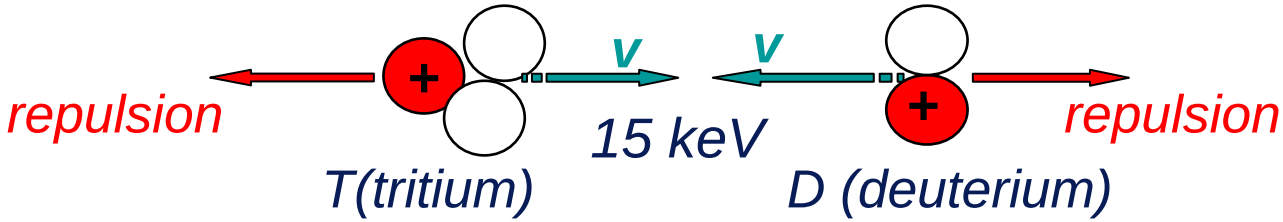
$T_{DT} \approx 150$ *millions K*

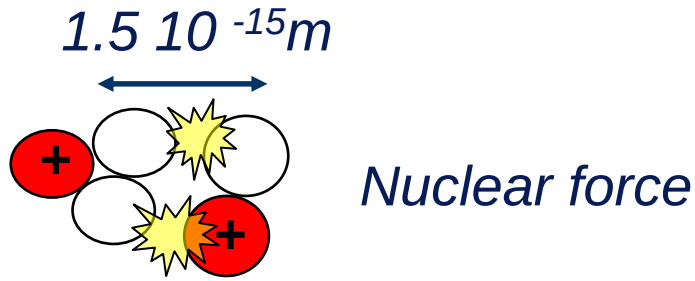
deuterium / deuterium or helium3

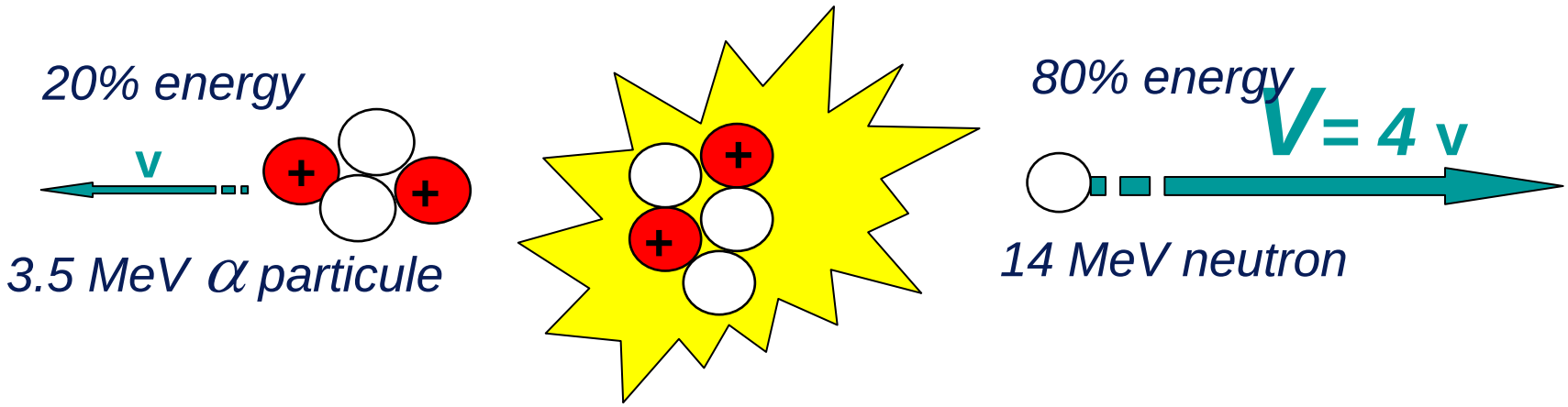
$T_{DD} \approx 700$ *millions K*

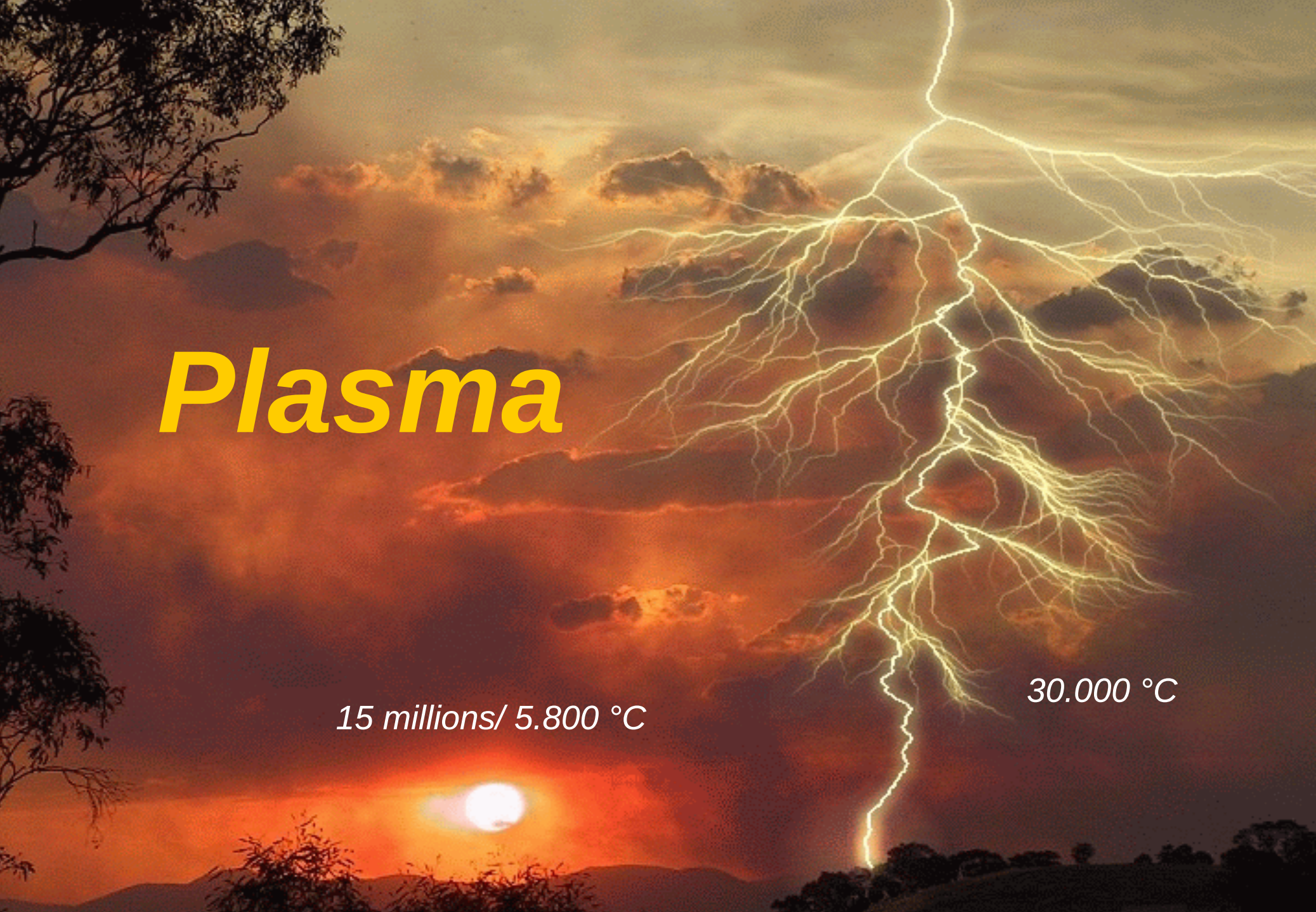

T (tritium)
D (deuterium)
n (neutron)
^{4}He (helium4)

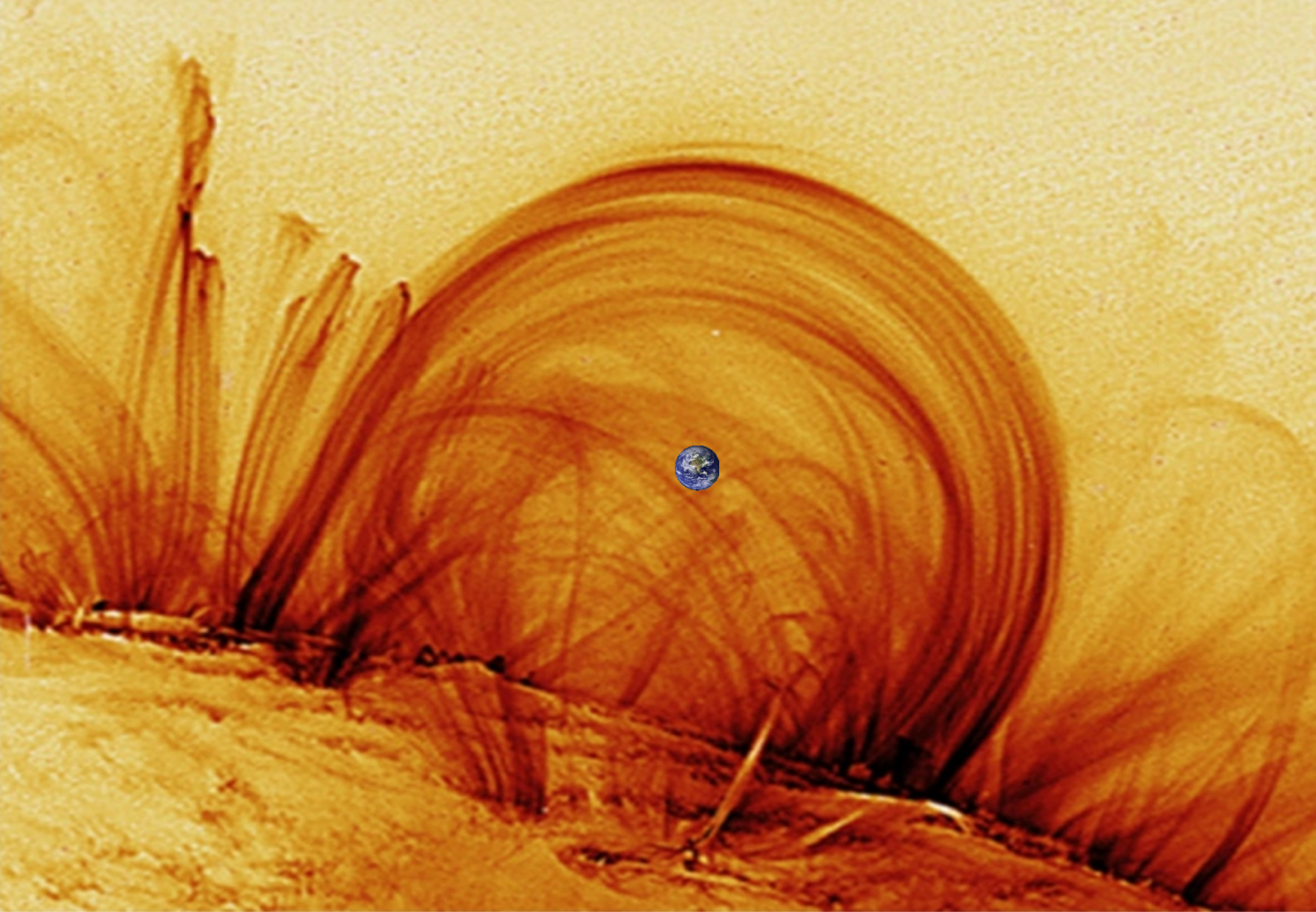
Deuterium tritium fusion



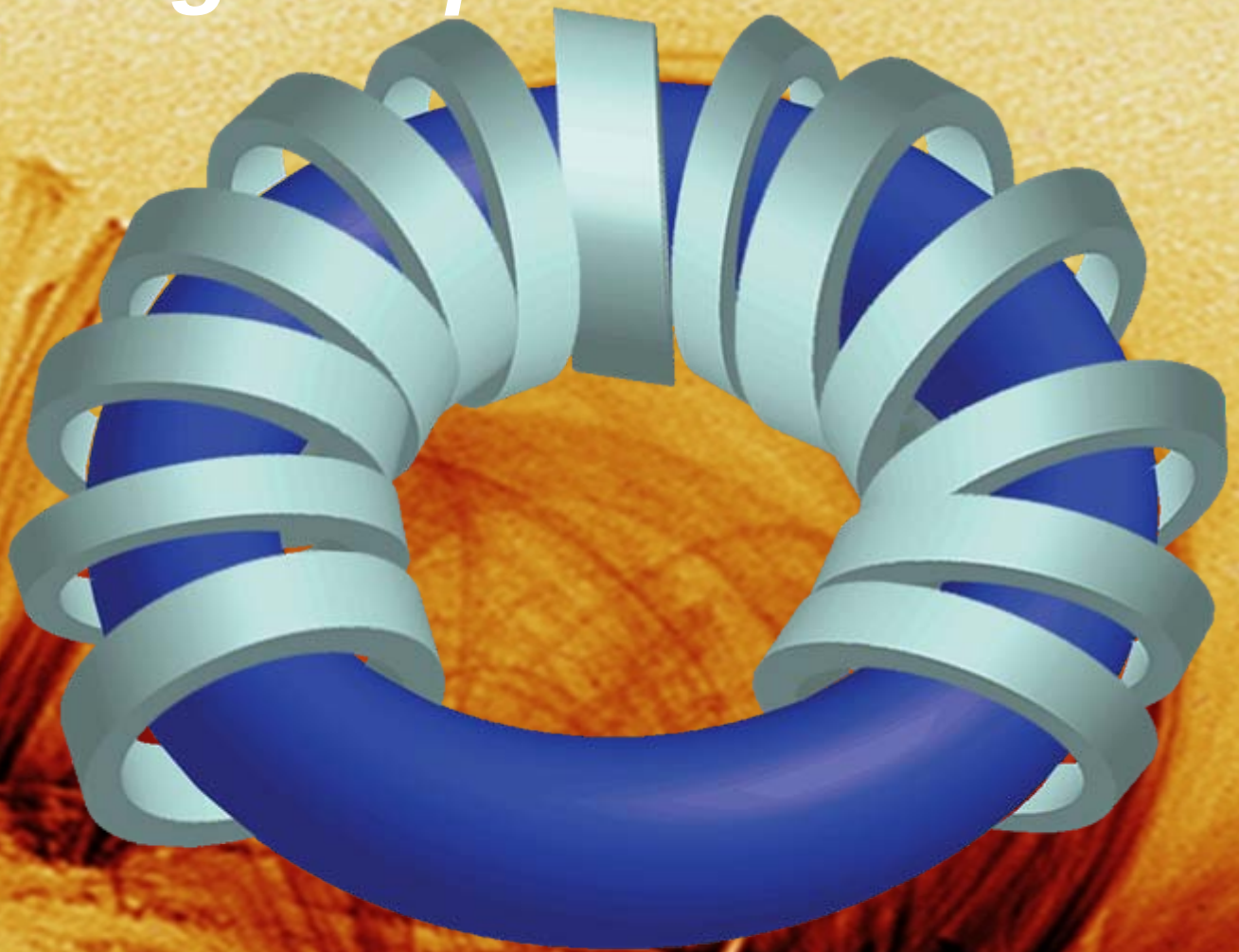




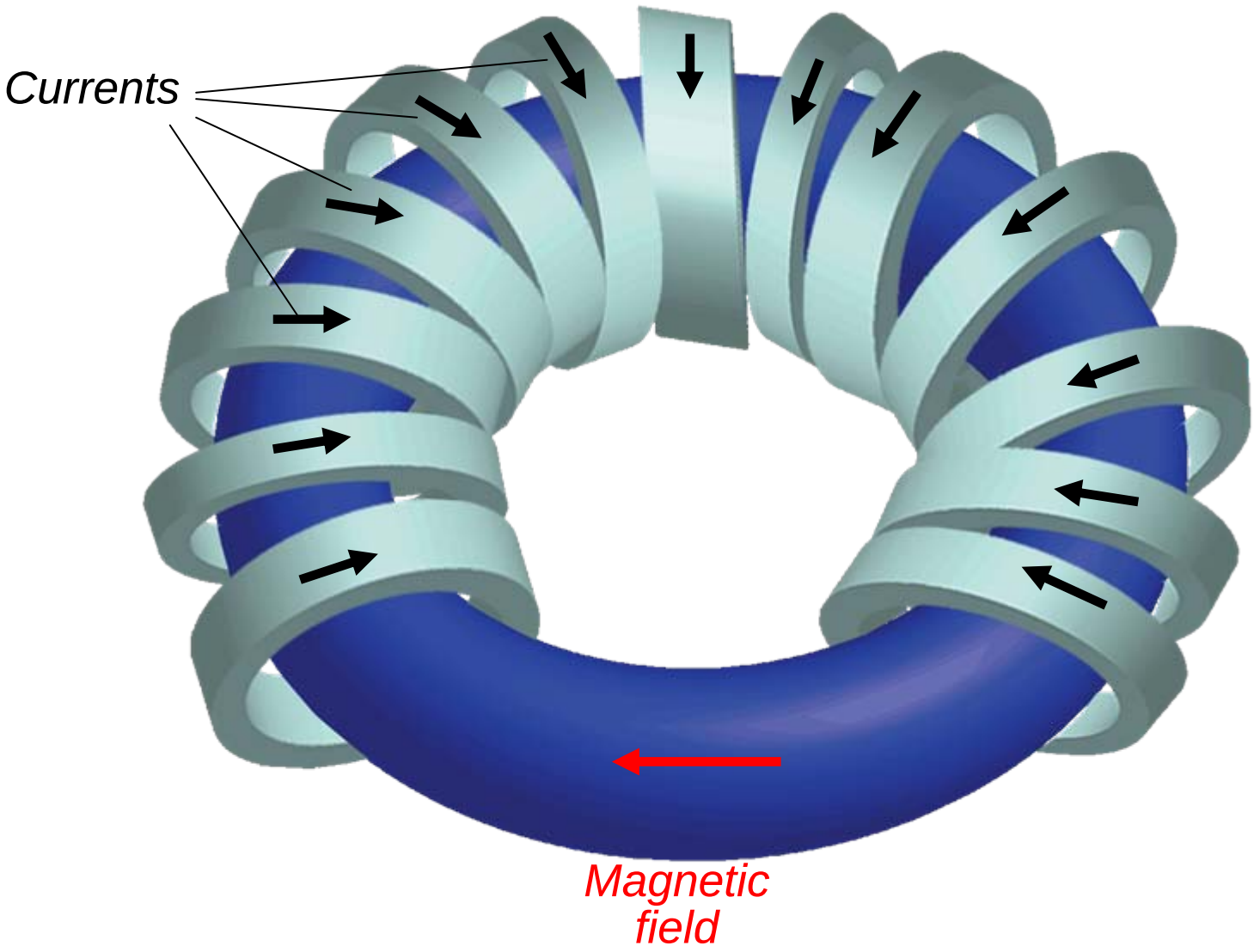

Plasma
15 millions/ 5.800 °C
30.000 °C



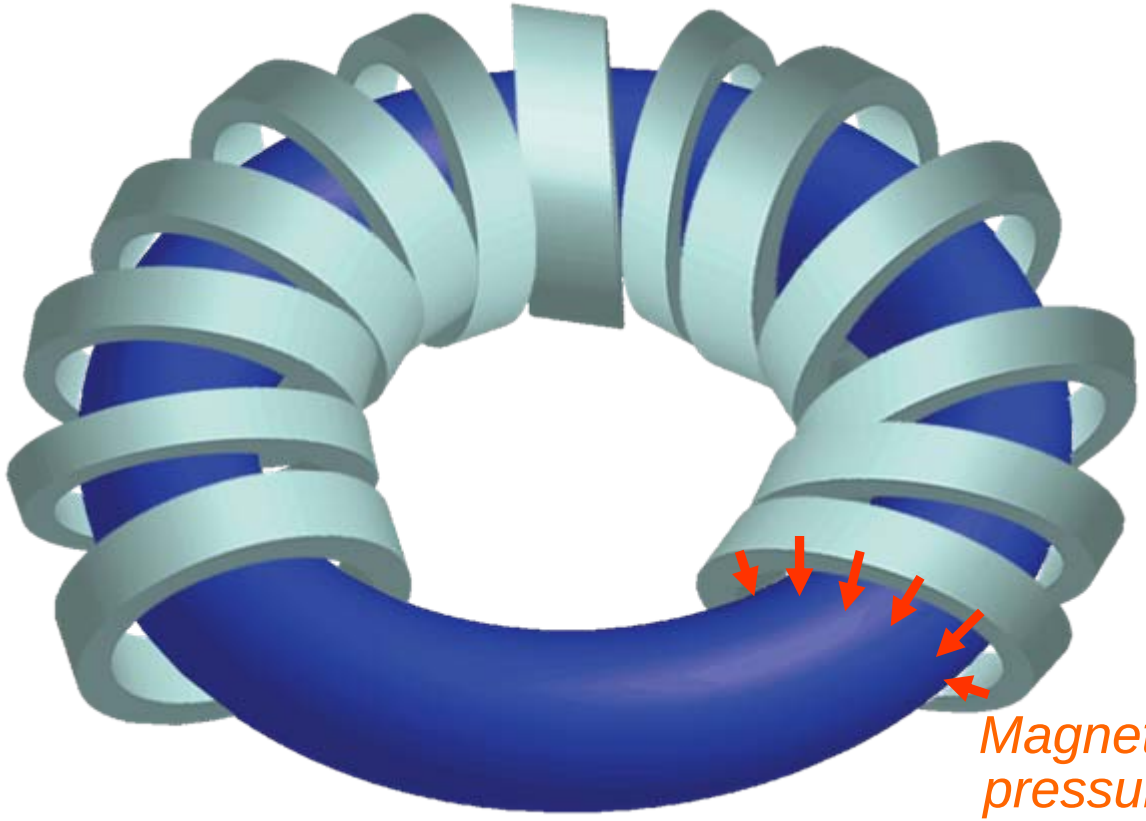
Fusion magnétique



A plasma torus confined by a magnetic field…



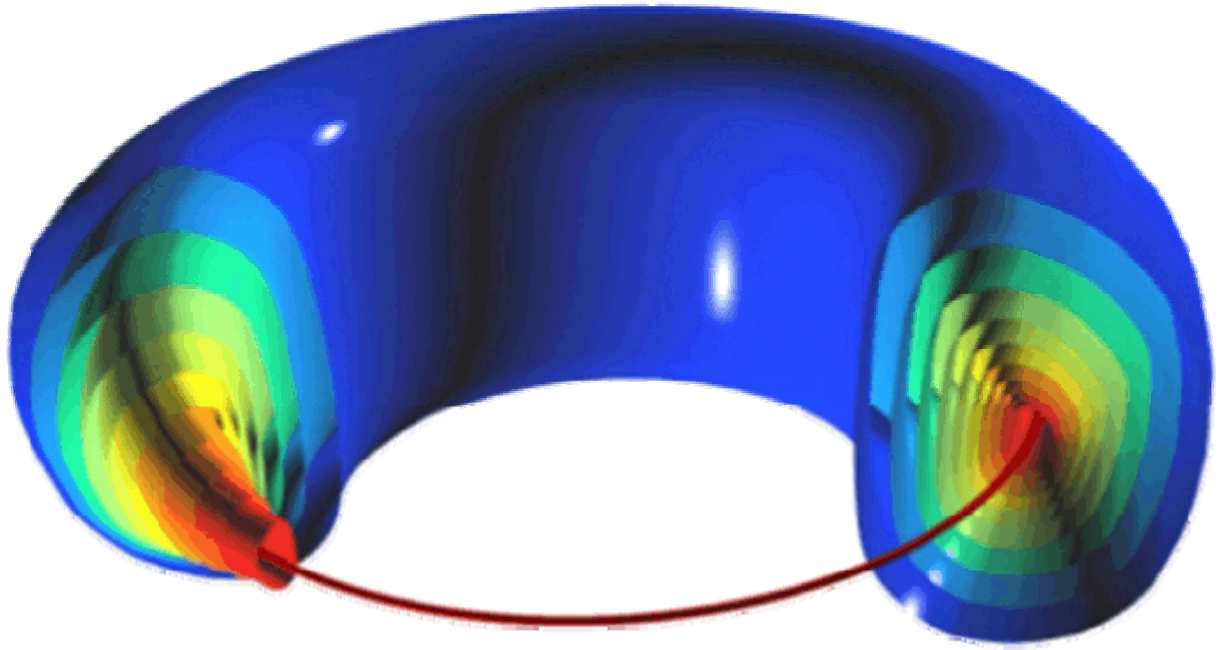
Pressure in a magnetic fusion plasma



maximum magnetic pressure ~ $B^2/2\mu_0$ ~ 100 atmospheres (B ~5T)

plasma pressure ~ few atmospheres

Cooling time of the plasma of a fusion reactor



Plasma core has to be "self-heated " by the high energy helium particles

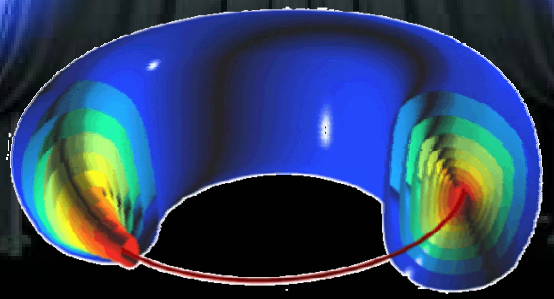
Heating power = helium fusion power (20% P_{fusion}) ~ MW/m^3

Losses = energy stored in the plasma / cooling time

energy stored in the plasma ~ atmospheres ~ MJ/m^3

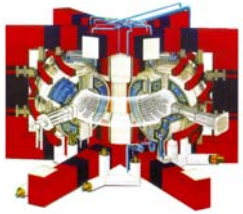
Cooling time of the plasma ~ second

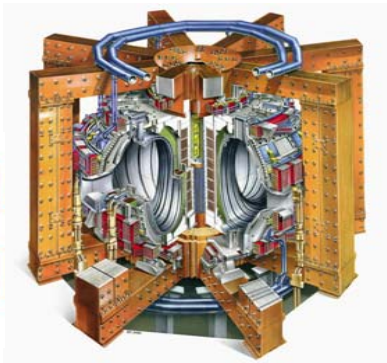
Parameters of magnetic fusion plasmas

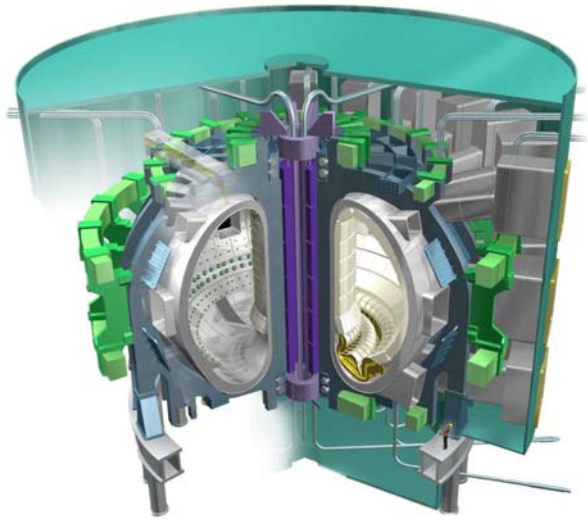


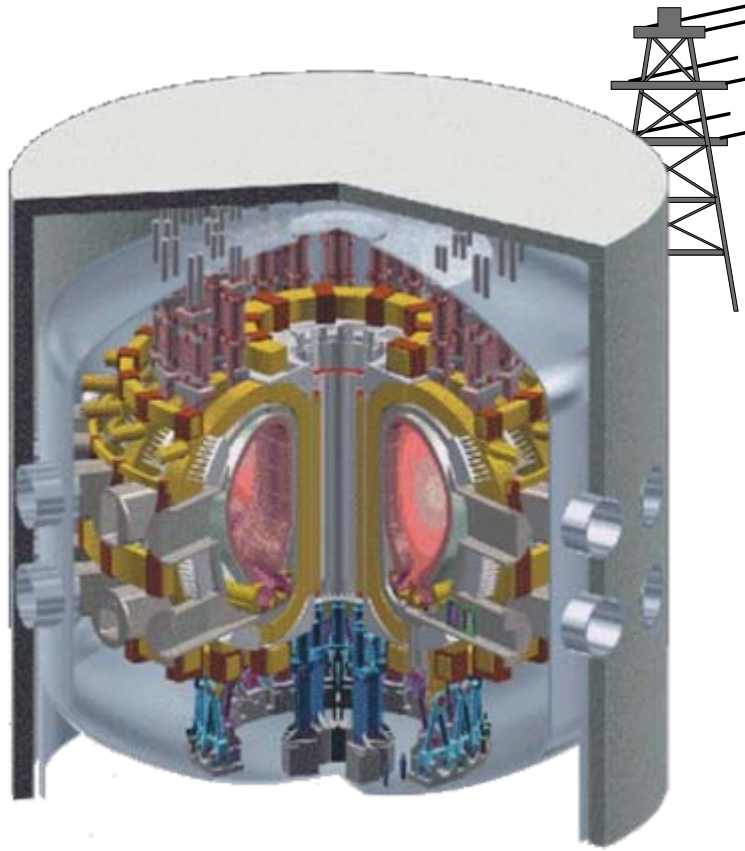
Core temperature	*150 million K*
Core pressure	*atmospheres (gram)*
Core cooling time	*few seconds*

Plasma cores better and better insulated…





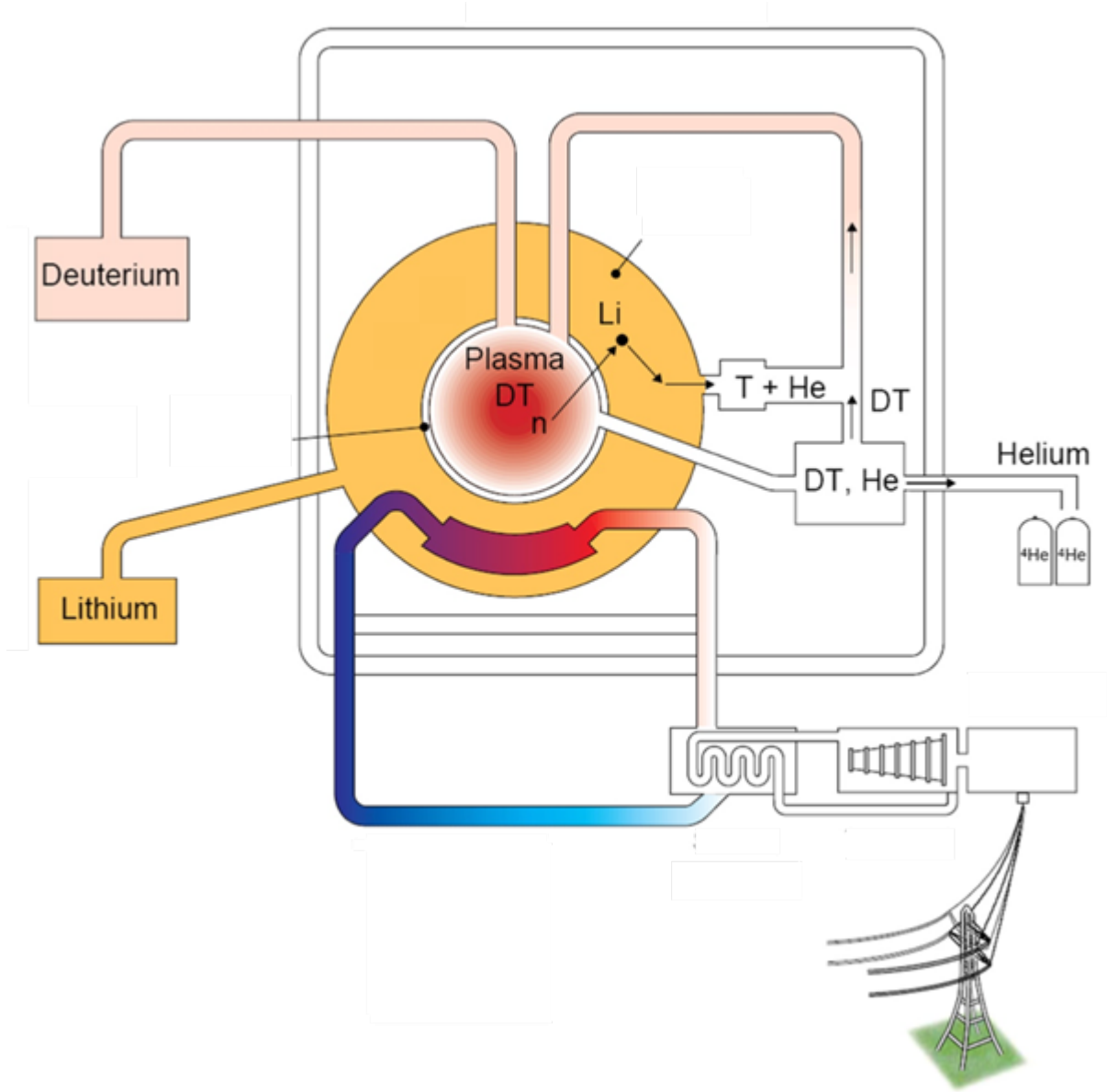




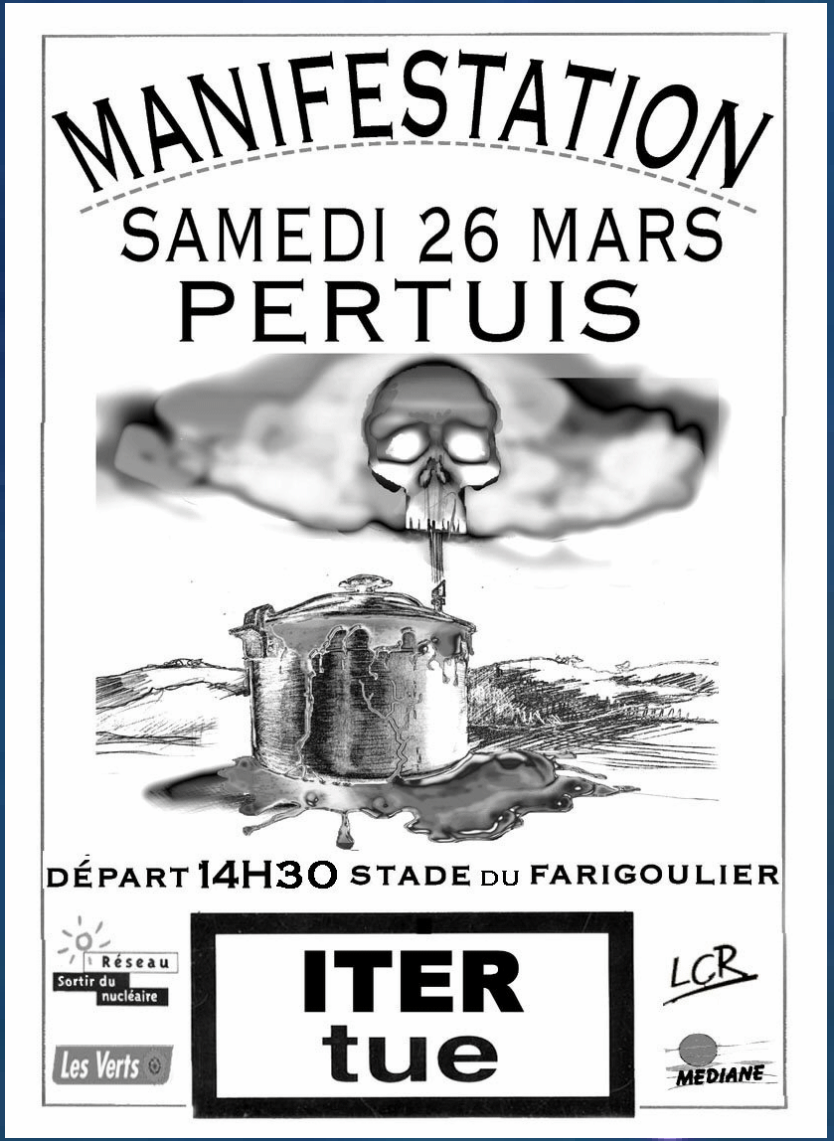
Tore Supra	*JET*	*ITER*	*Reactor*
25 m³	*80 m³*	*830 m³*	*~ 1500 - 2000 m³*
~ 0 MW	*~16 MW_{th}*	*~ 500 MW_{th}*	*~ 4 500 MW_{th}*
0%	*10%*	*70%*	*80 - 90%*

Self heating

A fusion reactor

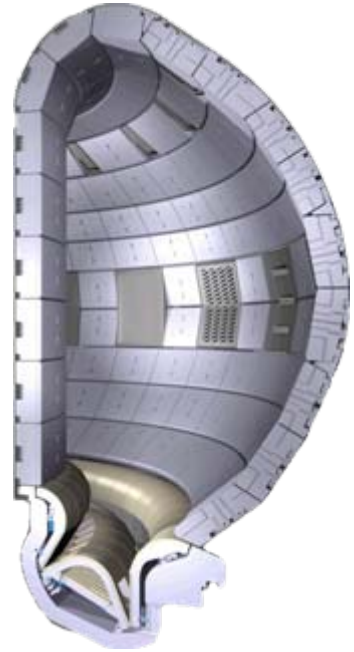


Fusion: a clean, safe and non-proliferating energy?




Waste

A clean energy?



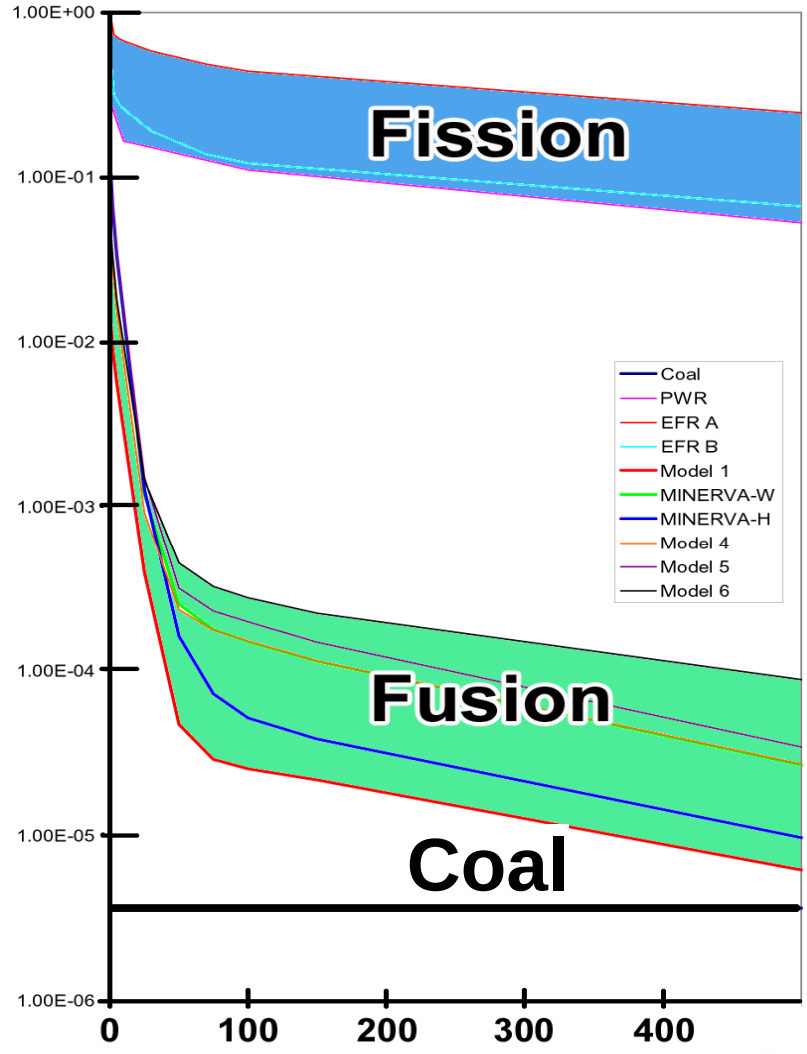
neutron + lithium → helium (harmless) + tritium (recycled)

***Ideal** reactor*
Full liquid lithium blanket

No nuclear waste…

A clean energy?

Radio toxicity of waste

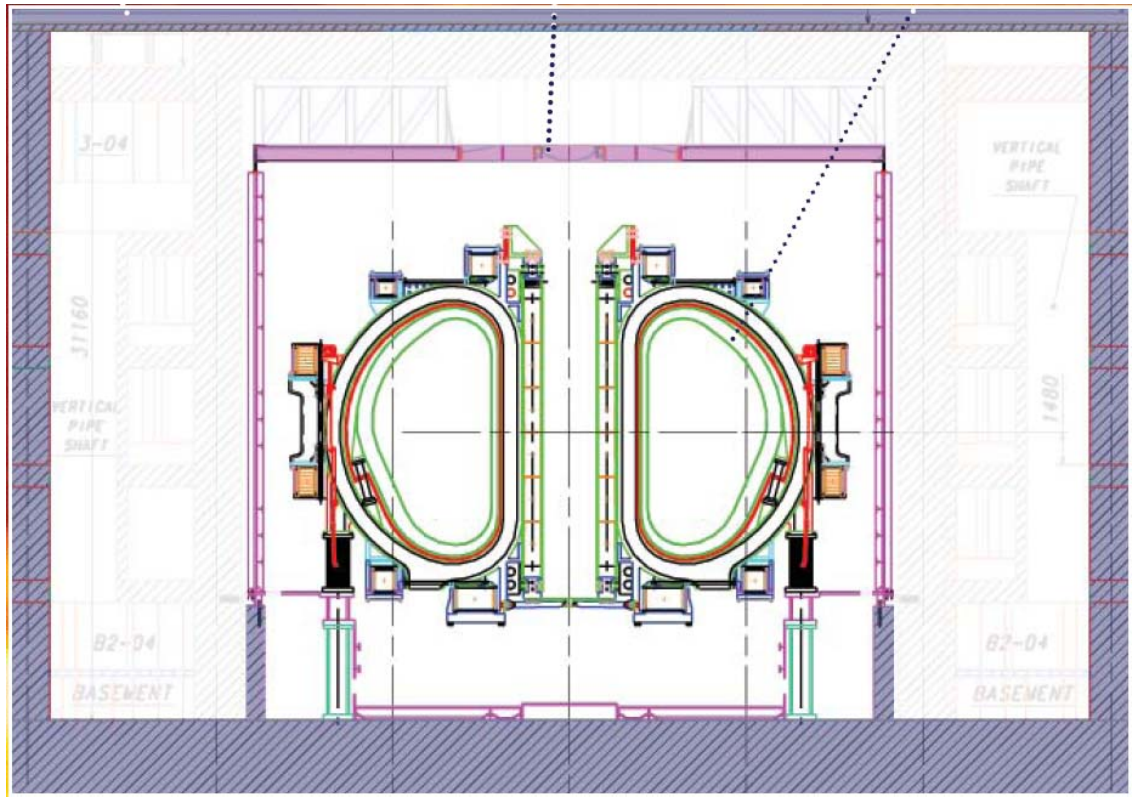


Years after shutdown

No wastes for the future generations?


DANGER!!
MELTDOWN IMMINENT!
Safety

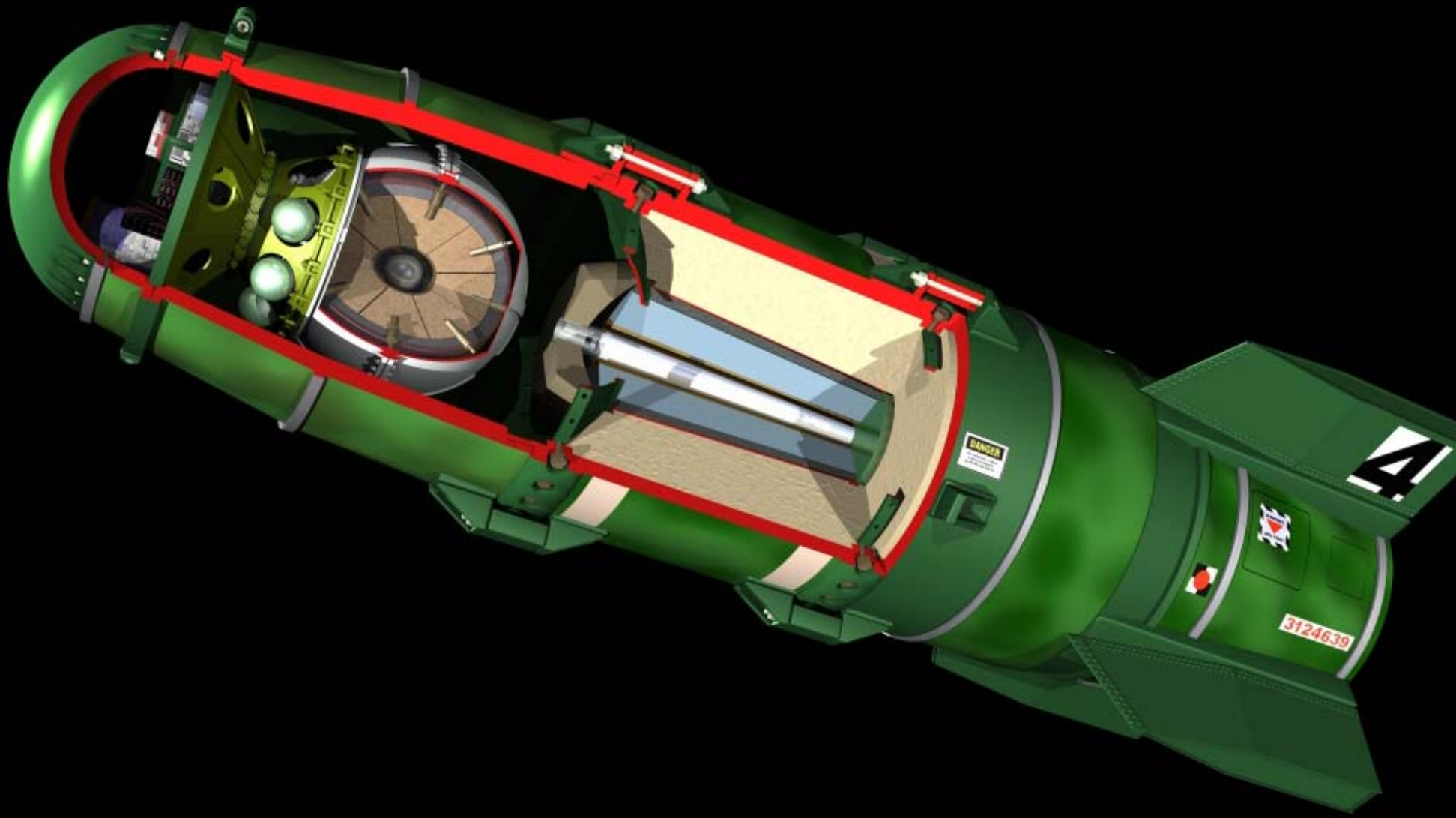
A safe energy?

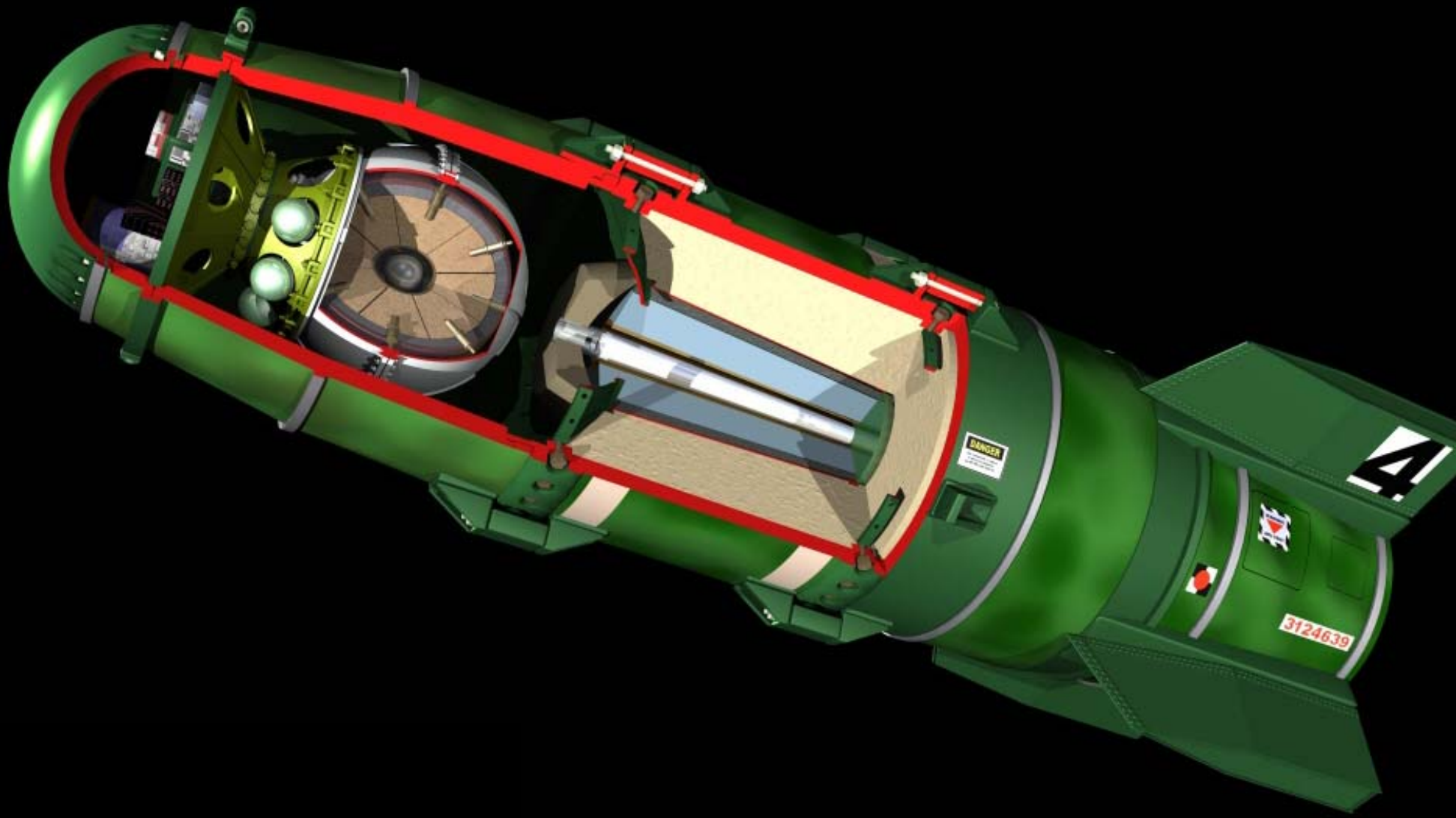


Worst accident in Ite ITER kills *um in the atmosphere*

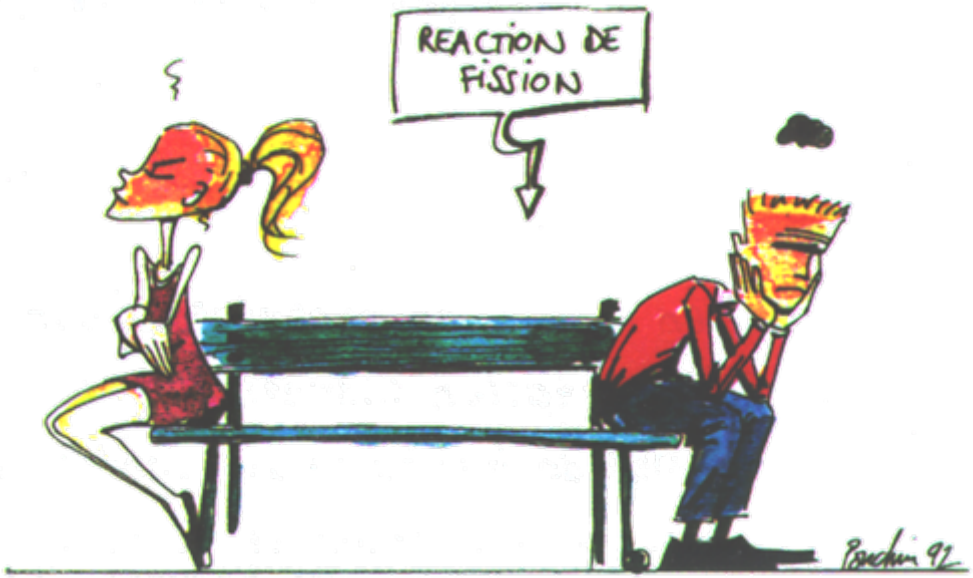
Cancer *igarettes*

Proliferation?


DANGER
4
3124639

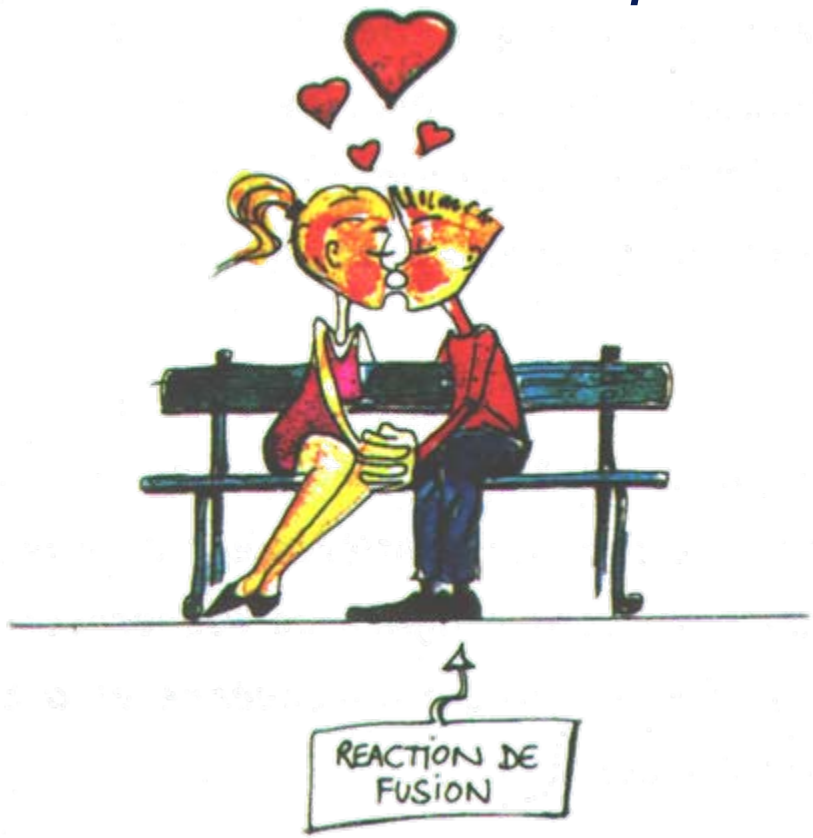

DANGER
4
3124639

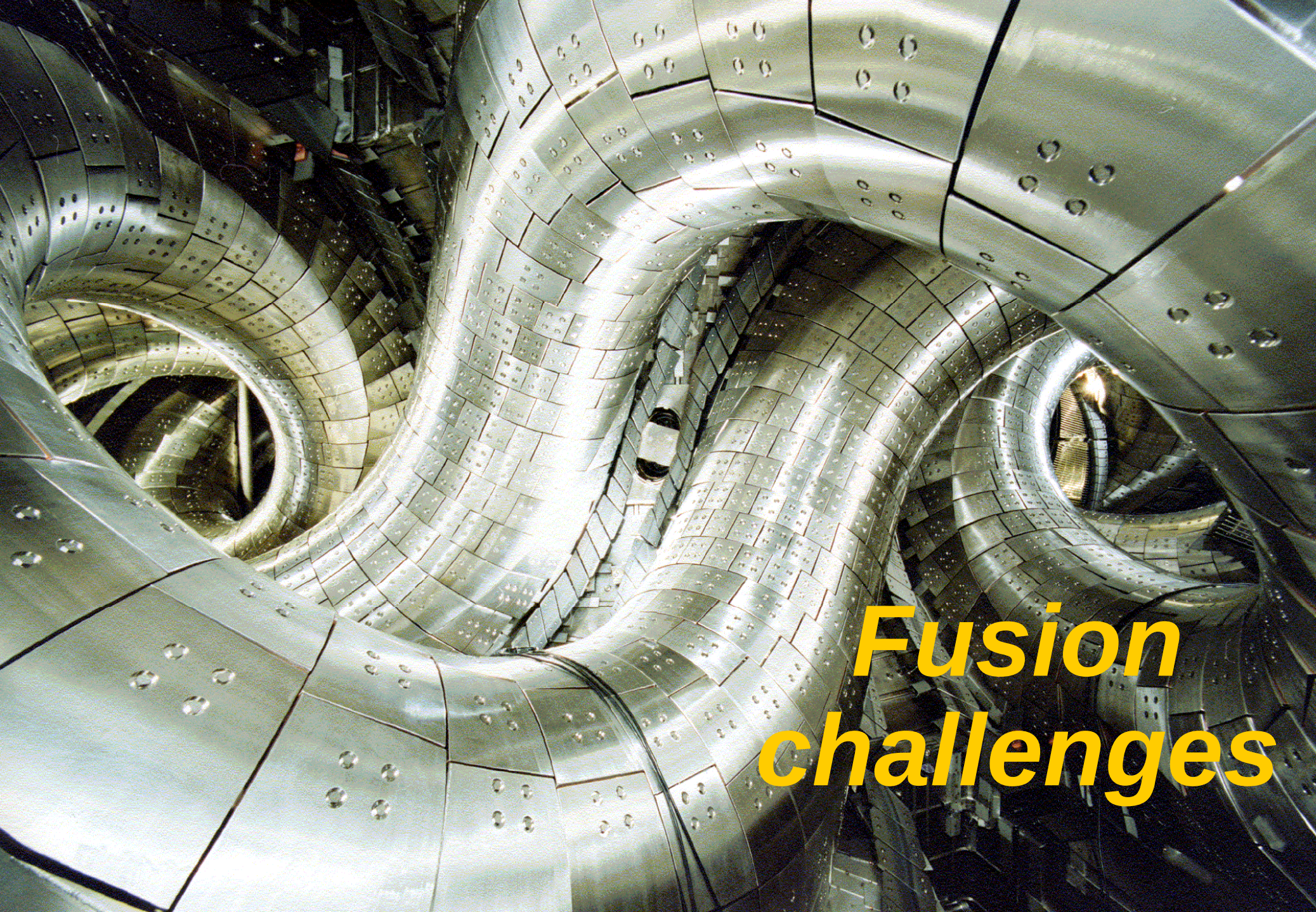
Fission / fusion



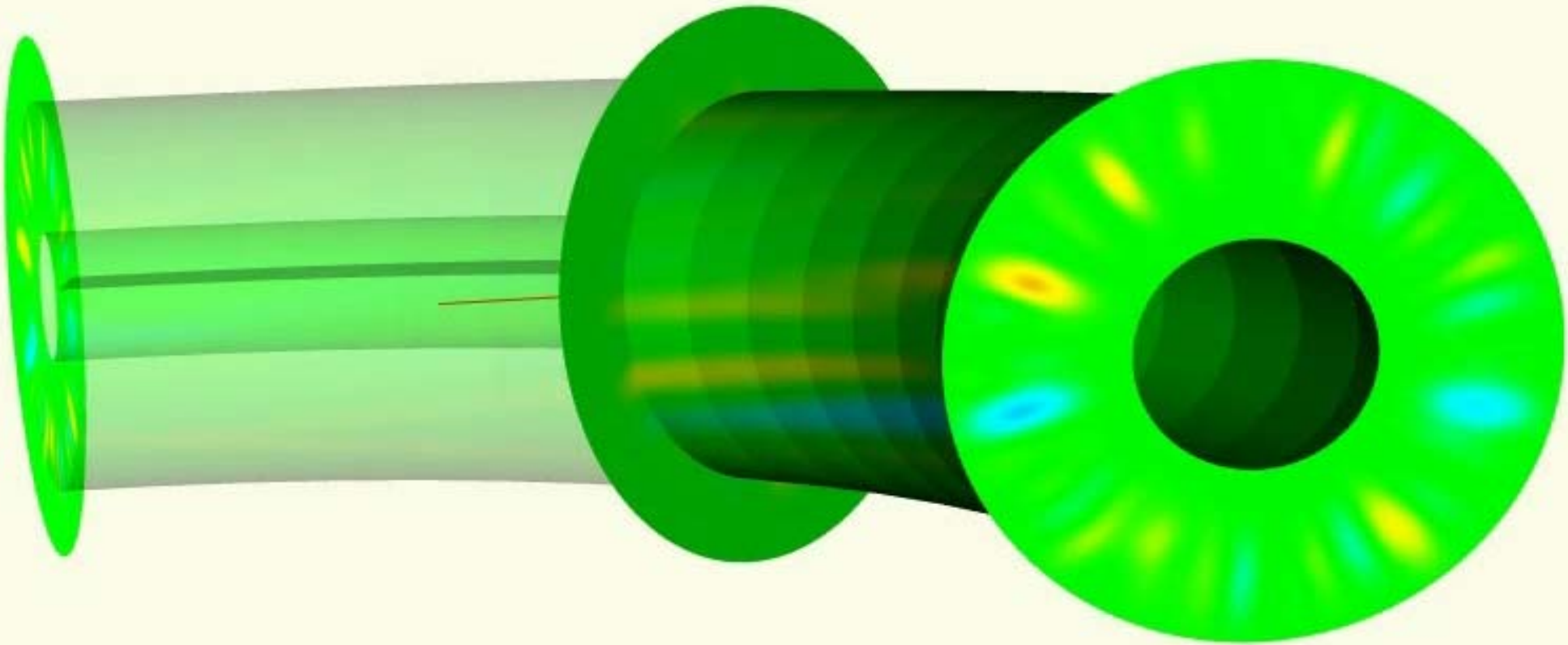
Fission
starts easily
chain reaction
avoid run away!

Fusion
hot, very hot
hard to start
tends to cool and stop!

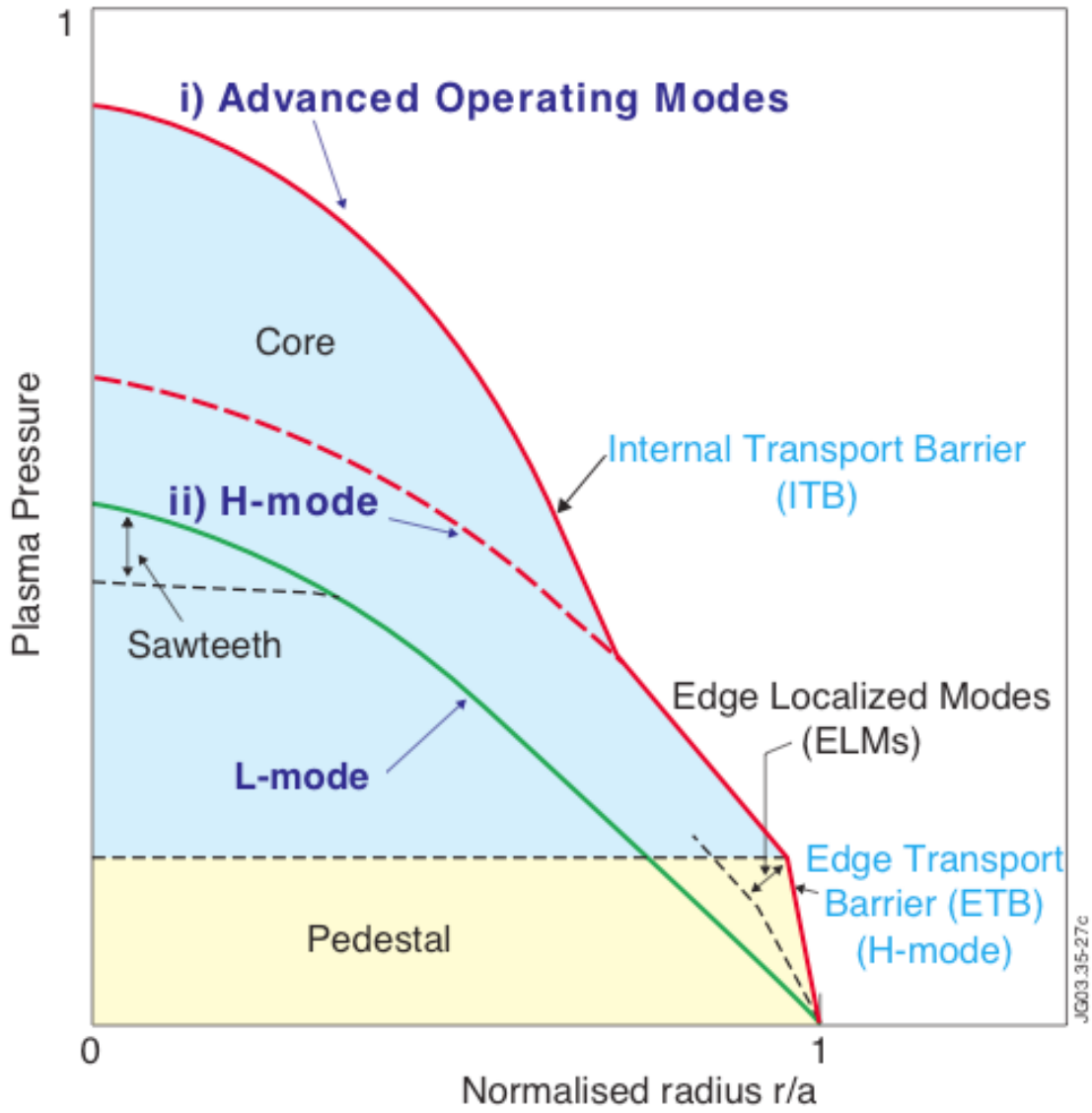



Fusion
challenges

Shear the large scale convective structures

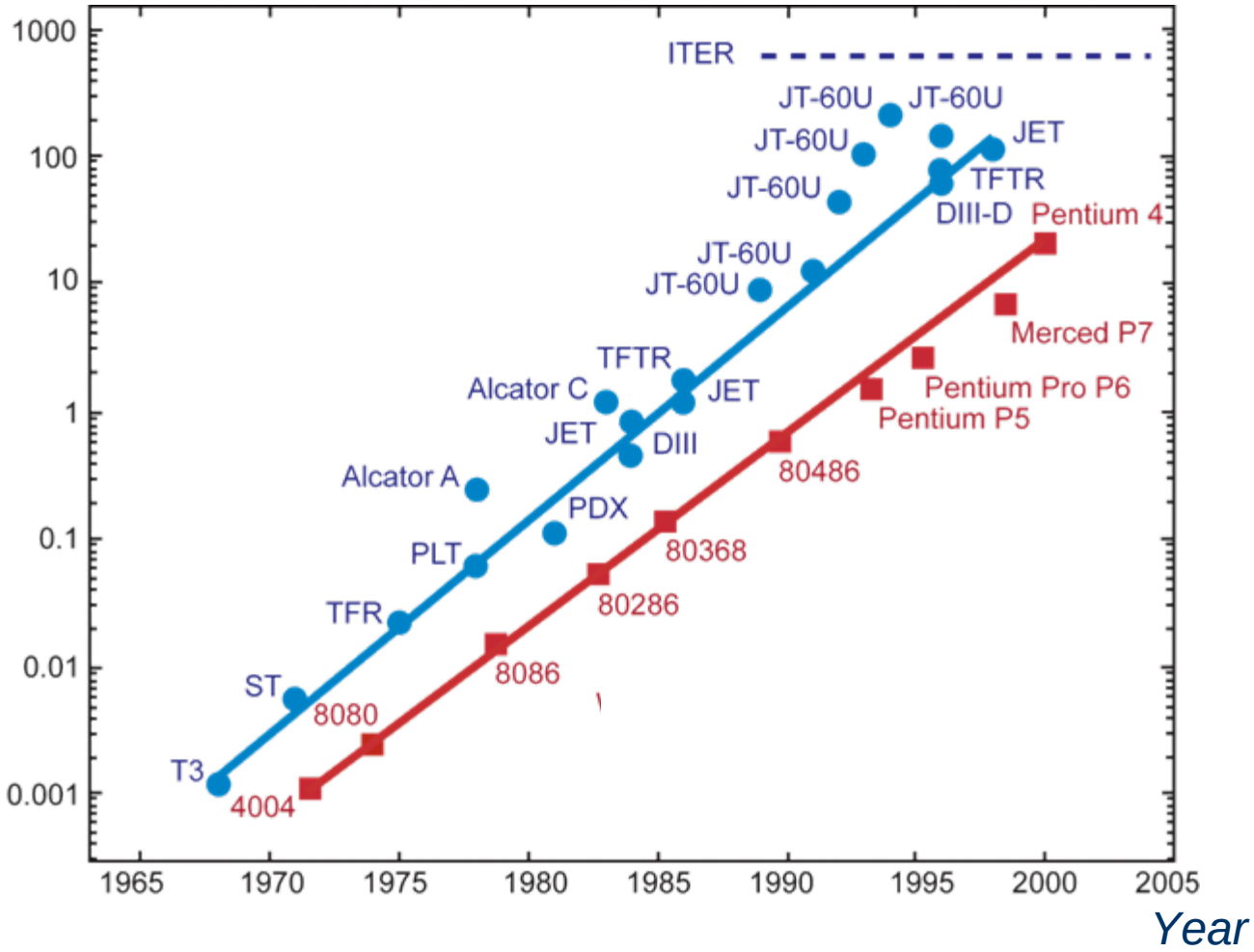


Enhance confinement…

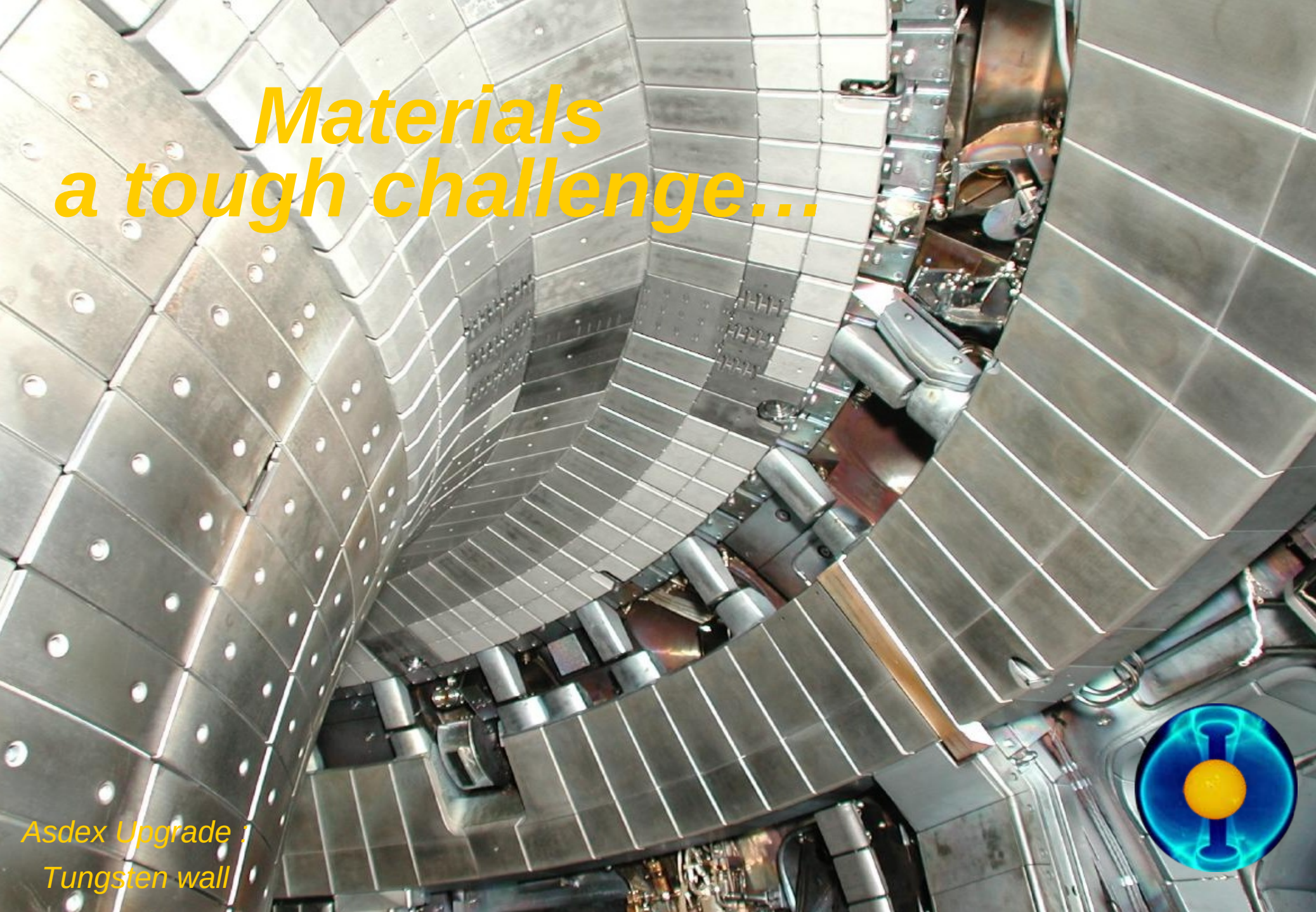


Fusion beats Moore's law

Performances



Materials
a tough challenge…



Asdex Upgrade :
Tungsten wall

Radiation Damage in Fusion Materials

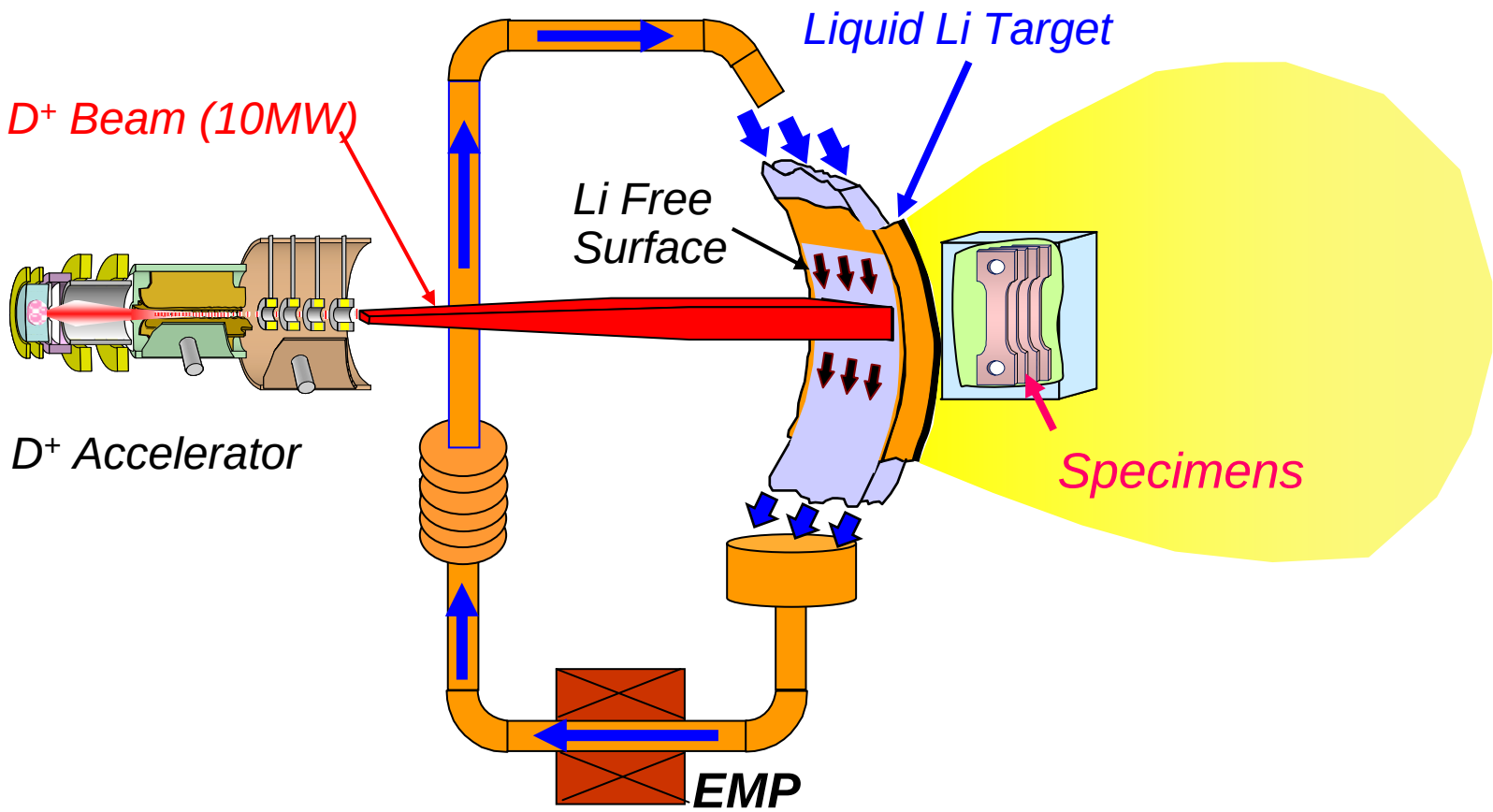
Neutrons

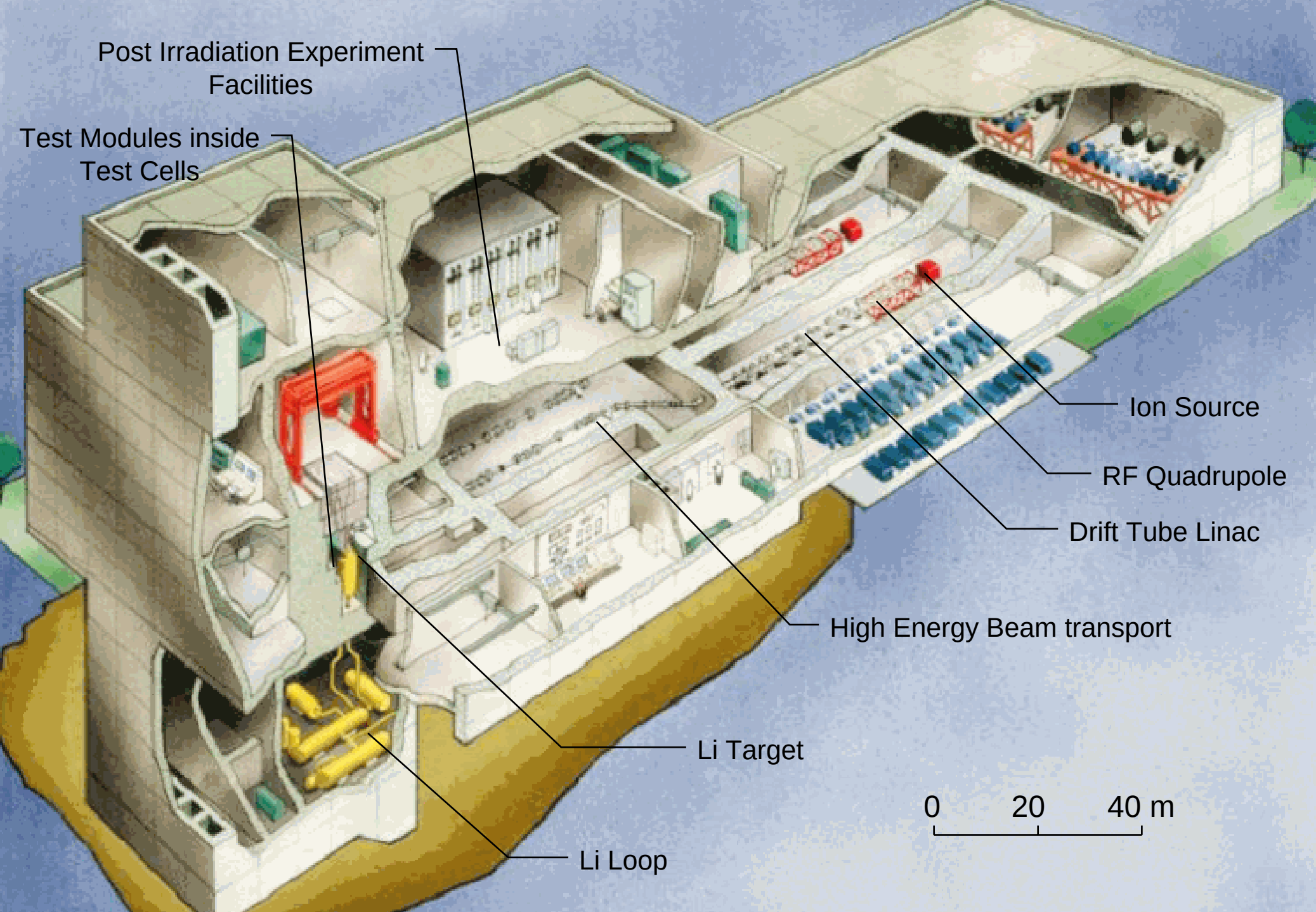
Fusion	*Fission*
14 MeV	*2 MeV*

Threshold reactions : ~100 times more hydrogen, ***helium***

Swelling, embrittlement

IFMIF a 14 MeV neutron irradiation facility (International Fusion Material Irradiation Facility)




Post Irradiation Experiment Facilities
Test Modules inside Test Cells
Ion Source
RF Quadrupole
Drift Tube Linac
High Energy Beam transport
Li Target
Li Loop
0
20
40 m

Iter in Cadarache…

ITER: cost sharing

20 %

Etat/CEA (~4%)

Euratom (~6%)

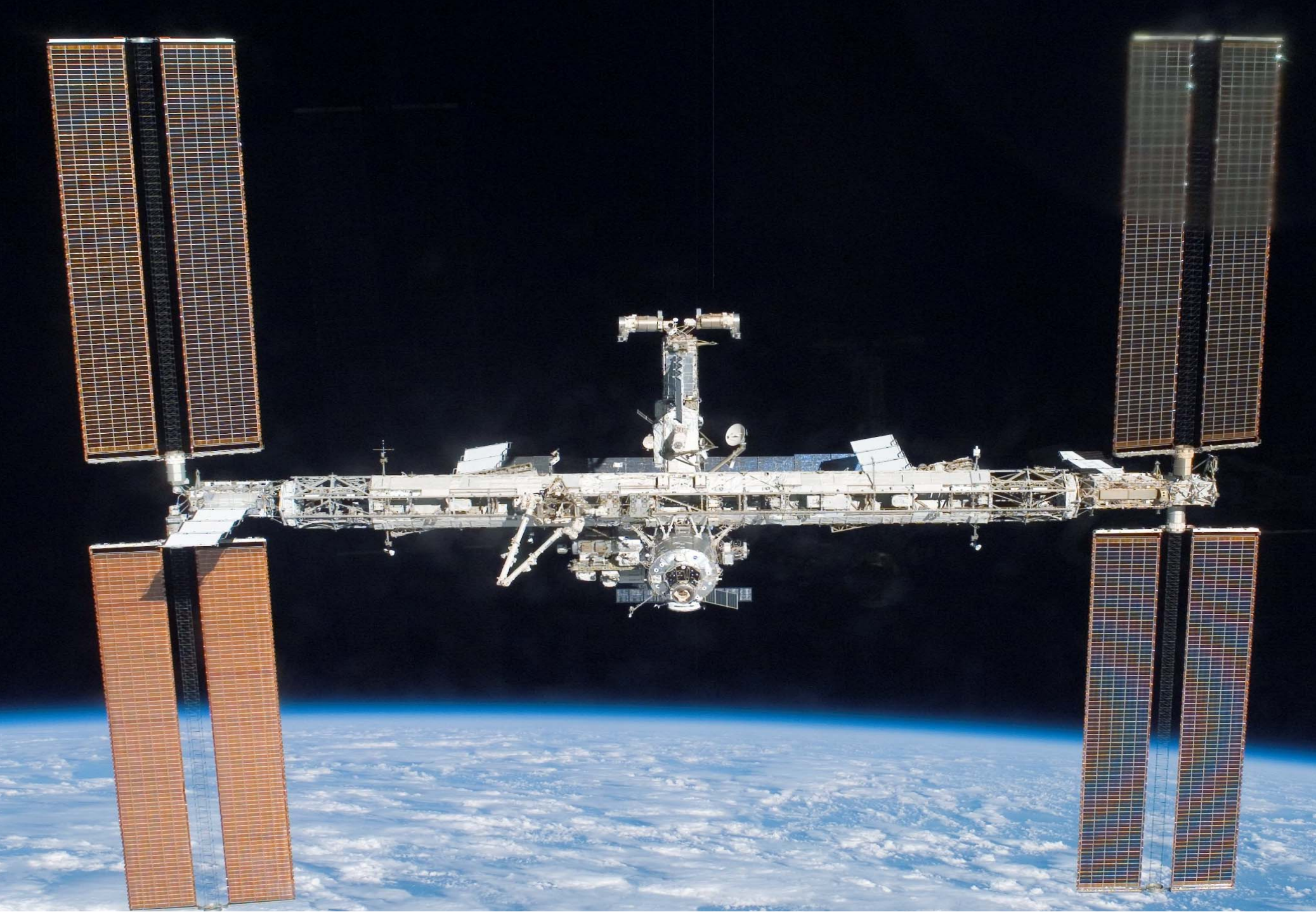
Local authorities (~10%)

Construction / 10 years / 4,7 billion €

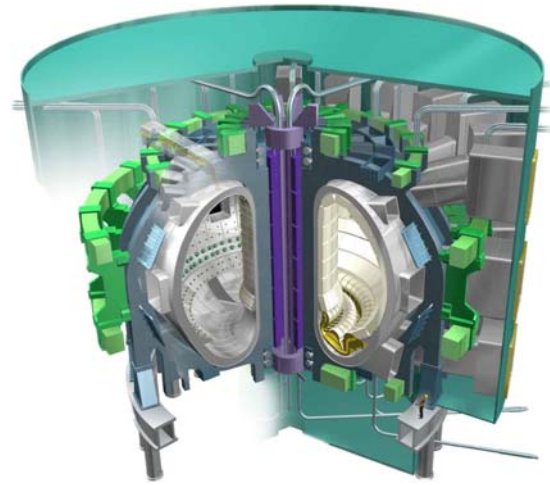
50 % 10 % 10 % 10 % 10 % 10 % 10 %

Operation / 20 years / 5,7 billion €

34 % 13 % 13 % 10 % 10 % 10 % 10 %



Would fusion be a sustainable energy?

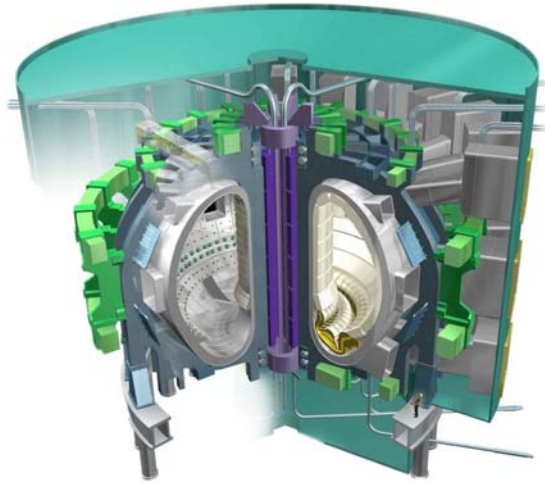


Almost inexhaustible fuels (D-T millions / D-D billions of years)
Fuels in the oceans, available to all (30 grams of fuel for the energy of a whole life)

No chain reactions, no power run-away
Plasma at ~ atmospheric pressure, energy density ~ ambiant air
1GWe reactor (~1 million people) only contains ~ 1 gram of fuel

No pollution, no greenhouse gases → marginal impact on health & climate
Wastes can be recycled after ~ 100 years, not a burden to the next generations
No risk of proliferation

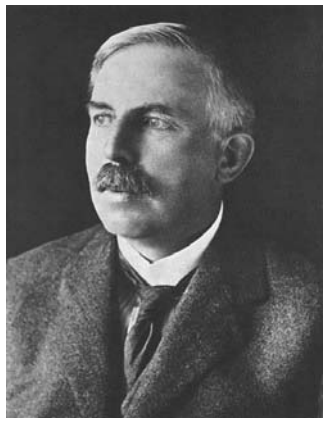
Fusion challenges



Self heated core (ITER : 70% reactor : 80-90%)

Materials (14 MeV neutrons, high heat fluxes)

" talking moonshine…" ?



IIASA scenario B

30

"South"

"North"

20

10

0

Energy consumption (Gtoe)

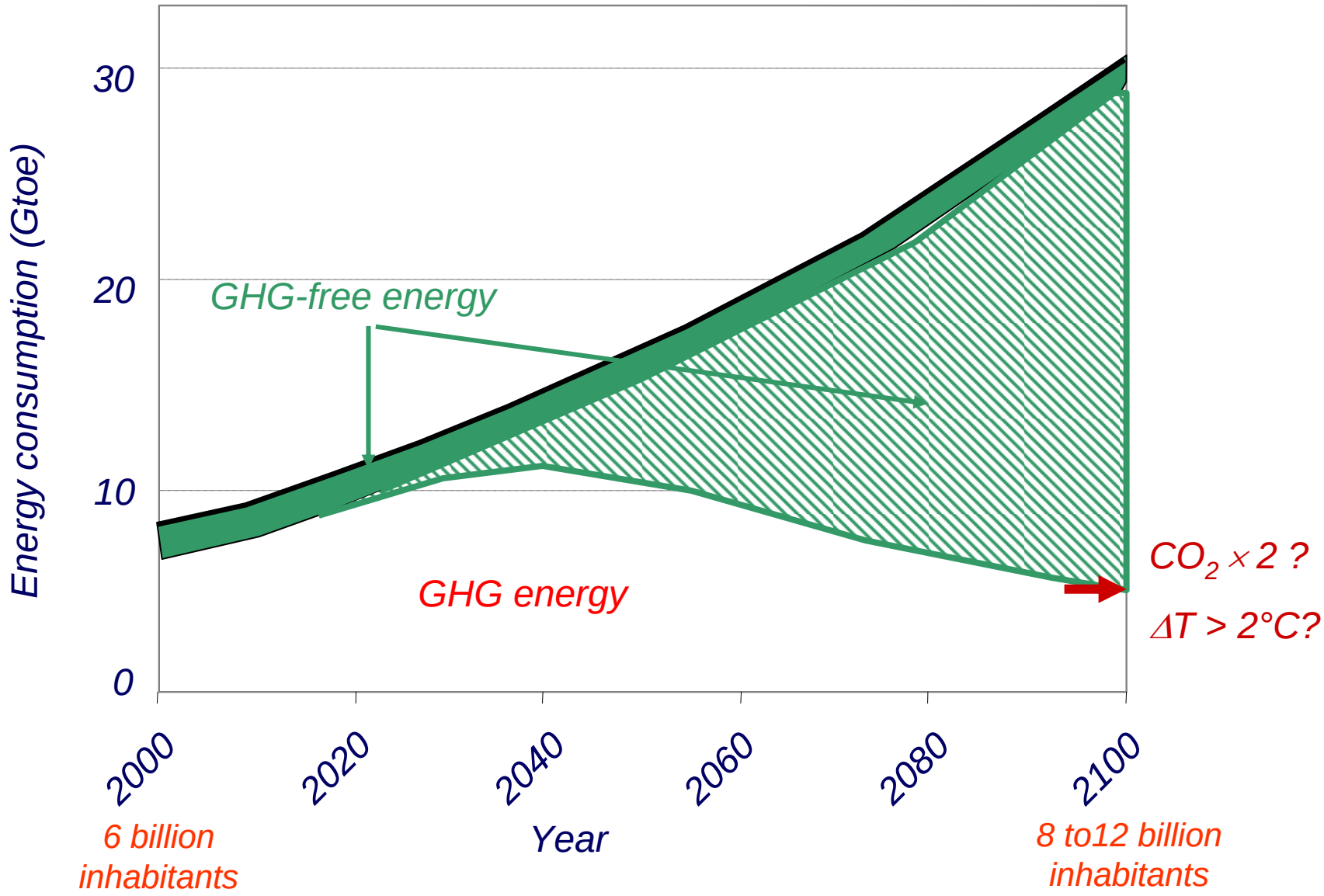
2000 2020 2040 2060 2080 2100

year

6 billion inhabitants

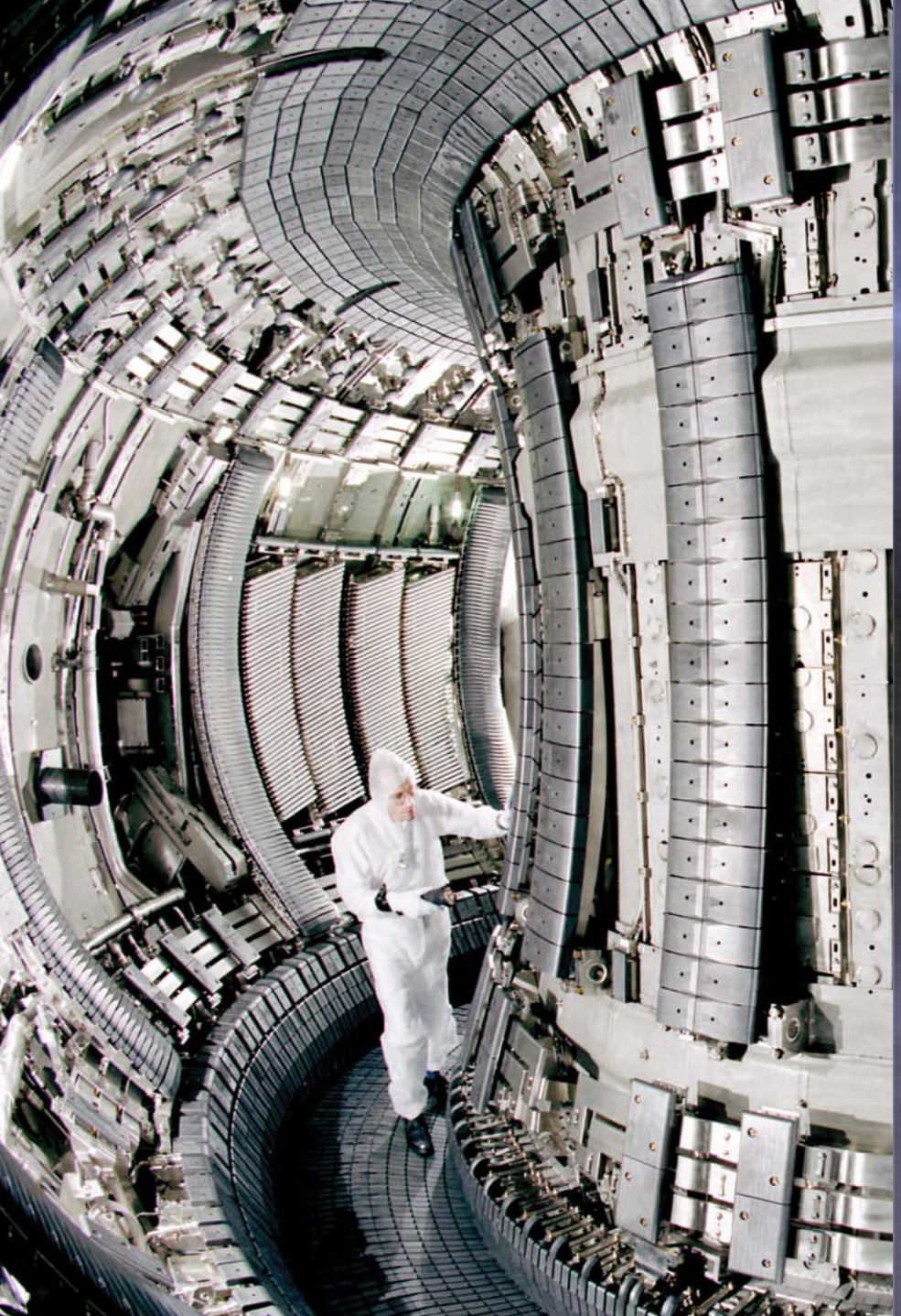
8 to12 billion inhabitants

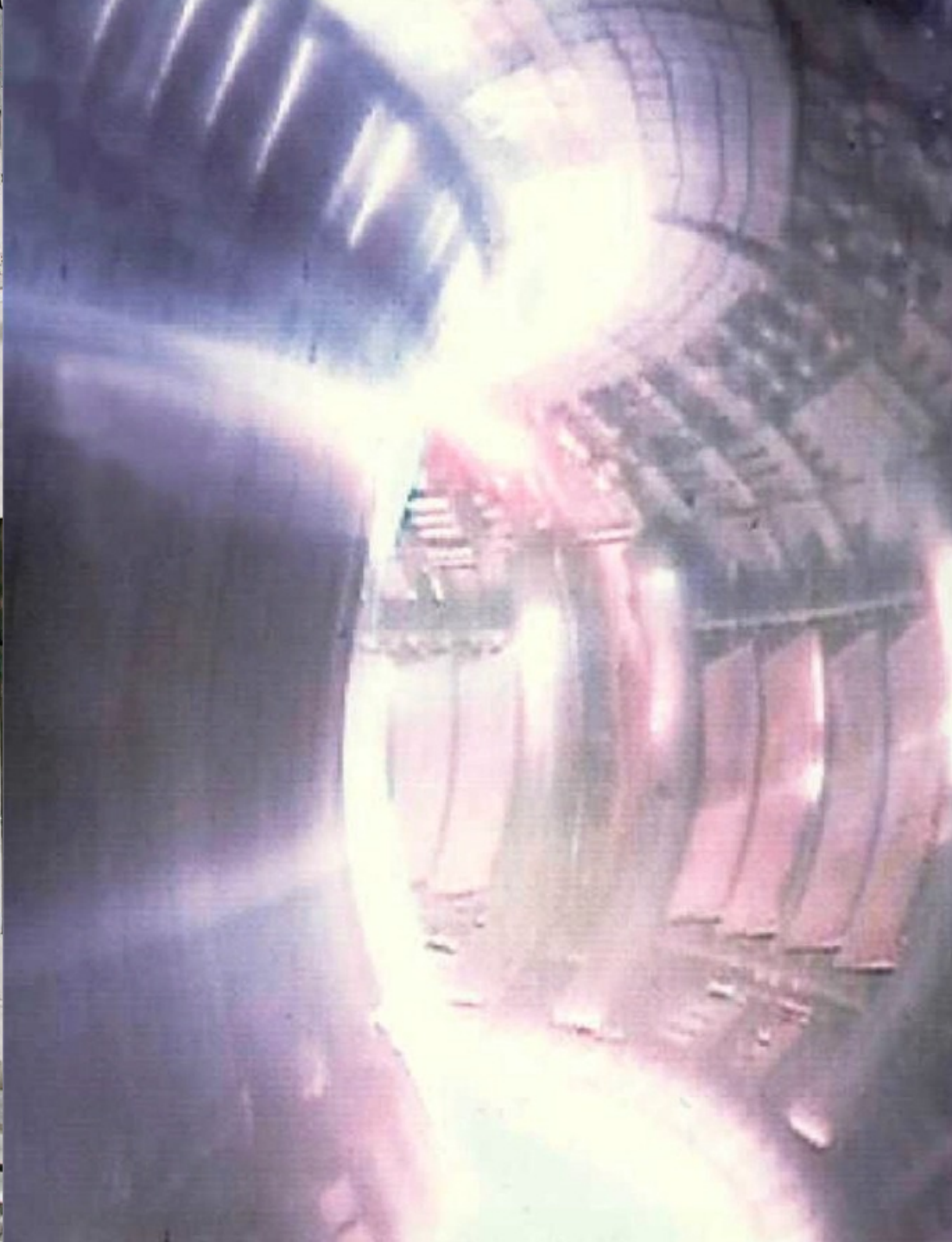
The challenge of the 21st century?



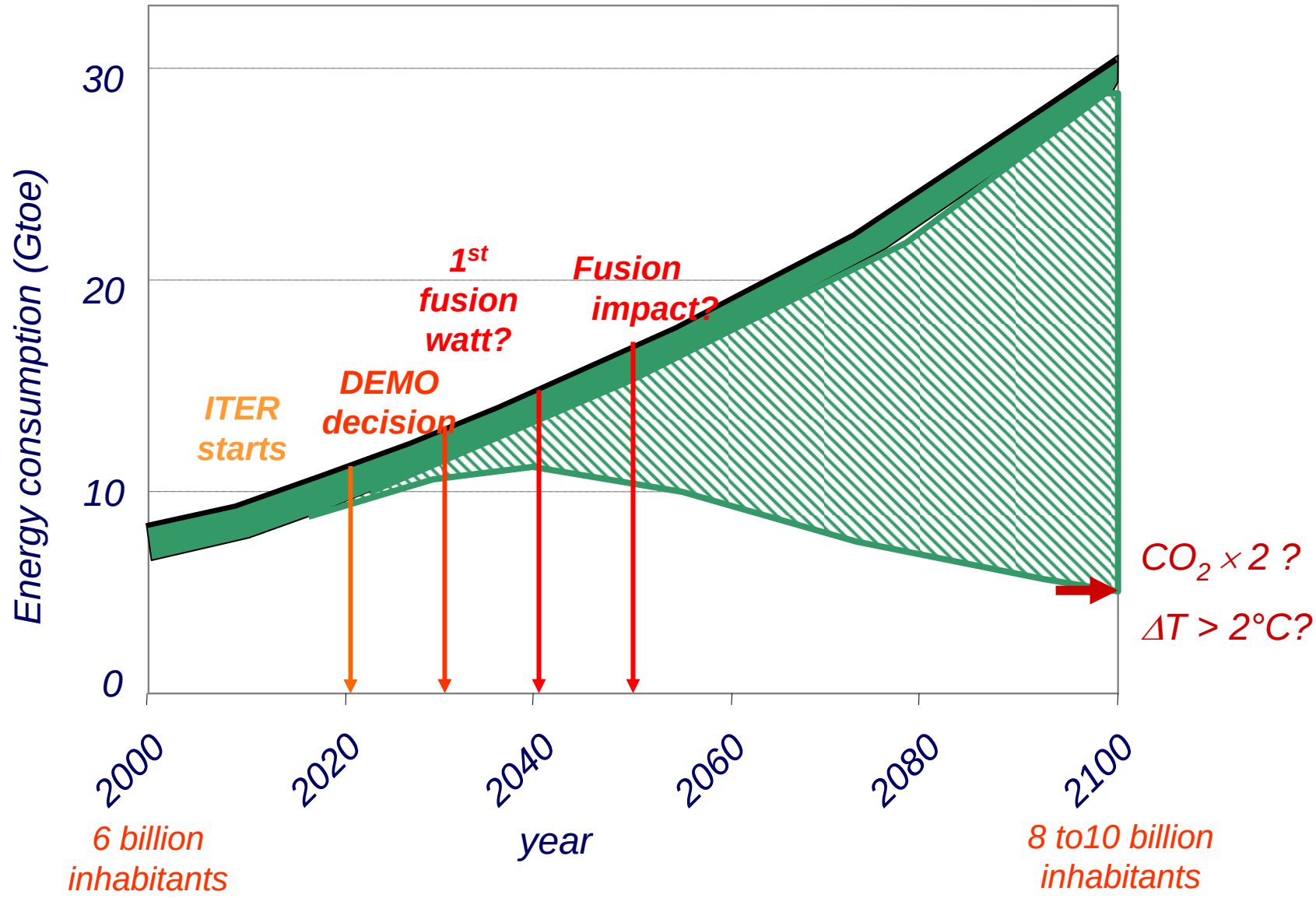

~~Sustainable development~~ Oxymoron?
~~Renewable energies~~ Oxymoron?
Sustainable energy ?


<1% uranium energy
1st step non breeding Fission



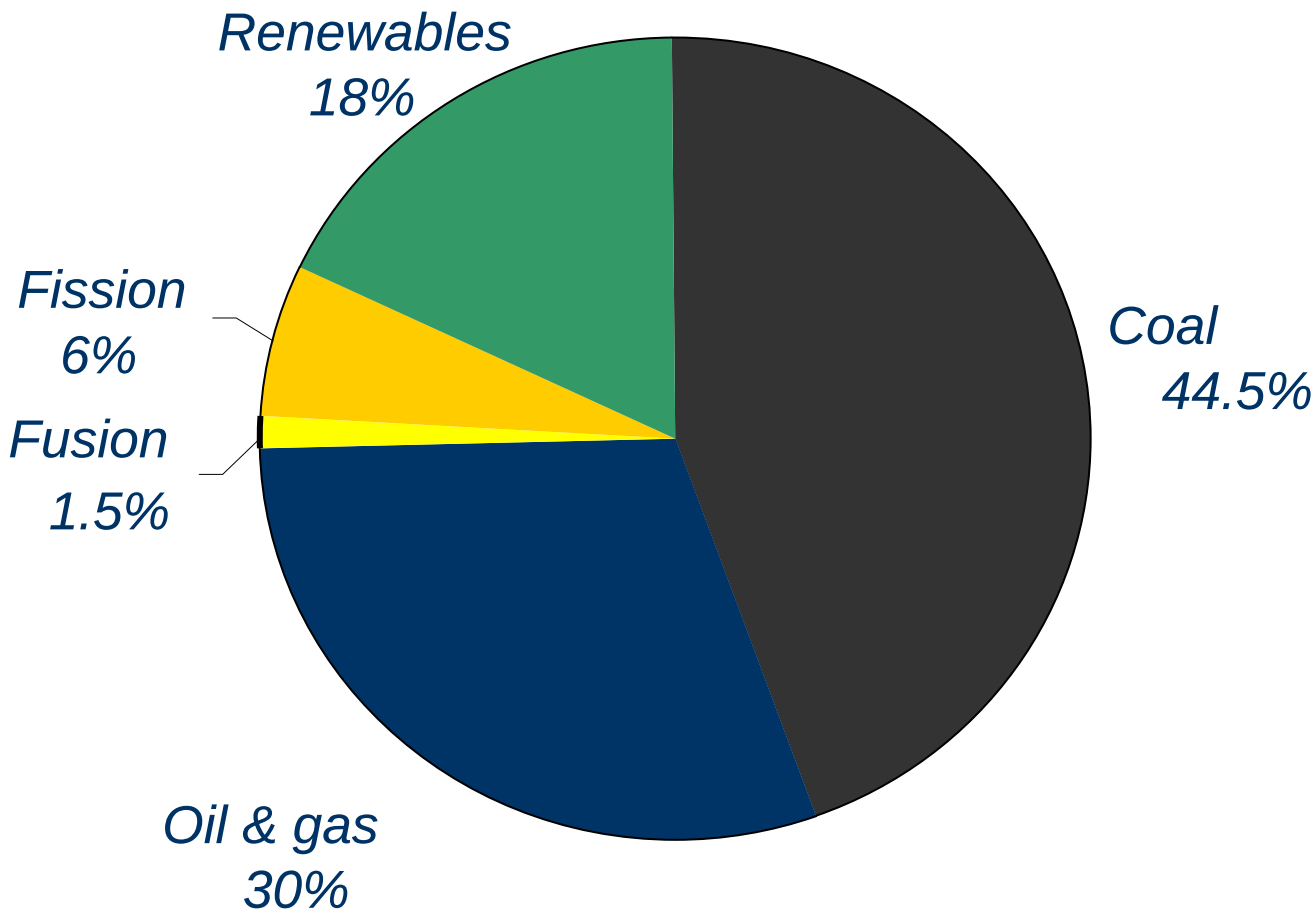


Fusion is the energy of the future and will always remains?



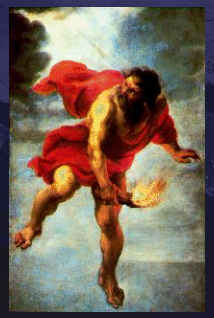
"…and we are blind to it "

R&D budgets and subsidies on energy in Europe ~ 30 billions €/year

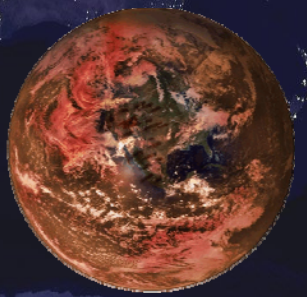


Source : EEA, Energy subsidies in the European Union: A brief overview, 2004.


Evolution of Temperatures
NEXT 100 YEARS:
°C
+4
+3
+2
+1
JOHANNESBURG
2002
Evolution of the Market
LAST 10 DAYS:
CHAPPATTE
Int'l Herald Tribune



Earth, at night



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