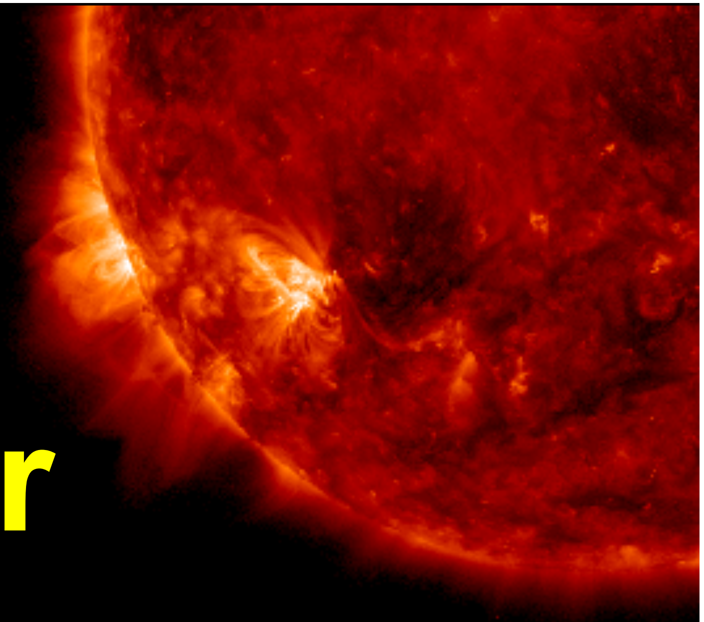
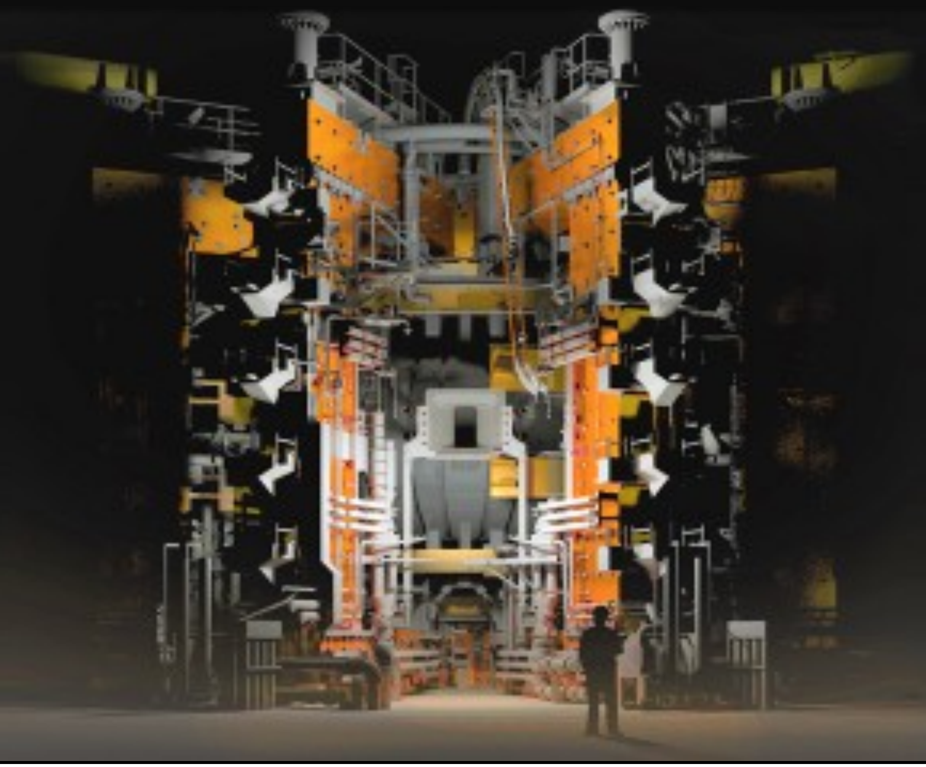
The fusion reactor

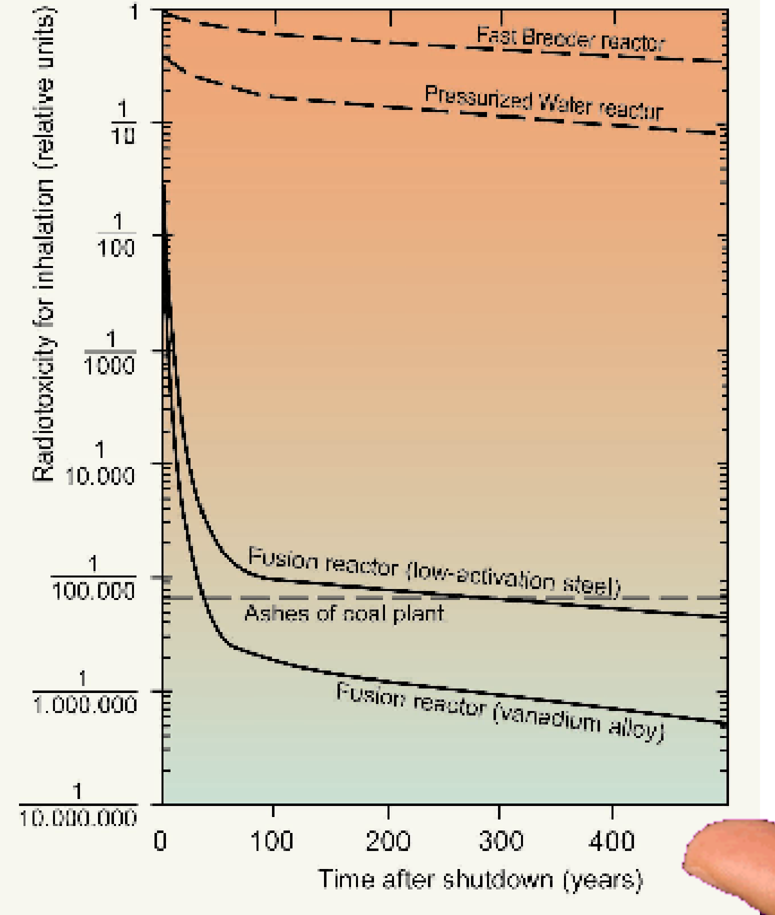


Jan Scheffel, professor
Fusion Plasma Physics
KTH

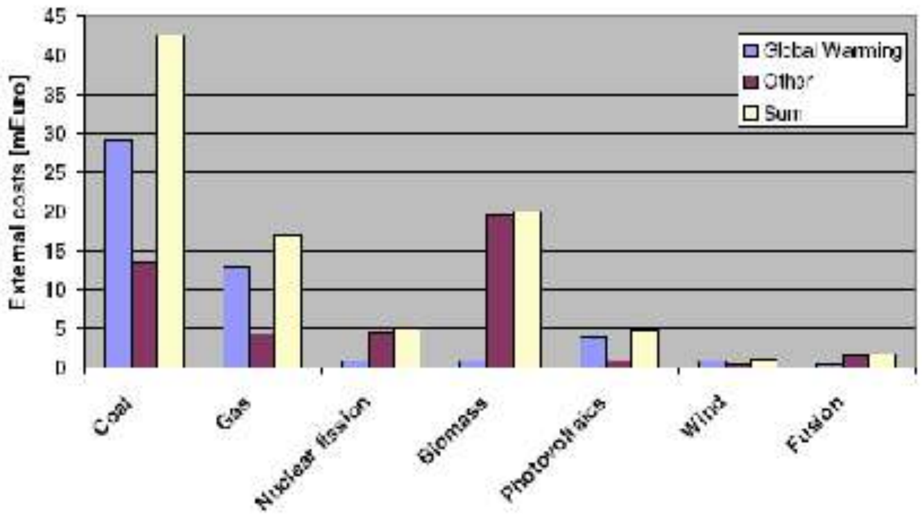


Fusion advantages

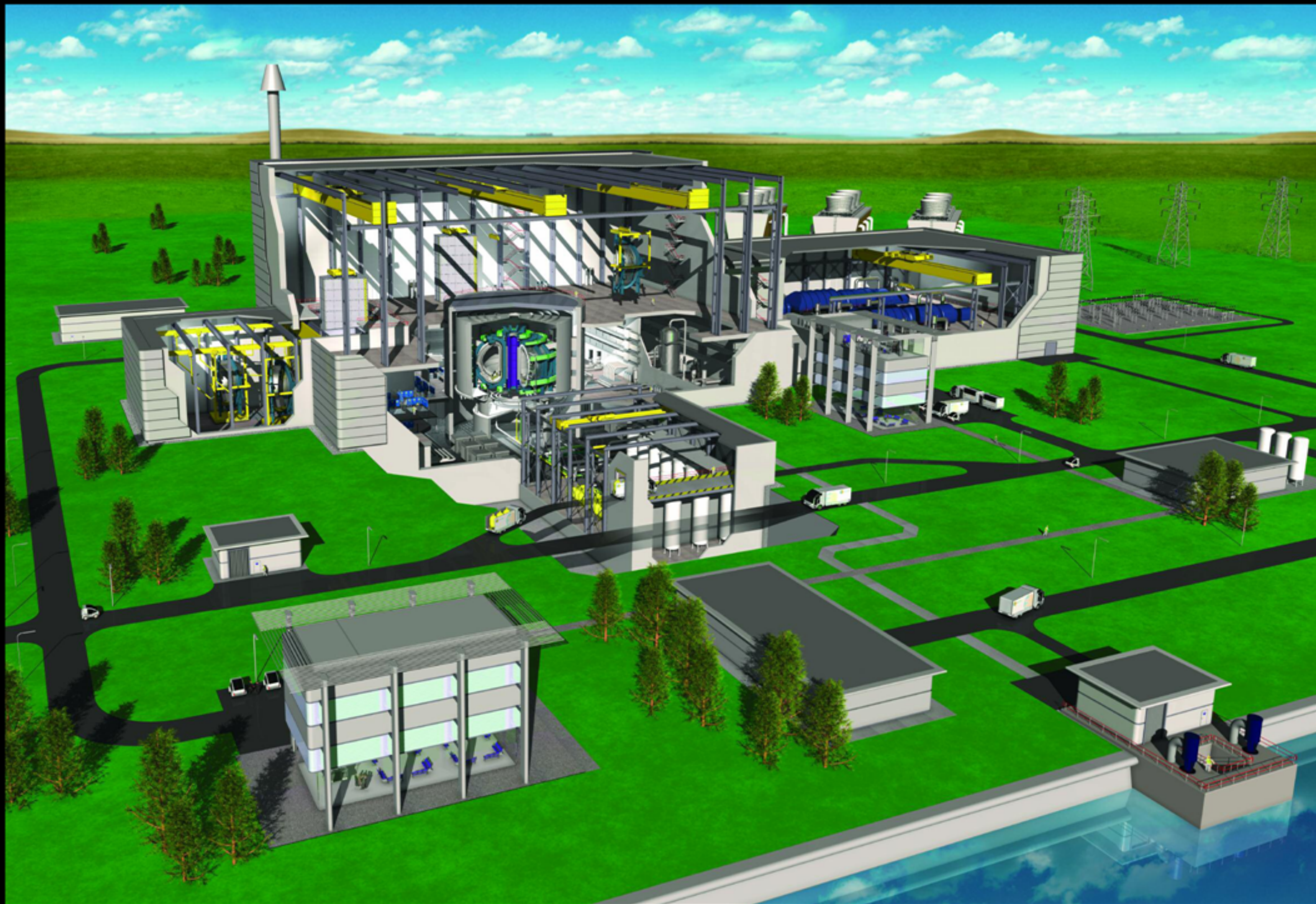
Low radioactivity

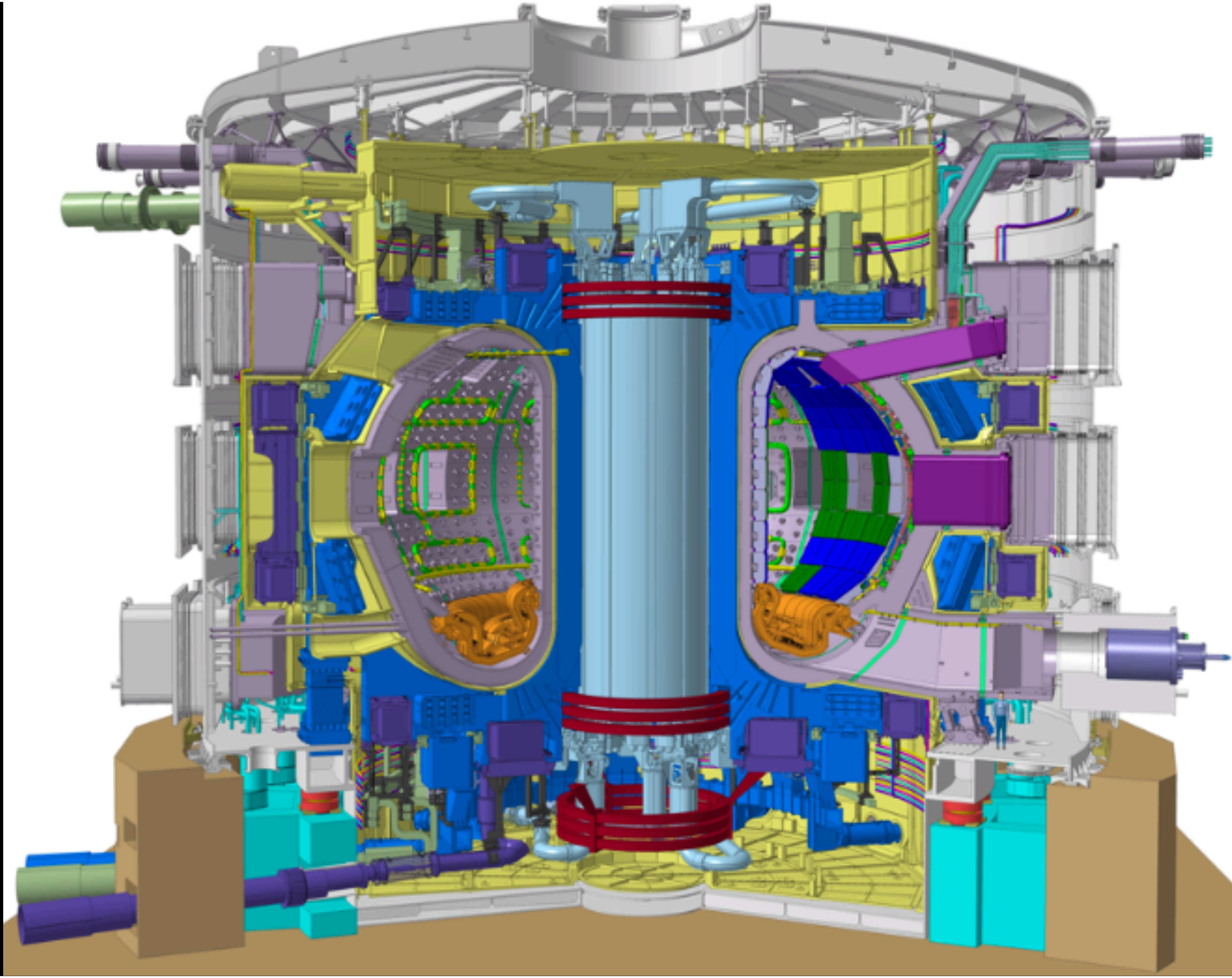


Low external costs

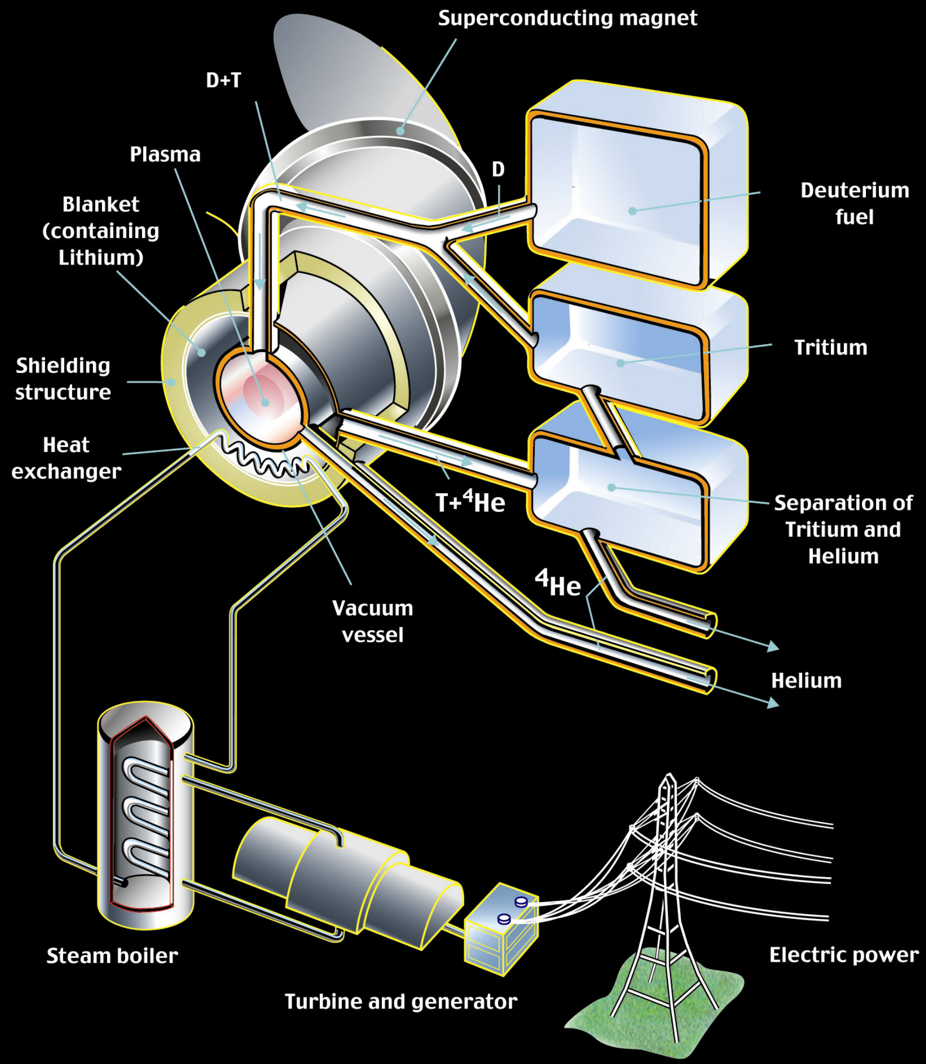


A fusion power station of the future





Fusion power station

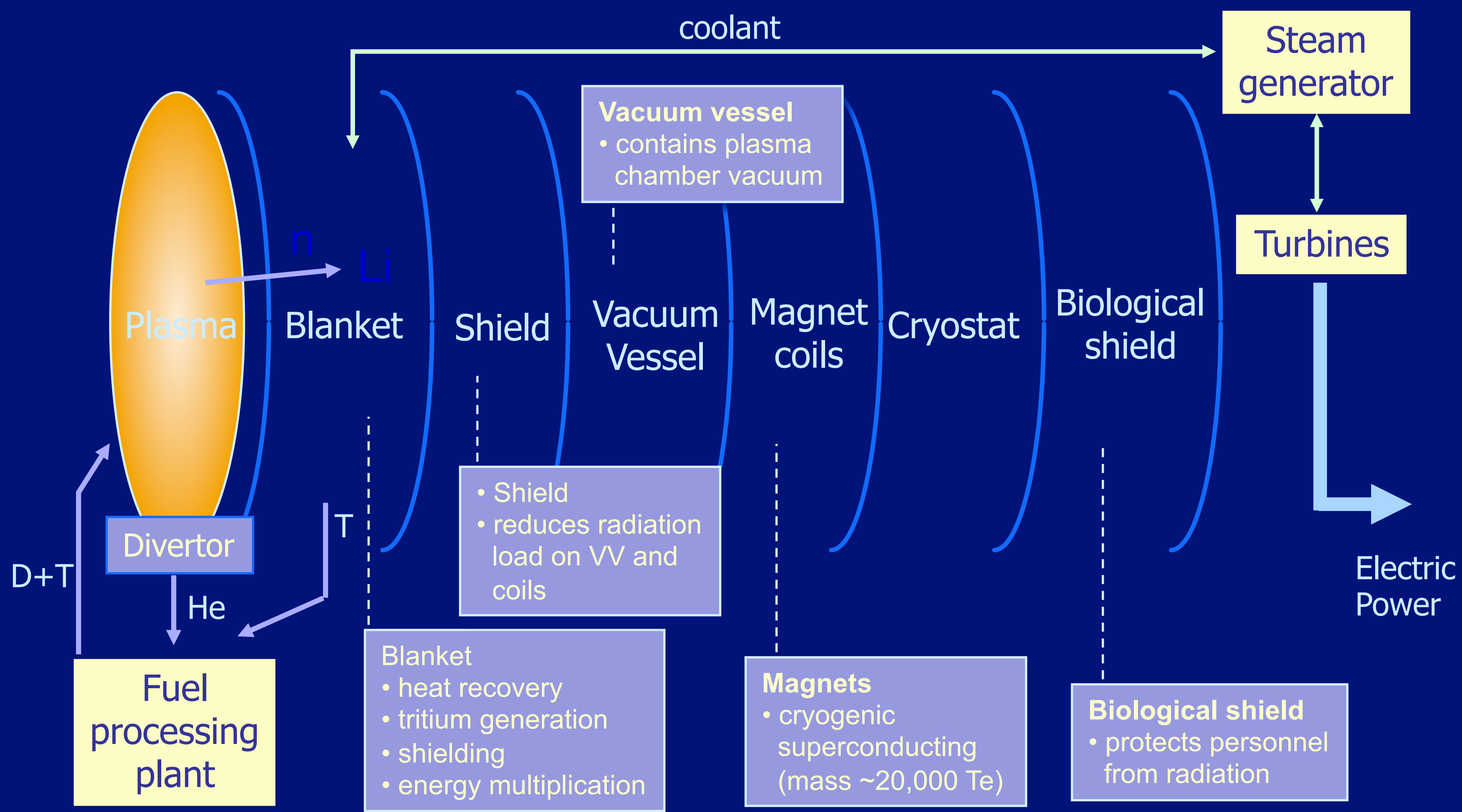


Blanket, containing lithium, captures energetic neutrons from the fusion reactions.

Blanket serves two purposes:

- **Hot cooling water provides steam for turbines and generators**
- **Neutrons and lithium combine to tritium which, together with deuterium, is the fuel**

Fusion Power Plant operation

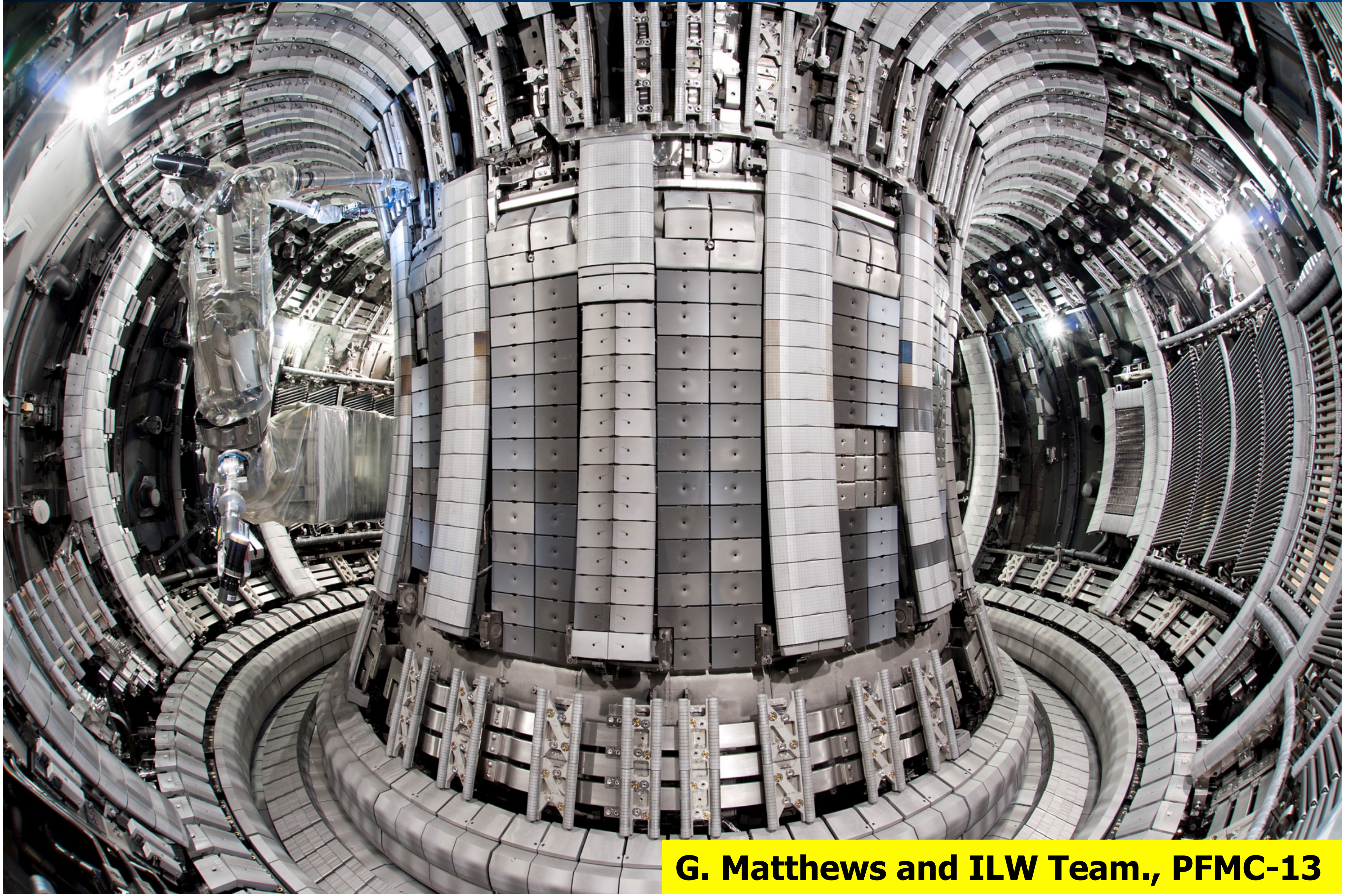


UKAEA

Experiments at JET prepare for ITER

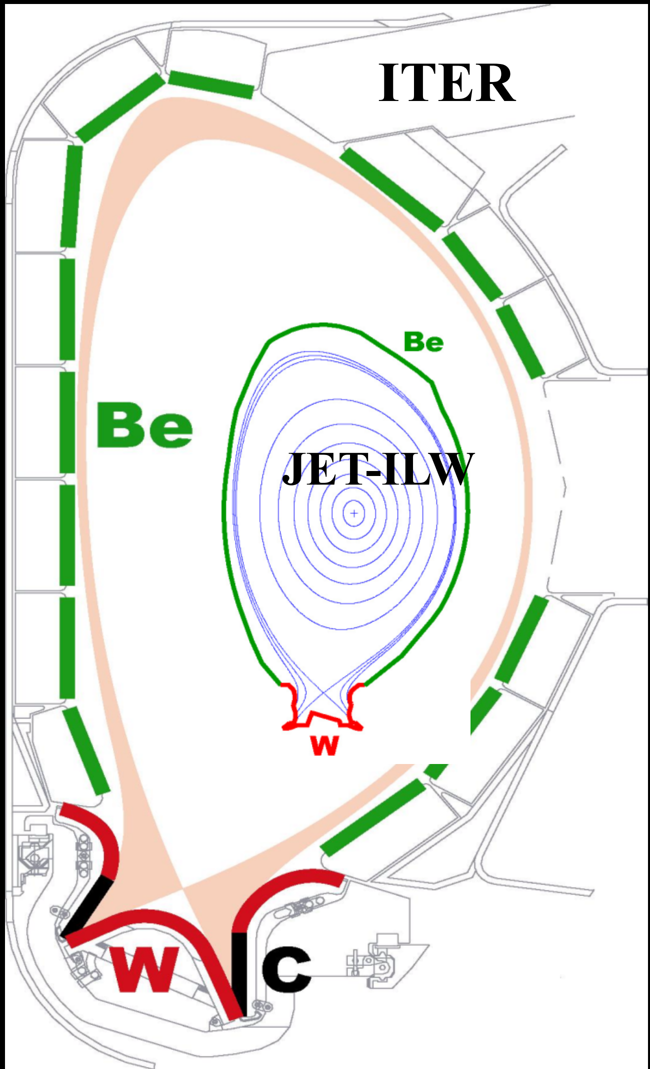
ITER – like wall
has been installed

The ITER-Like Wall: May 8, 2011



G. Matthews and ILW Team., PFMC-13

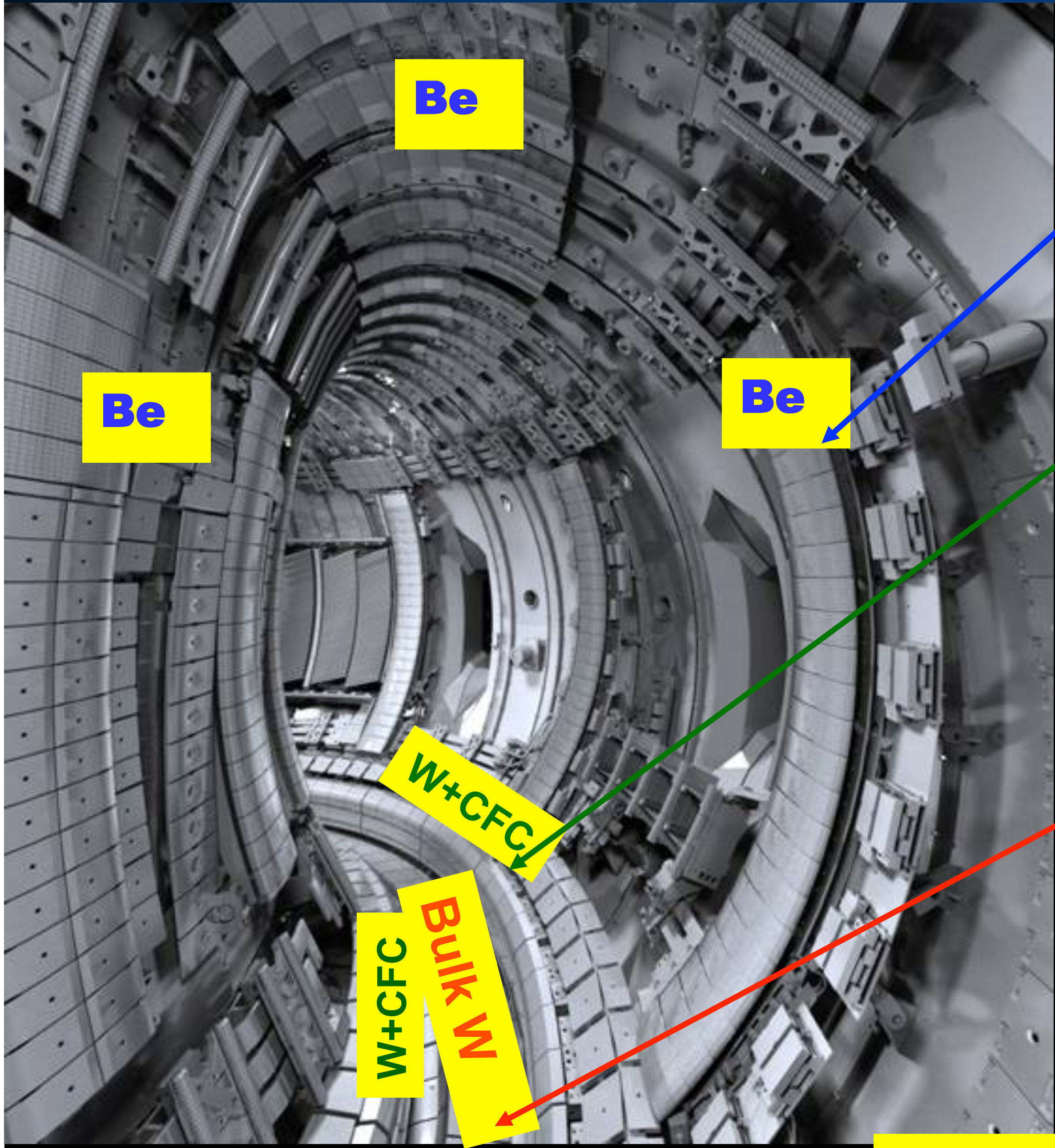
ITER-Like Wall at JET



All W divertor & Be wall

- Minimises risk of contamination by carbon.
- Compatibility of JET with beryllium and tritium.

The ITER-Like Wall: Operation limits



-

Solid Be
Surface temperature < 900°C

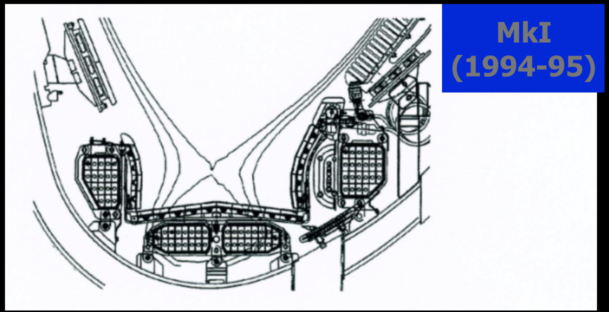
W-coated CFC
Temperature <1200°C

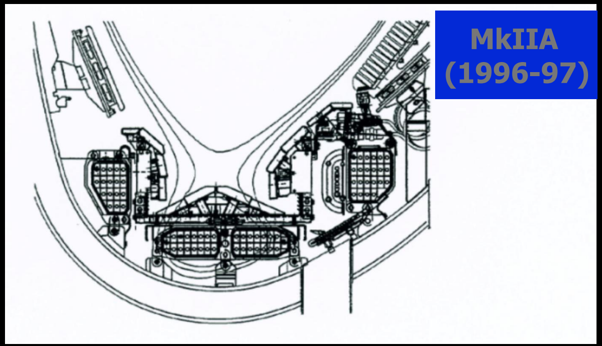
W stacks
Surface temperature limit
<1200°C-2200°C

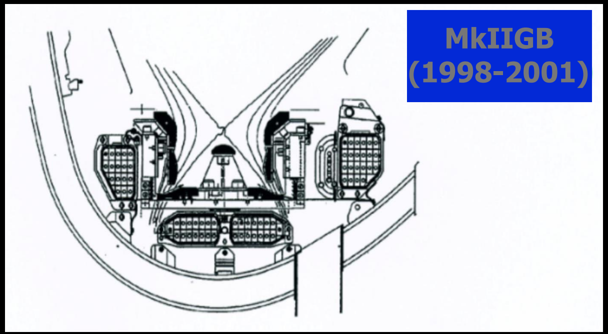
G. Matthews and ILW Team., PFMC-13

Keeping the plasma pure

- Fusion plasmas can become polluted by impurities from the vessel wall as it is heated up.
- Helium 'ash' is also produced by the fusion reaction.





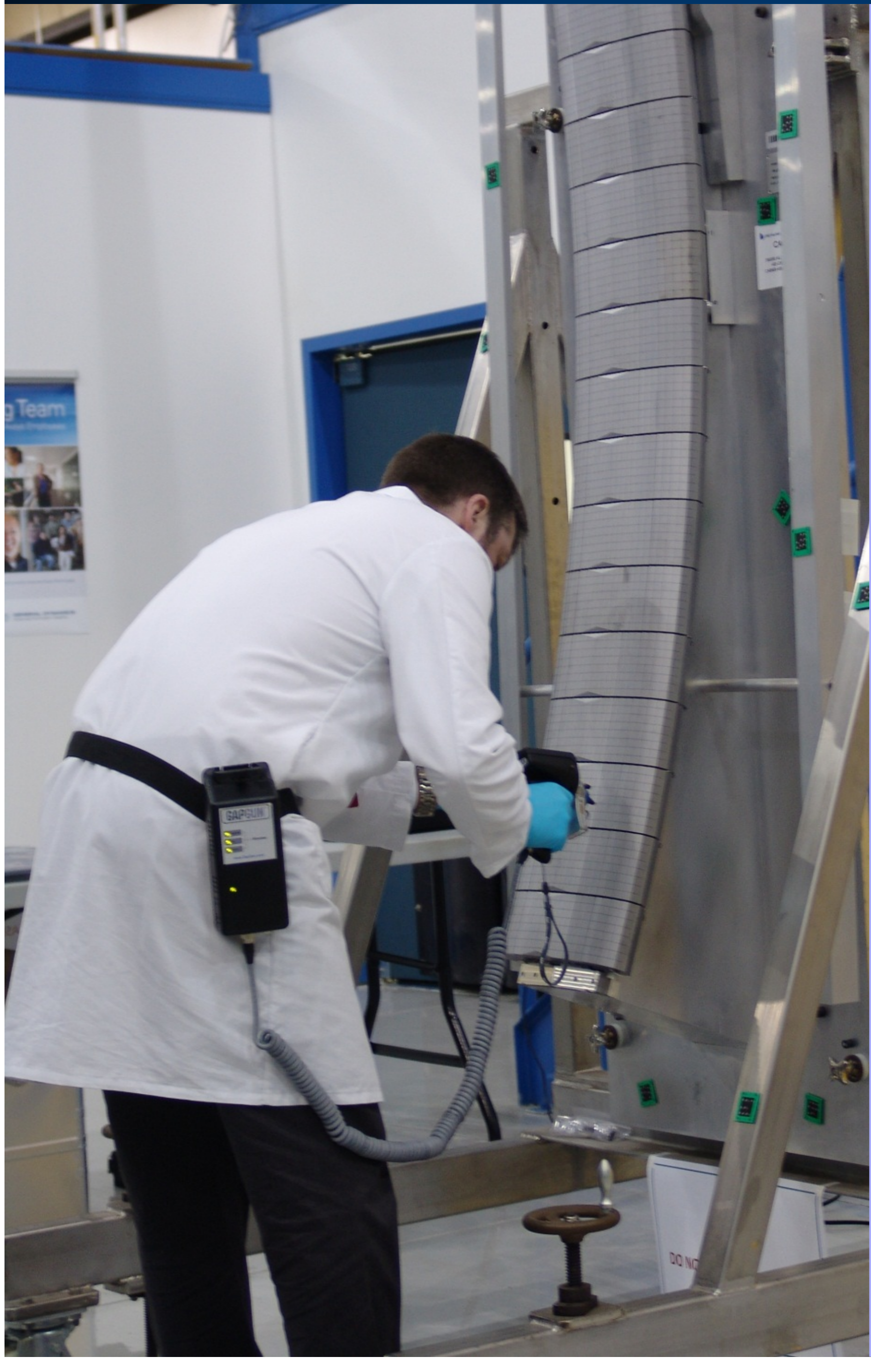


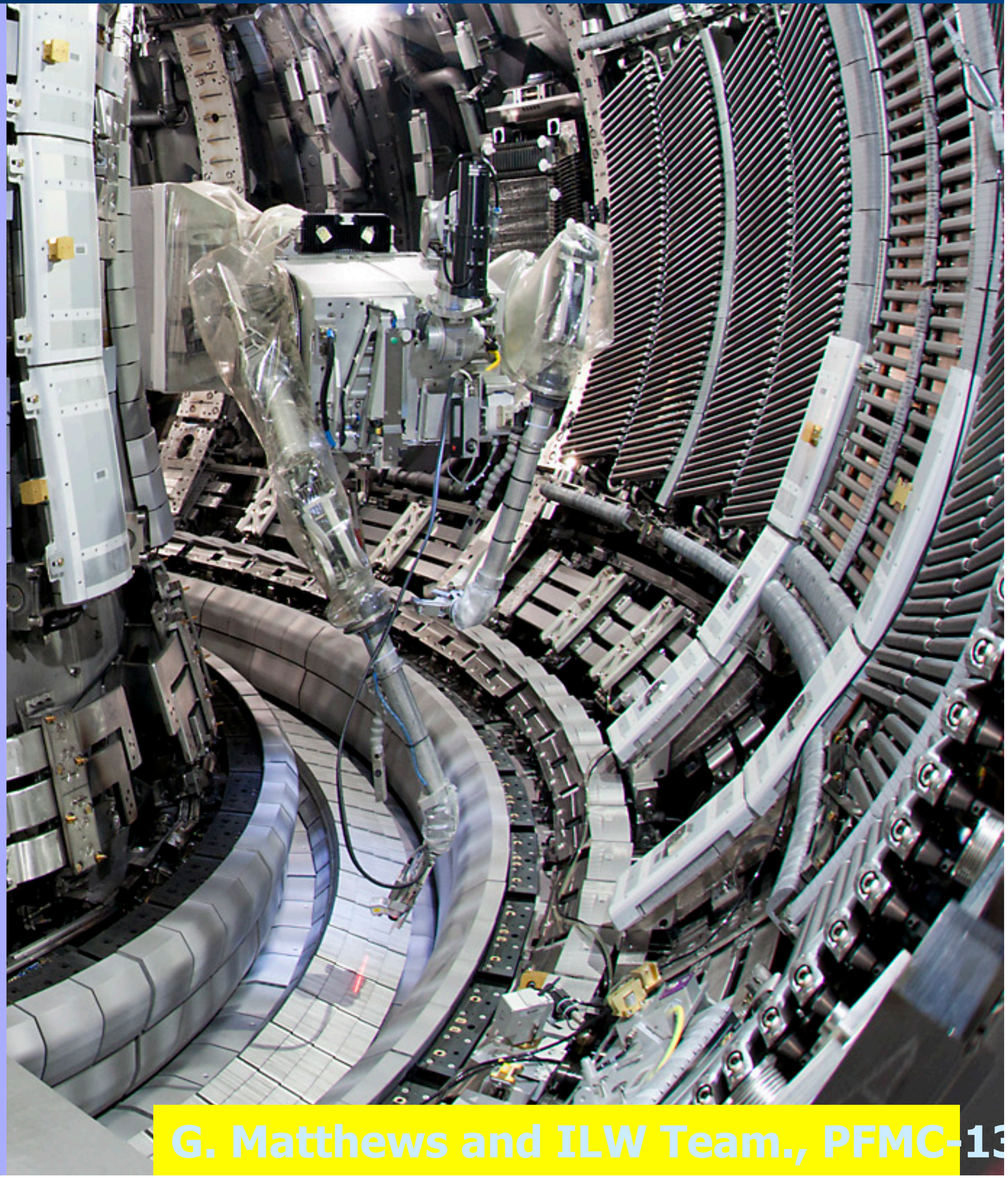
- In a 'divertor' the main plasma is separated from the target tiles by a 'private' plasma.
- Flows in the 'private' region can resist impurity influx.

The ITER-Like Wall: Tungsten Divertor

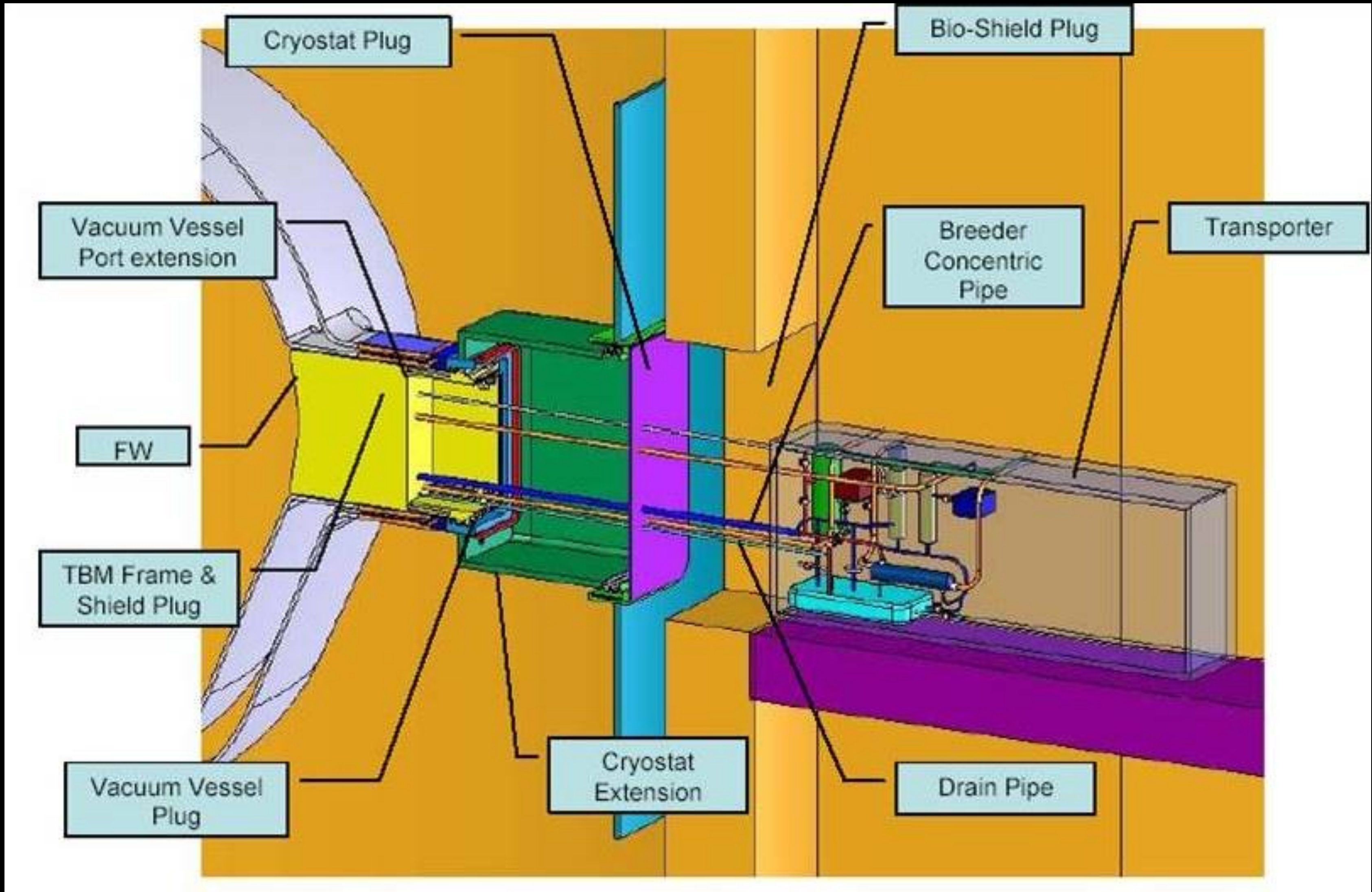
G. Matthews and ILW Team., PFMC-13

The ITER-Like Wall: Remote Handling



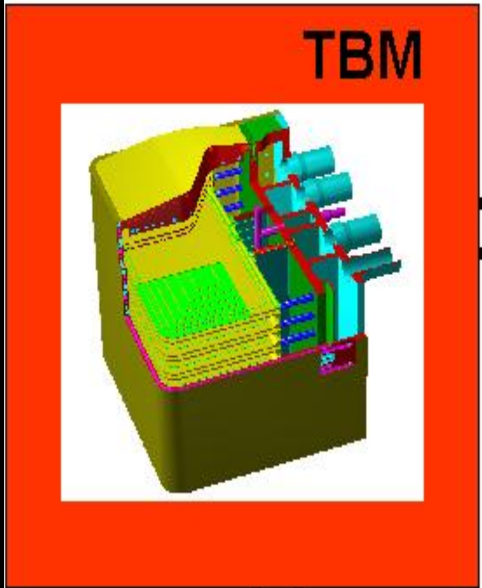


Tritium breeding in ITER
- three test blanket modules (TBM)

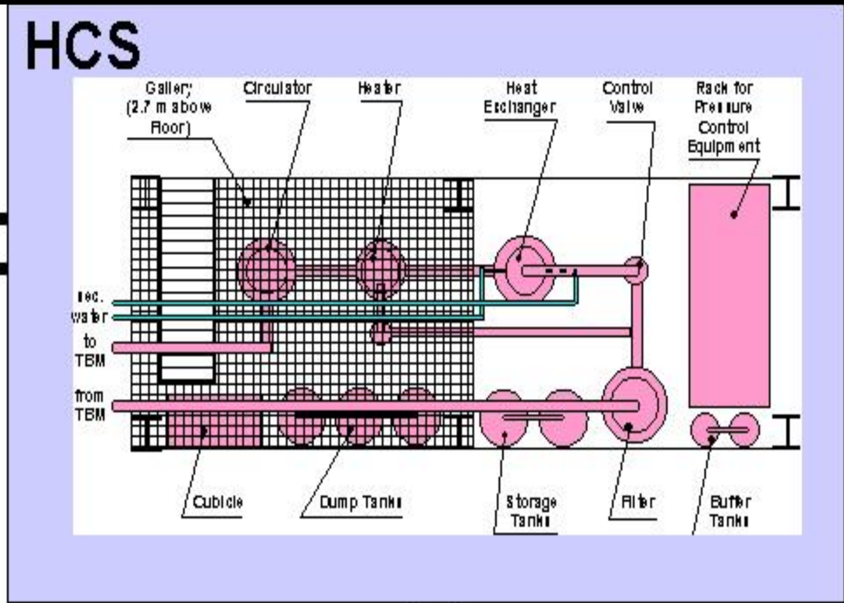


ITER - Blanket Module and Auxiliary Systems

Test Blanket Module



Helium Coolant System



Tritium Extraction System

Coolant Purification System

Fusion: safety and environmental issues - general considerations

- **Negligible climate effect – no emission of greenhouse gas**
- **No long lived radioactive waste, no transports of waste**
- **No risk for nuclear meltdown**
- **Only small amount of tritium fuel active**

Fusion energy is sustainable energy

See http://ec.europa.eu/research/energy/euratom

Fusion: safety and environmental issues - general considerations

Many studies have looked at

- potential impact of fusion power on the environment
- possible risks associated with operating large-scale fusion power plants

Results: fusion can be a very safe and sustainable energy source.

European Safety and Environmental Assessment of Fusion Power (SEAFP):
studied conceptual designs of fusion power stations
and their safety, including
identification and modelling of every conceivable accident scenario.

This research has been extended in subsequent studies.

Fusion: safety and environmental issues - general considerations

SEAFP concluded that fusion has very good inherent safety qualities:
- absence of 'chain reaction’
- no production of long-lived, highly radiotoxic products.

The worst possible accident would not be able to breach the confinement barriers.

Even *if* confinement barriers would be breached, accidental radioactive release from a fusion power station cannot reach levels that would require the evacuation of the local community.

The inherent safety characteristics of a fusion reactor are due to
- very low fuel inventory in the reactor during operation
- rapid cooling, extinguishing fusion reactions should a malfunction occur

As tritium is produced and used inside the reactor, no transport of radioactive fuel is needed.

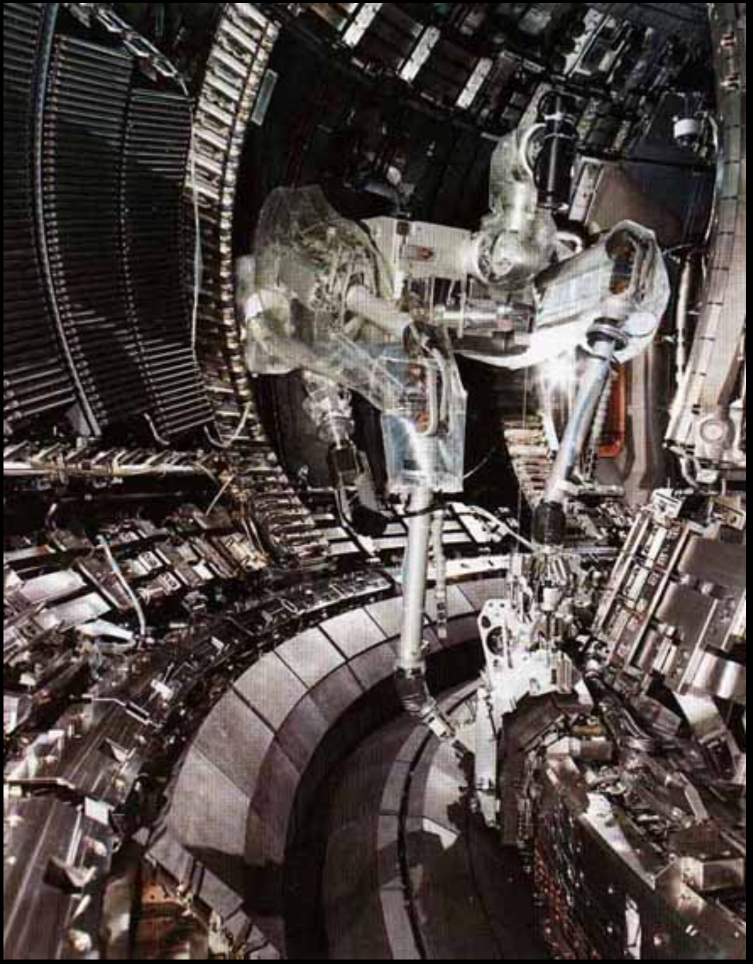
Fusion: safety and environmental issues

- **T-fuel is radioactive** (beta decay, 12 y halftime, extremely unlikely loss of 1 kg T causes however only 50 mSv 1 km away; evacuation not needed)

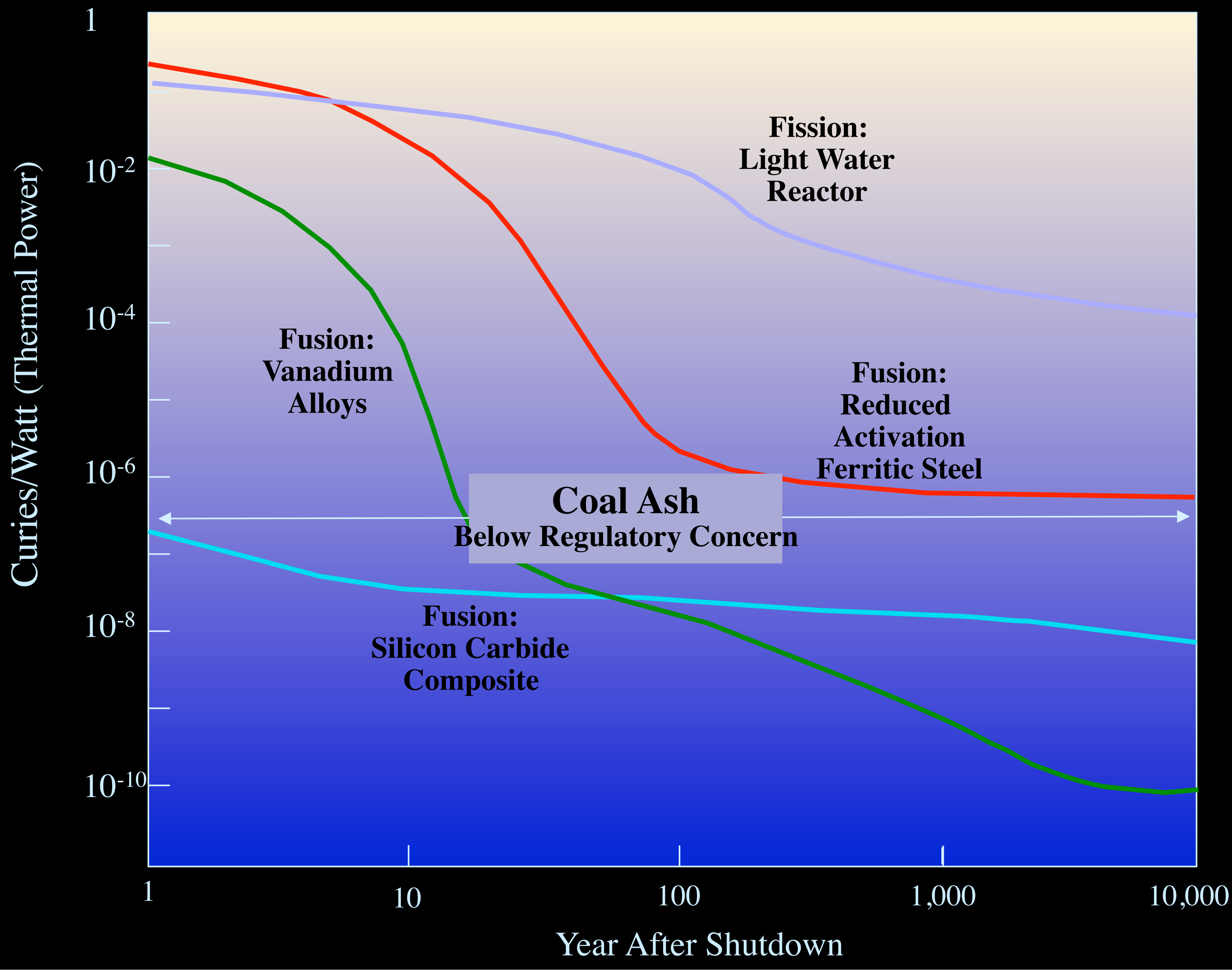
- **Reactor walls activated** (initial activity as for fission, but within 10-100 y the activity is 4-5 orders of magnitude lower than that of fission)

- **Disruptions** can cause wall damage or harm supraconducting magnets

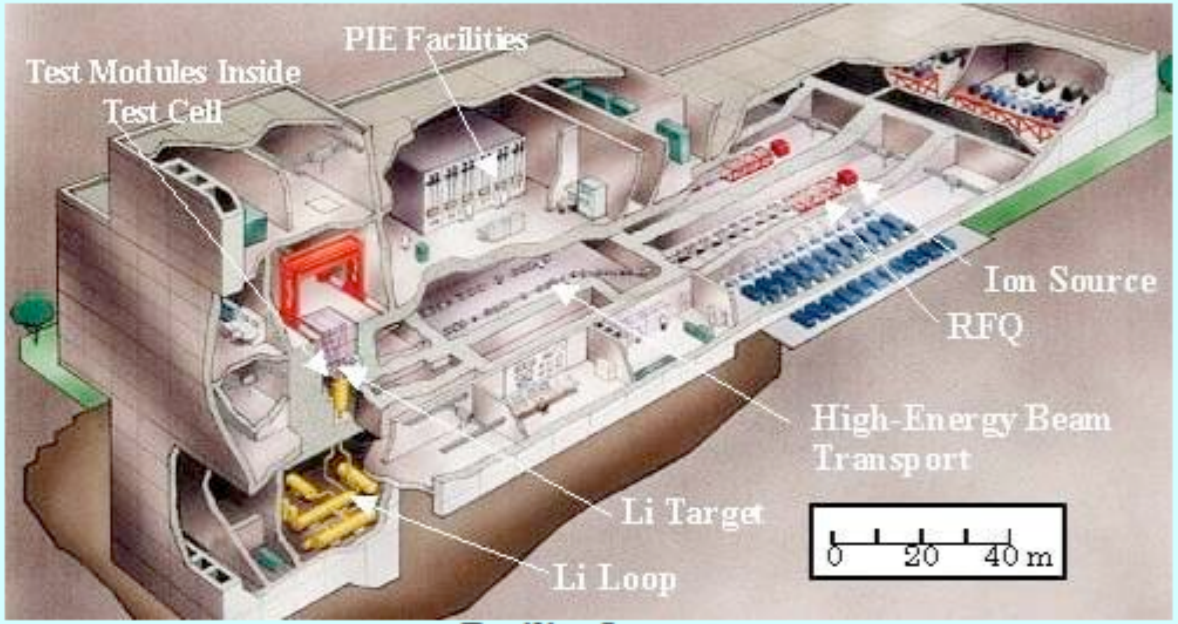
- **Liquid lithium**, if used as coolant, is highly reactive



Comparison - radioactivity from fission and fusion after shutdown



IFMIF -
International Fusion Material Irradiation Facility
- Material test facility



Facility Layout

JAEA, Japan:

2 parallel, 50 m, 40 MeV, 250 mA D-accelerators
Liquid Li - target (20 m/s)
Neutron flux: 2 MW/m^2 in 0.5 l volume, 14 MeV, 20 dpa/y

Conclusion – safety and environment

European Safety and Environmental Assessment of Fusion Power (SEAFP)

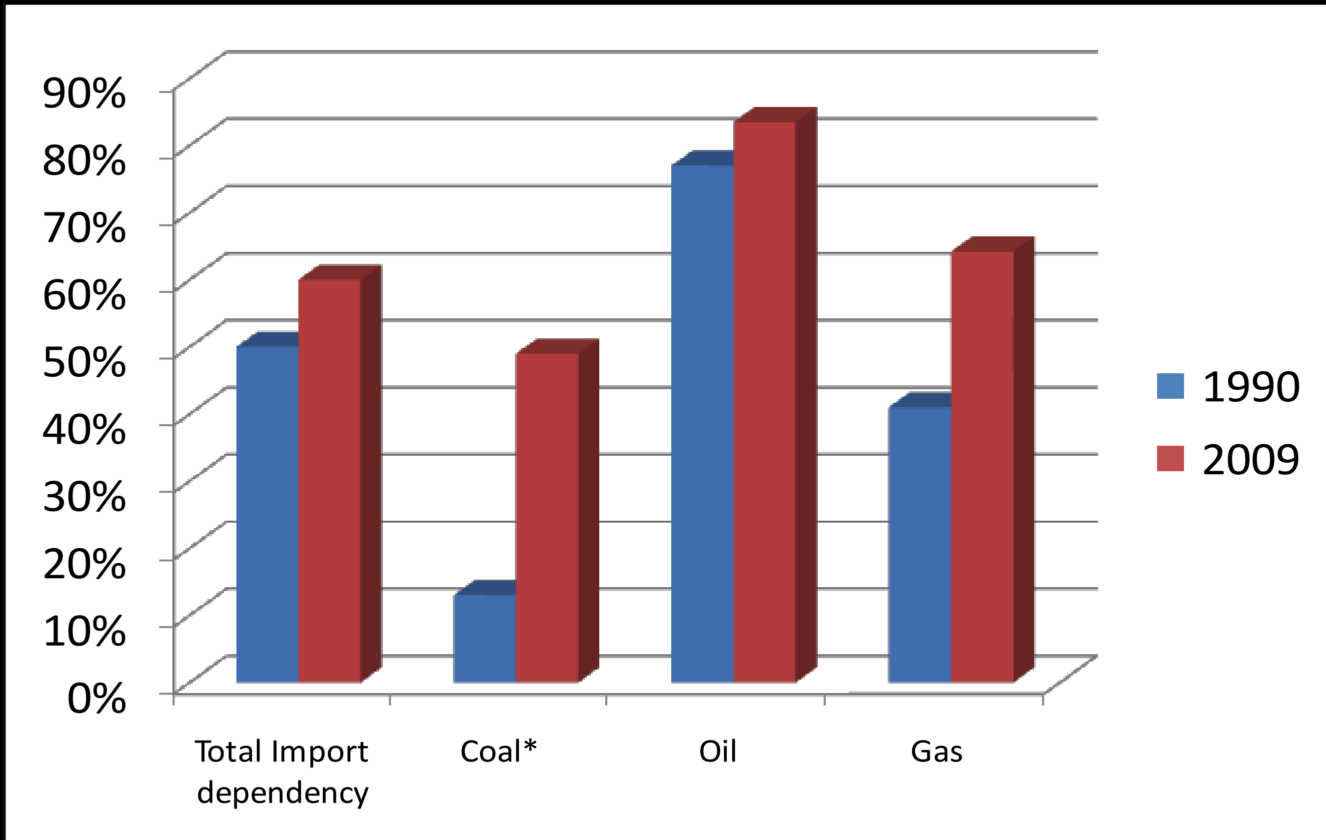
finds that

fusion has potential for becoming a safe energy source with low external costs.

EU Energy Dependency

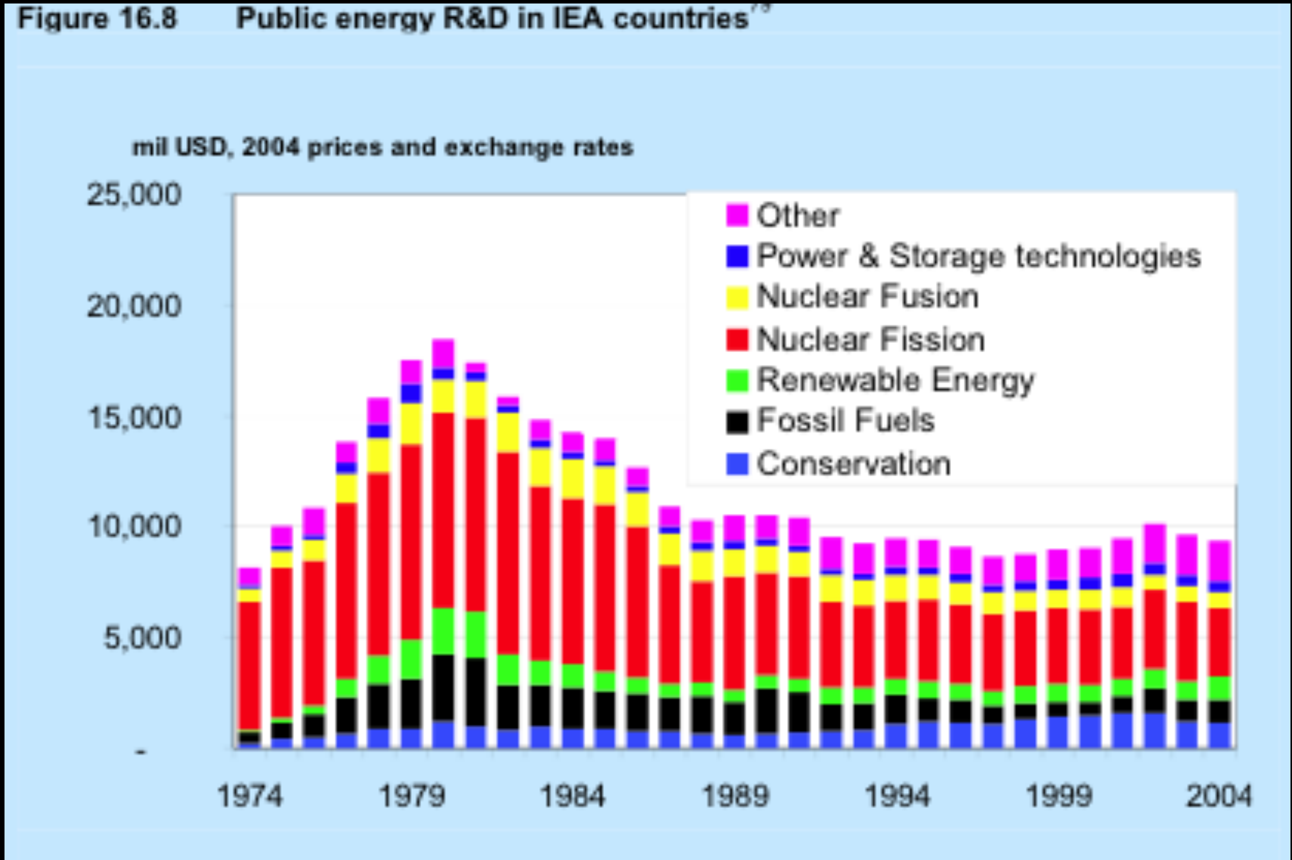
EU dependency on import is increasing for all fossil fuels...
Dependency on oil imports reached 83.5% in 2009 and 64.2% for gas.

EU-27 Energy import dependency



Source: Eurostat May 2011- *Coal and other solid fuels

Stern report - “The Economics of Climate Change”



In a 700 page report, on connection between world economy and global heating, Stern emphasizes the importance of a new policy for investment in innovations within the energy field:

"Globally, support for energy R&D should at least double, and support for the deployment of new low-carbon technologies should increase up to fivefold."

DEMO parameters: factors in Cost of Electricity

- **DEMO Phase 2 is the last stage before Commercial Power Plant - we must consider Cost of Electricity (CoE).**
- **PPCS studies reveal Relatively simple scaling can be developed for Cost of Electricity (CoE).**
- **CoE depends on:**
  - **capital cost and hence size of 'nuclear island' (magnets,vacuum vessel, vessel contents)**
  - **Operational parameters:**

$$\mathrm{CoE} \propto \left(\frac{1}{A}\right)^{0.6} \frac{1}{\eta_{th}^{0.5}} \frac{1}{P_e^{0.4}\,\beta_N^{0.4}\,n^{0.3}}$$

Availability

Thermodynamic efficiency

Net electrical power

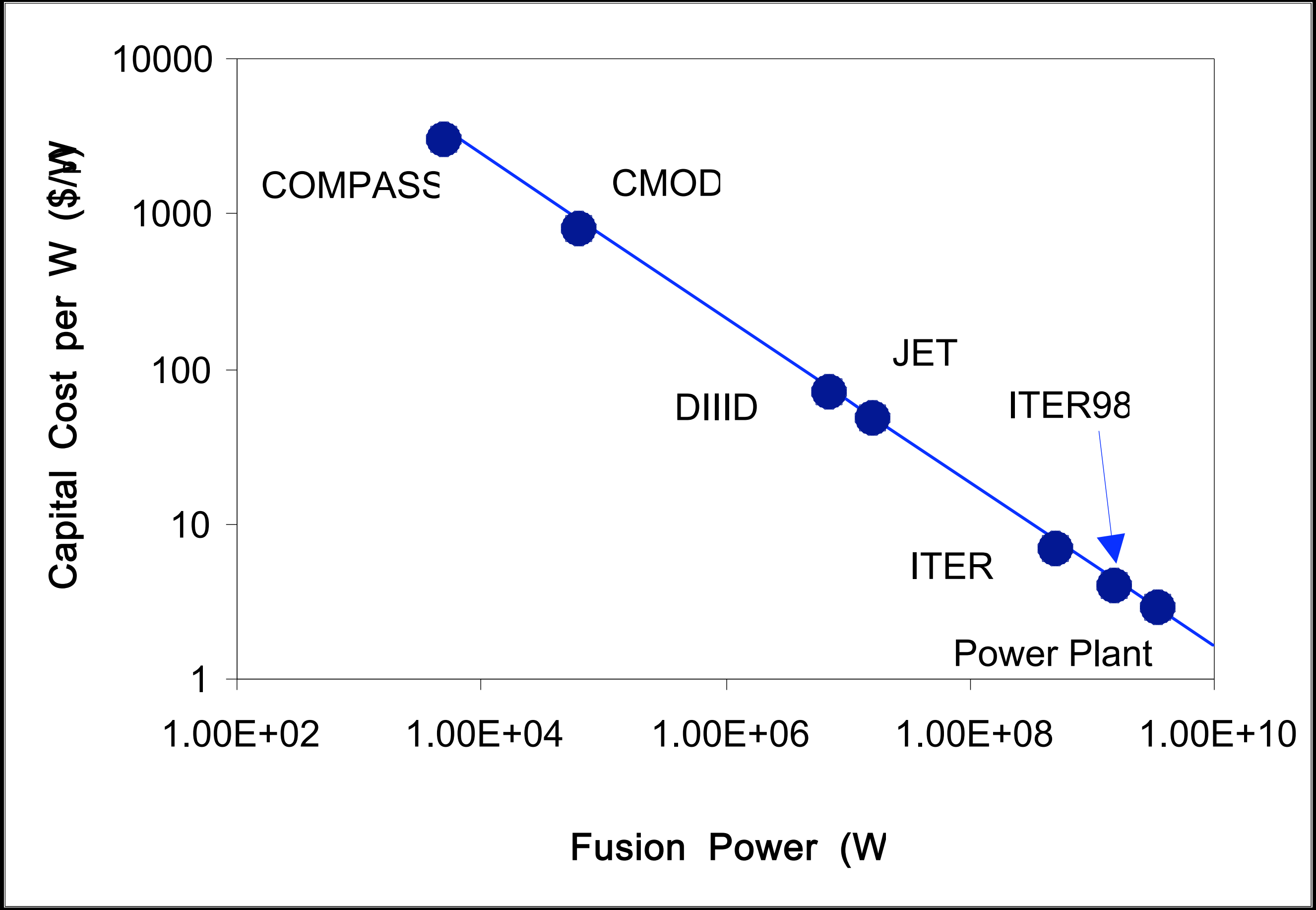
Physics - high β, high density

UKAEA

UKAEA Fusion Working with Europe

Economy for fusion

Direct costs (COE), according to EFDA SERF-study:
ca 0.06-0.08 €/kWh electricity



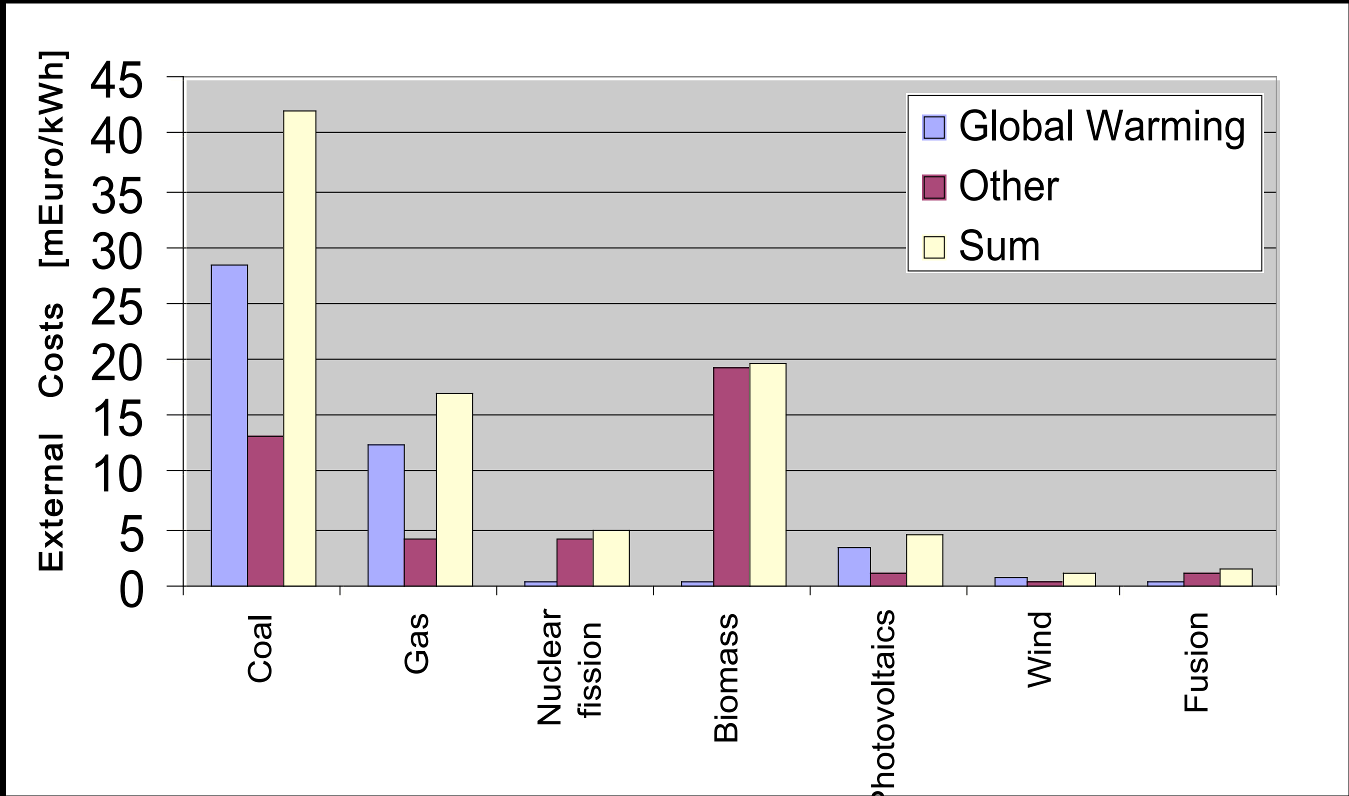
Direct costs: construction, maintenance, fuelling, shutdown.

Energiequelle	Kapitalkosten in Euro pro kW	Produktionskosten in Euro per kWh	Übliche Größe des Kraftwerks in kW	Emission von Treibhausgasen in °C equiv. pro kWh	Landverbrauch in km^2 pro 1.000 MW
Ölprodukte	1.000	0,25	1-10.000	200	1
Kohle	800 - 1.100	0,05	1.000 - 1.000.000	270	1-2,5 plus Minen
Gas	300 - 600	0,035 - 0,05	1.000 - 1.000.000	180	1
Kernspaltung	1.000 - 1.500	0,05 - 0,08	250.000 - 1.000.000	6*	1 plus Minen und Sicherheitszonen****
Wasserkraft	1.400	0,05	10.000 - 20.000.000	20*	30 - 40
Solar PV (photovoltaisch)	4.000 - 6.000**	0,25	0,01-10	25*	23
Wind	700 - 1.200**	0,06 - 0,10	0,1-100.000	34*	490
Biomasse	1.300 - 1.700	0,05 - 0,10	1-150.000	10*	2.000
Fusion	6.000***	0,05 - 0,10***	1.000.000 - 3.000.000	9*	1

Direct costs for different energy sources

(Energy Information Agency, EFDA)

External costs, electricity production



External costs: greenhouse gas effects on environment, pollution, waste management, radioactivity, accidents.

Only windpower has lower external costs than fusion

From EFDA SERF-study (2007)