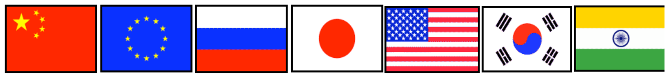
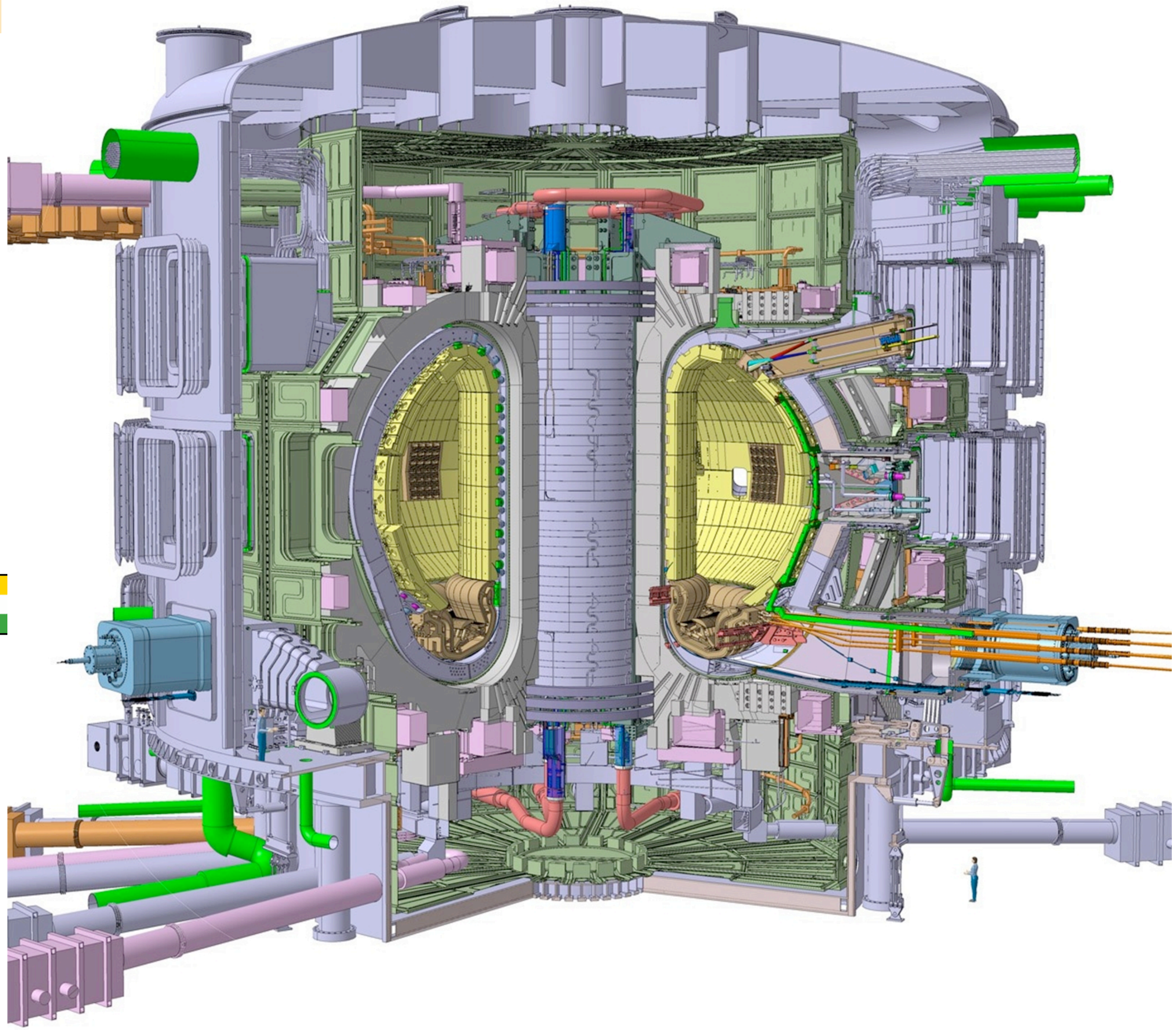
ITER

First Sustained Burning Plasma.
Starts in 2019.

BASIC PARAMETERS.
Plasma Major Radius 6.2m
Plasma Minor Radius 2.0m
Plasma Current 15.0MA
Toroidal Field on Axis 5.3T
Fusion Power 500MW
Burn Flat Top >400s
Power Amplification Q>10

Cost is > 10 Billion Euro.

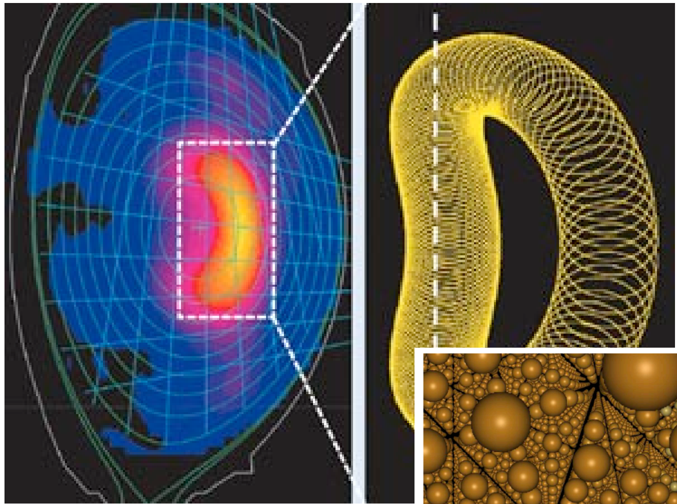


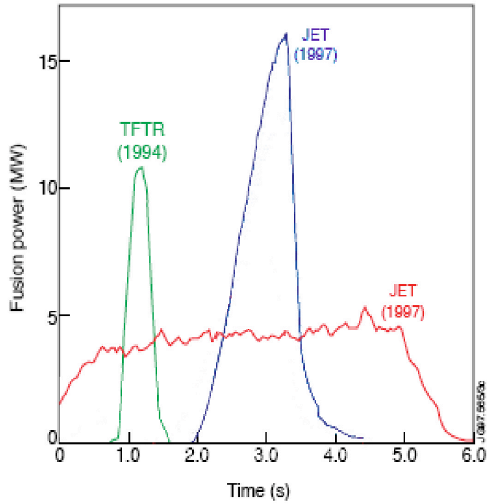


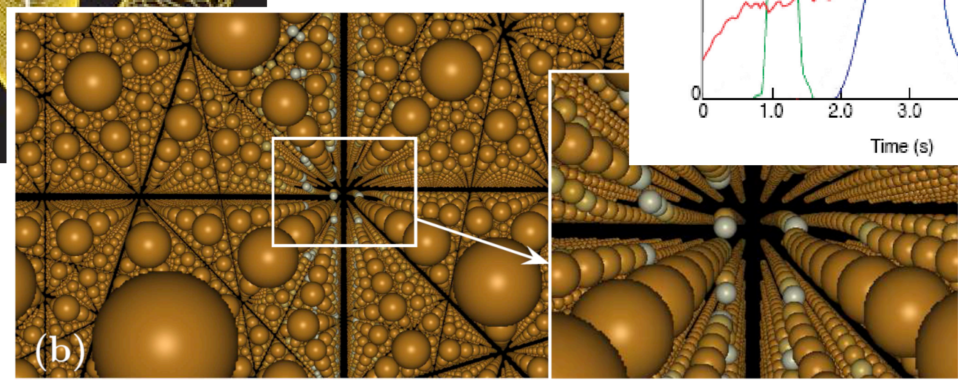
CCFE
CULHAM CENTRE FOR FUSION ENERGY

Fusion
Energy -- International Science.

Steve Cowley -- Culham, UK Atomic Energy Authority







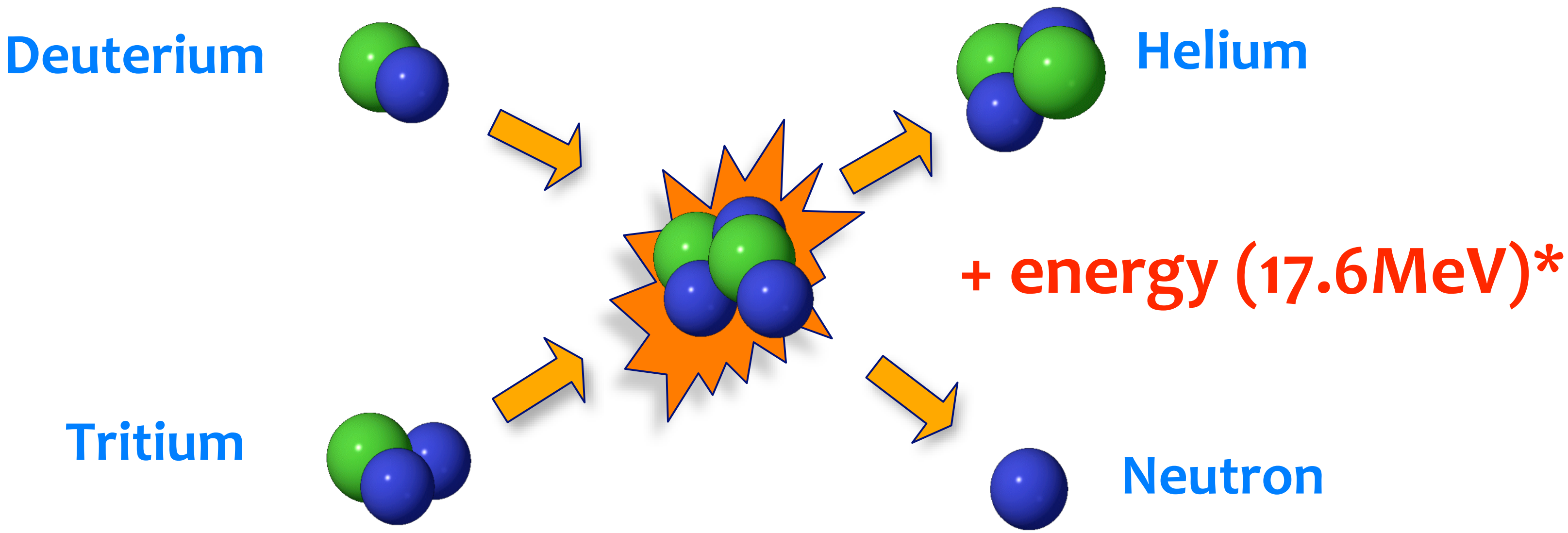
CCFE
CULHAM CENTRE FOR FUSION ENERGY

United Kingdom Atomic Energy Authority

Outline

- ITER -- what will it do? What does it mean?
- How do we know it will work?
- The reactor step, when?
- Start with a very basic introduction to fusion.
- I will highlight issues -- not time to be comprehensive.

Which Fusion?



Tritium is bred from lithium using the neutron

$Li^6 + n \rightarrow He^4 + T$

CCFE CULHAM CENTRE FOR FUSION ENERGY

United Kingdom Atomic Energy Authority

Why?

Sustainable Energy

- Fusion has enormous fuel reserves enough to power the world for many million years.
  - ~30 million years of lithium
  - ~60 billion years of deuterium

  This is why we must do fusion.

- No greenhouse gases, minimal environmental impact.

- Low risk of significant accident.

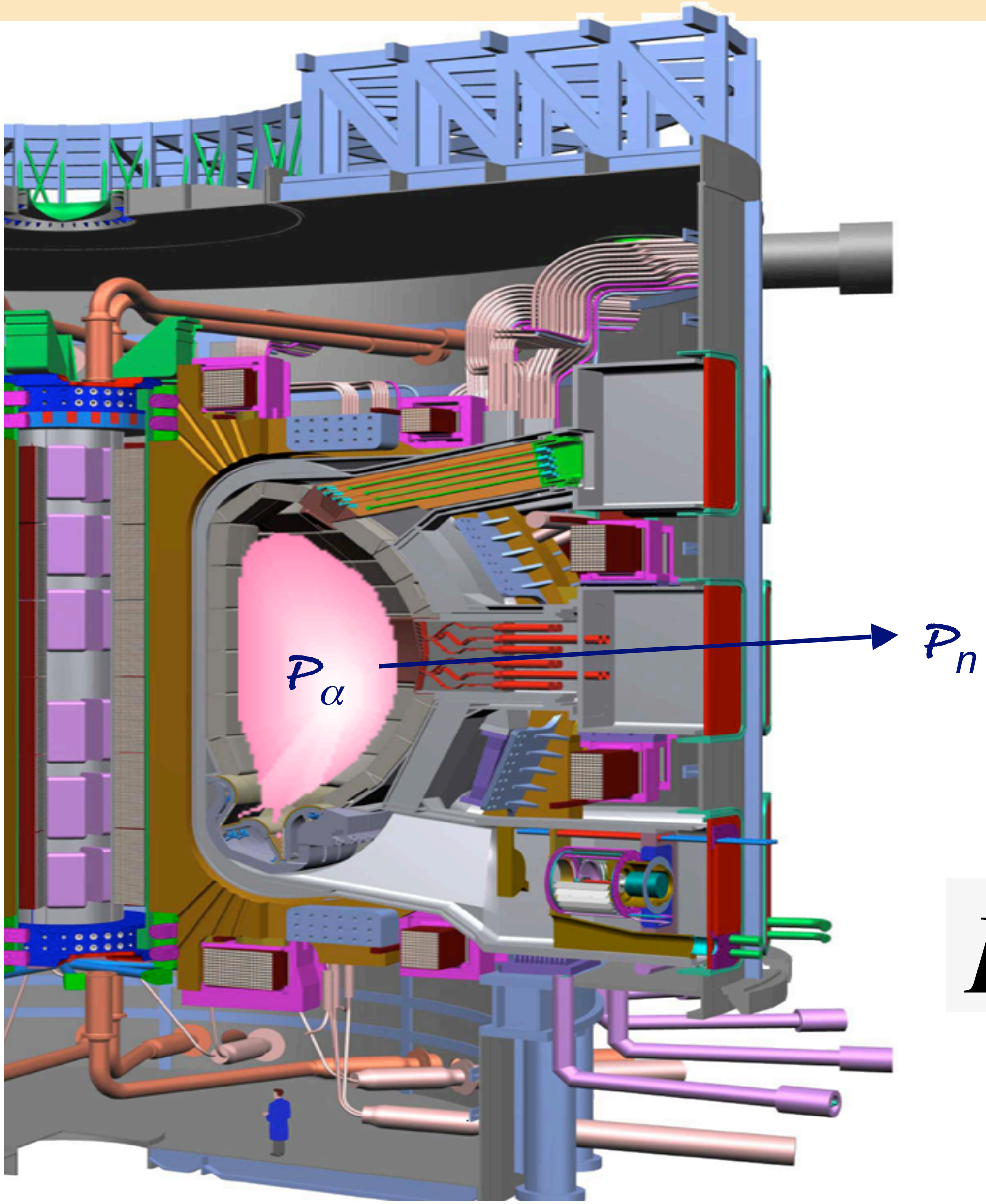
- Low land use.

- Can it be made commercially competitive?

CCFE CULHAM CENTRE FOR FUSION ENERGY

United Kingdom Atomic Energy Authority

Fusion Energy Balance in ITER



'Baseline Performance'

Power in alphas captured by Plasma $\mathcal{P}_\alpha \sim 100MW$.

Power in neutrons escaping Plasma $\mathcal{P}_n \sim 400MW$.

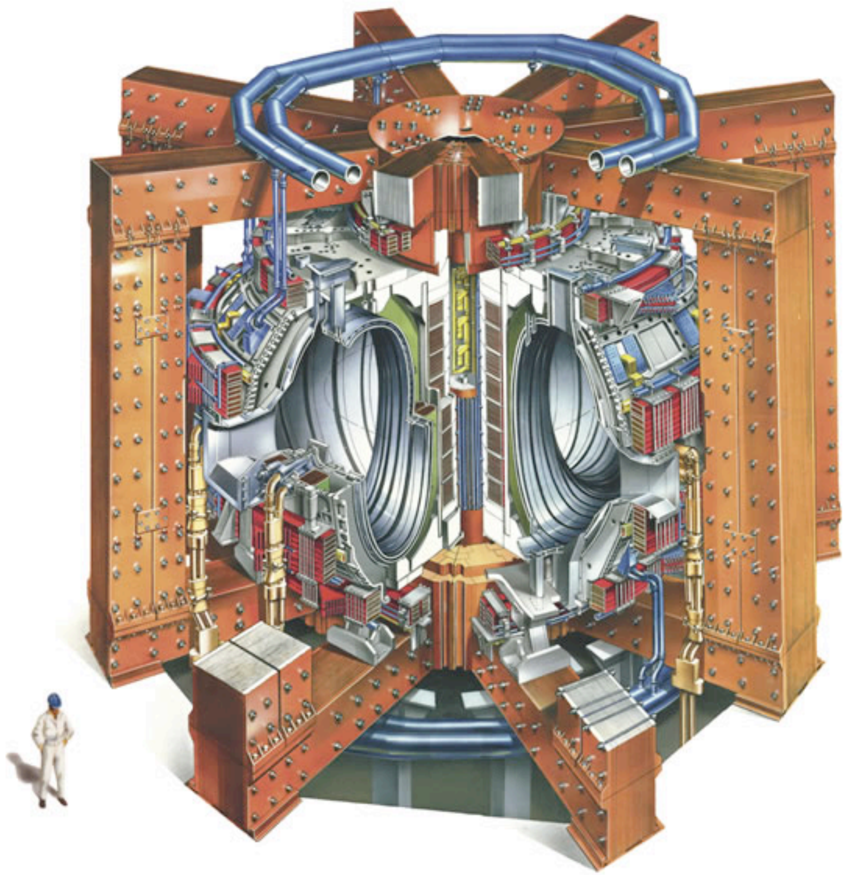
$\mathcal{P}_n + \mathcal{P}_\alpha = \mathcal{P}_{Fusion}$

$$D + T \rightarrow He^4 + n$$

3.5MeV 14MeV

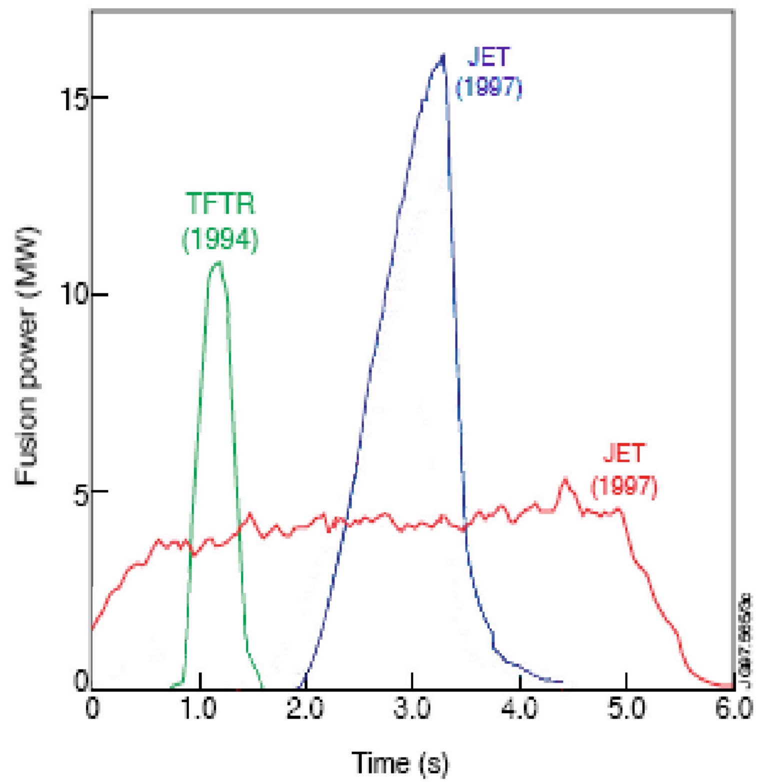
How do we know this will happen?

SUCCESS!! 1997 at Culham



Currently the only machine capable of fusion

16MW fusion power 1997



CCFE
CULHAM CENTRE FOR FUSION ENERGY

Gyro-kinetic simulation.

DIII-D Shot 121717

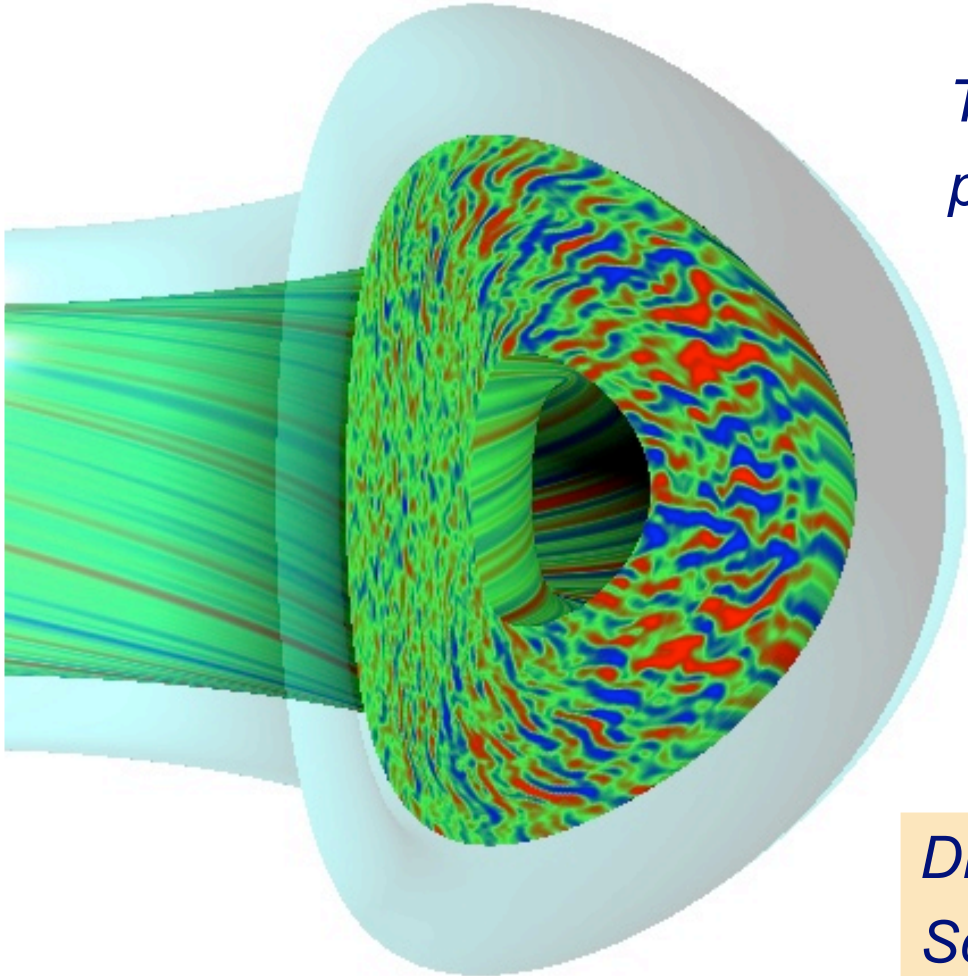
GYRO Simulation

Cray X1E, 256 MSPs

CCFE CULHAM CENTRE FOR FUSION ENERGY

GYRO code simulations by Jeff Candy and Ron Waltz GA

Energy Confinement -- Random walk of heat/particles.



Time for heat to leave the plasma "Energy Confinement Time=

$$\tau_E \sim N\tau_{eddy} \sim (\frac{L^3}{\rho_i^2 v_{thi}})$$

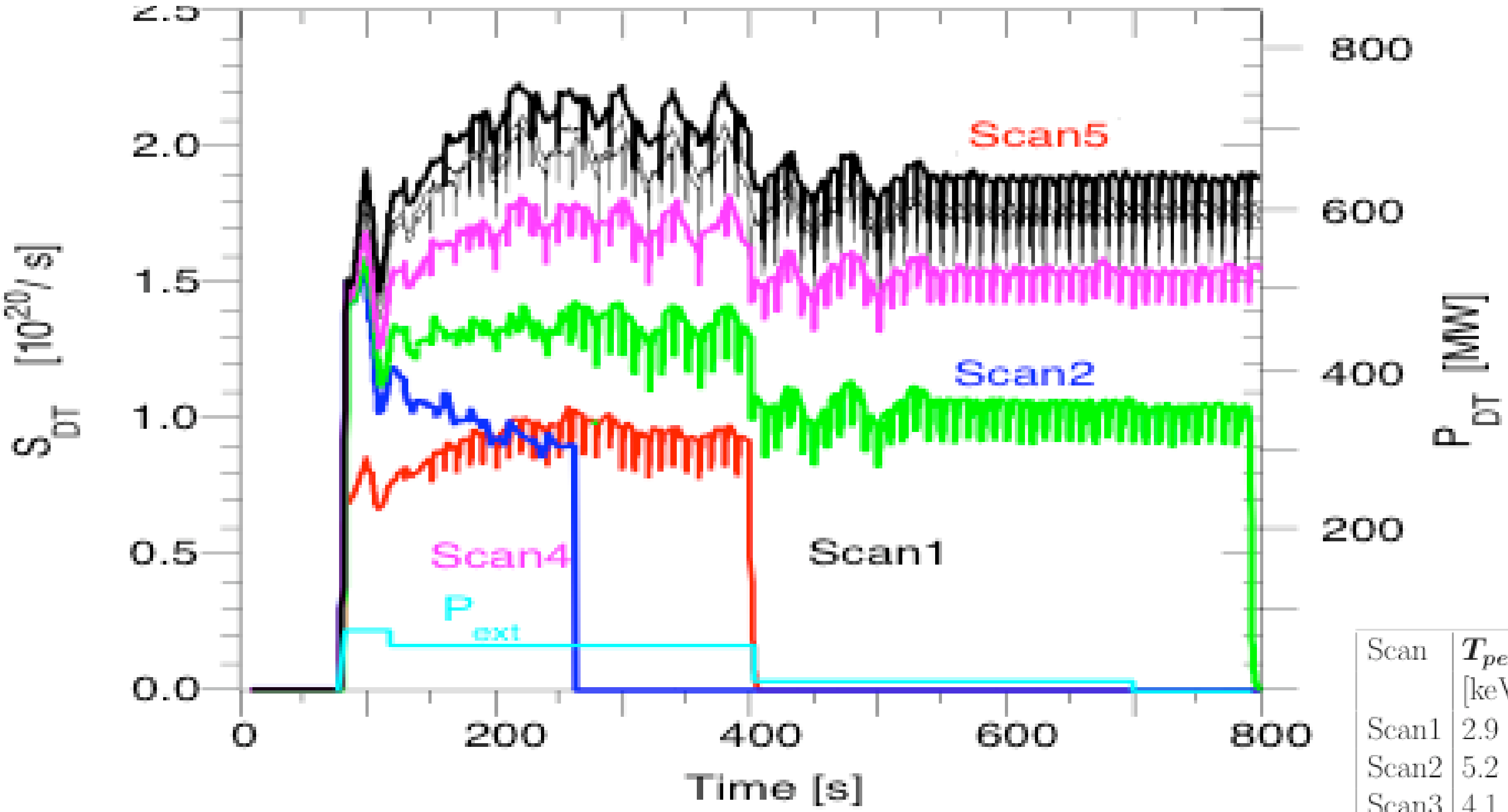
$$\propto L^3 B^2 T^{-1}$$

Dramatic scaling with size!
Scaling approximately agrees with data BUT geometry dependant.

CCFE
CULHAM CENTRE FOR FUSION ENERGY

Detailed Modeling e.g.

Budny 2009



Scan	T_{ped} [keV]	D_{ash} $[m^2/s]$	V_{ash} $[m/s]$
Scan1	2.9	0.1	+0.1
Scan2	5.2	0.1	+0.1
Scan3	4.1	0.1	+0.1
Scan4	4.1	0.1	-0.1
Scan5	4.1	0.15	-0.1
Scan6	4.1	0.25	-0.1
Scan7	4.1	0.5	-0.1
Scan8	4.1	1.0	-0.1

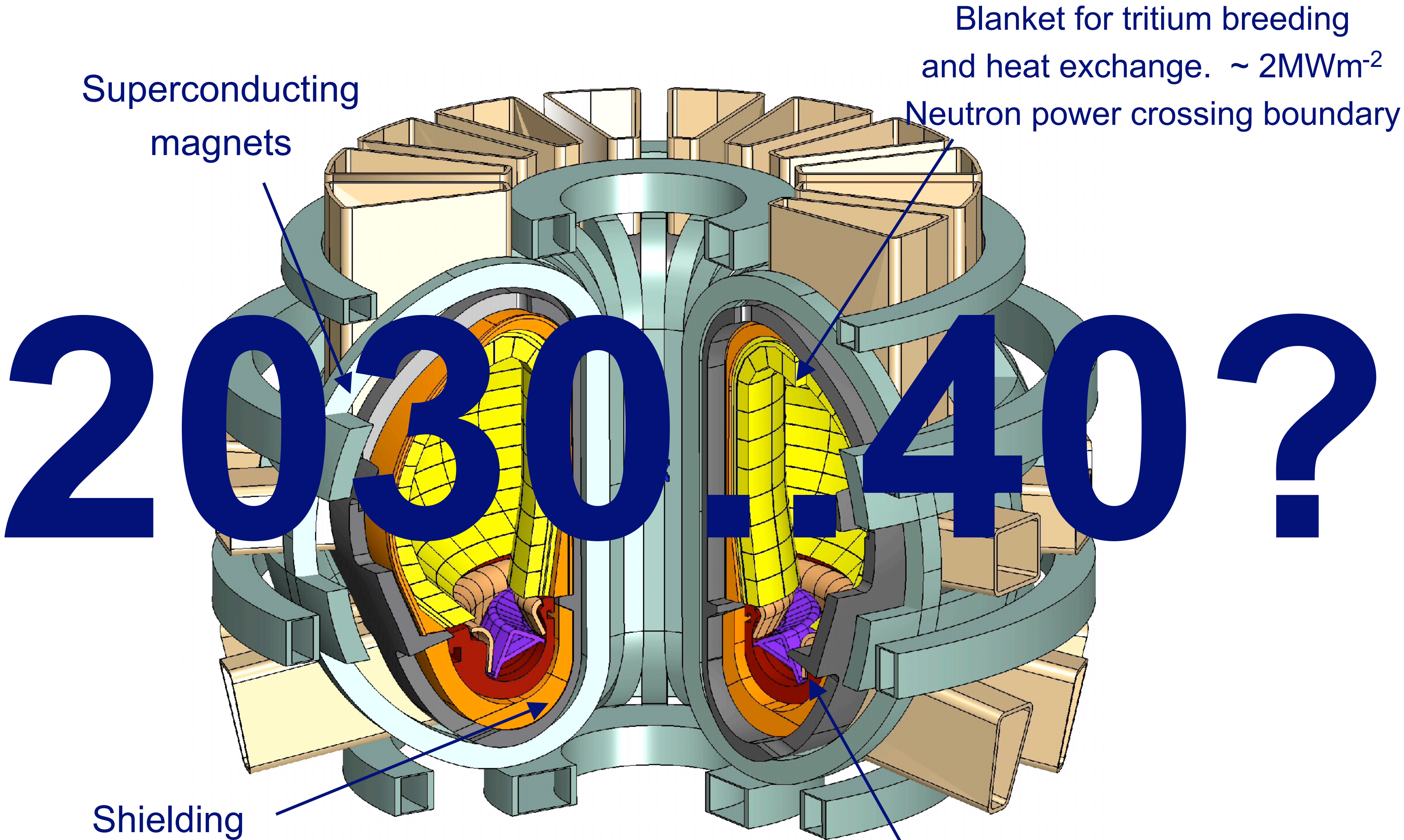
CCFE
CULHAM CENTRE FOR FUSION ENERGY

The reactor step -- when?

CCFE
CULHAM CENTRE FOR FUSION ENERGY

United Kingdom Atomic Energy Authority

Demo Reactor -- some electricity.



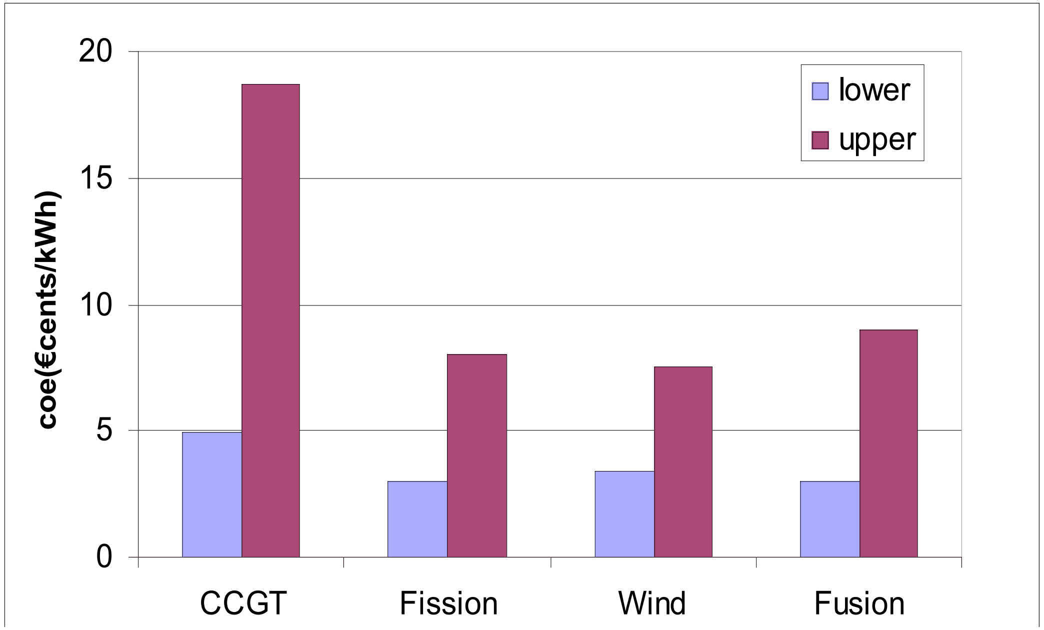
CCFE
CULHAM CENTRE FOR FUSION ENERGY

Cost -- is it competitive?

CCFE
CULHAM CENTRE FOR FUSION ENERGY

United Kingdom Atomic Energy Authority

Direct Cost Comparison with Other Future Projections



Large uncertainty inherent in projections. Include projected fuel price increases but no carbon tax. Wind is near term technology but no standby or storage costs.

Source: "Projected Costs of Generating Electricity" IEA, 1998 Update, PPCS

CCFE CULHAM CENTRE FOR FUSION ENERGY

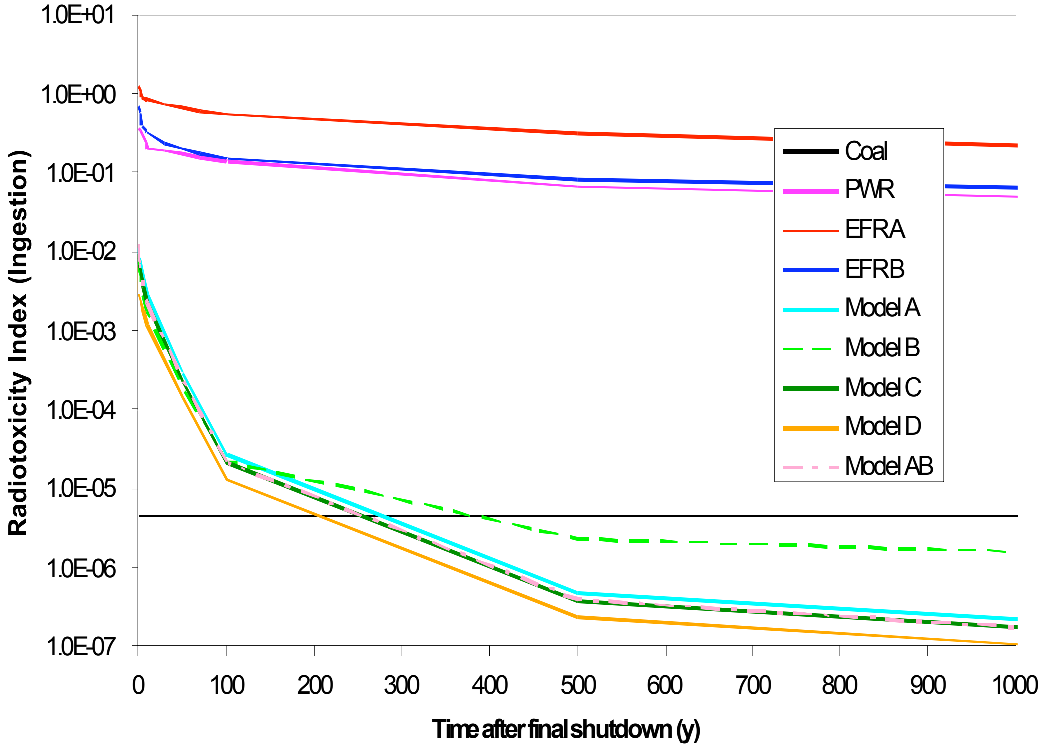
United Kingdom Atomic Energy Authority

Waste

CCFE
CULHAM CENTRE FOR FUSION ENERGY

United Kingdom Atomic Energy Authority

Potential Harm from Waste Materials



Radiological hazard from fusion materials decays rapidly, with half life of around 10 years.

Source: PPCS

CCFE CULHAM CENTRE FOR FUSION ENERGY

United Kingdom Atomic Energy Authority

What next?

CCFE
CULHAM CENTRE FOR FUSION ENERGY

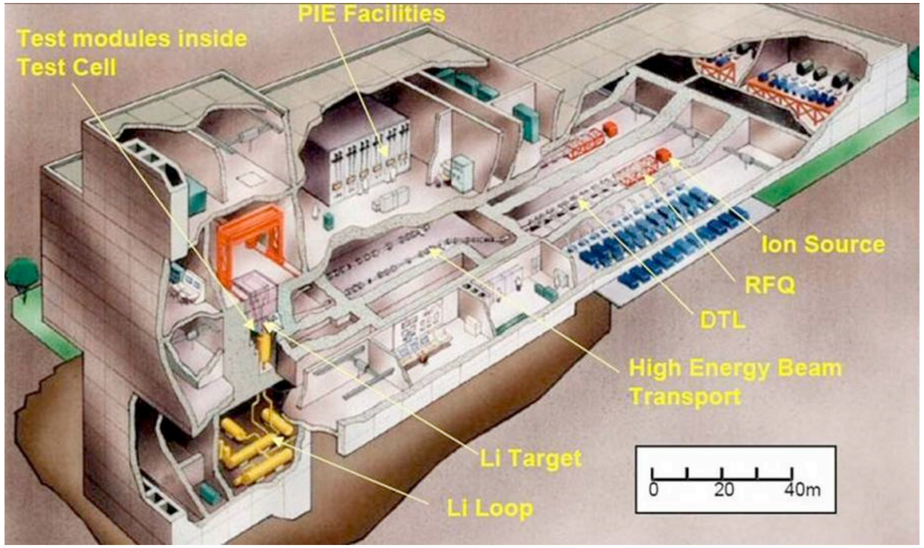
United Kingdom Atomic Energy Authority

Materials Testing --The IFMIF/EVEDA Project

- EU-JA bilateral agreement. Its an addition to the ITER project

- IFMIF: International Fusion Materials Irradiation Facility -> intense flux of 14MeV neutrons for material characterization

  (2 CW linacs, 125mA deuterons, 40MeV, lithium target)



- EVEDA: Engineering Validation and Engineering Design Activities -> prototype for IFMIF (1 CW accelerator 125mA, 9MeV)

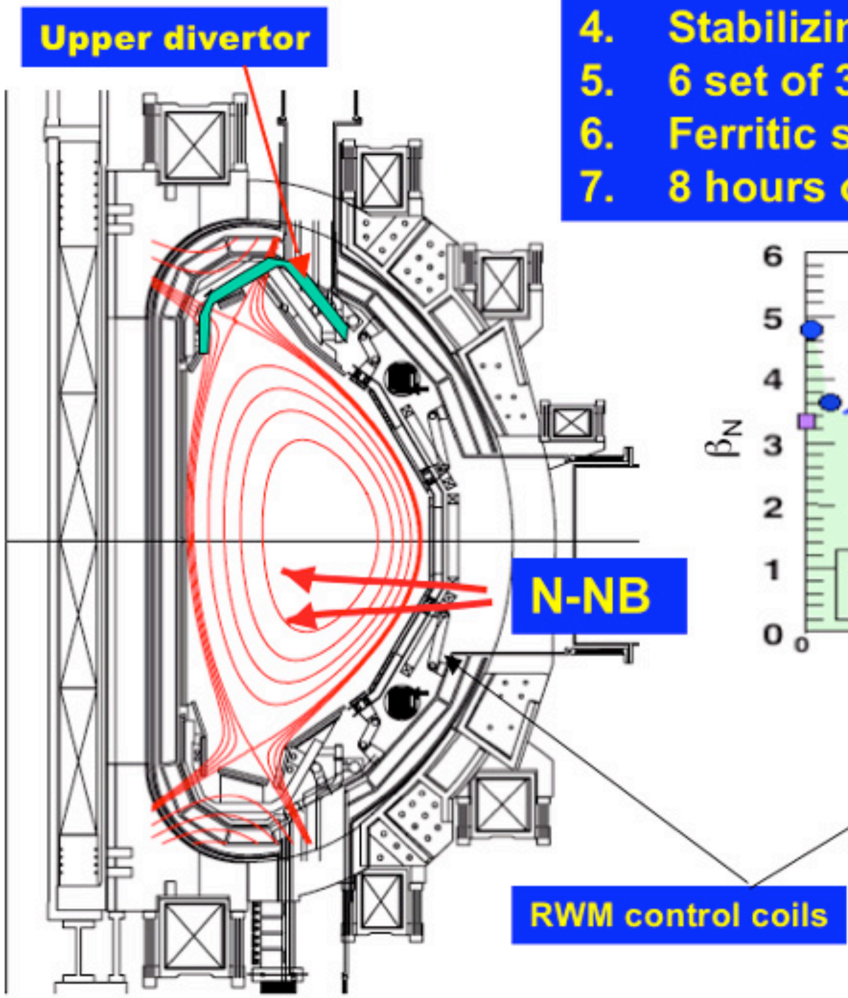
CCFE CULHAM CENTRE FOR FUSION ENERGY

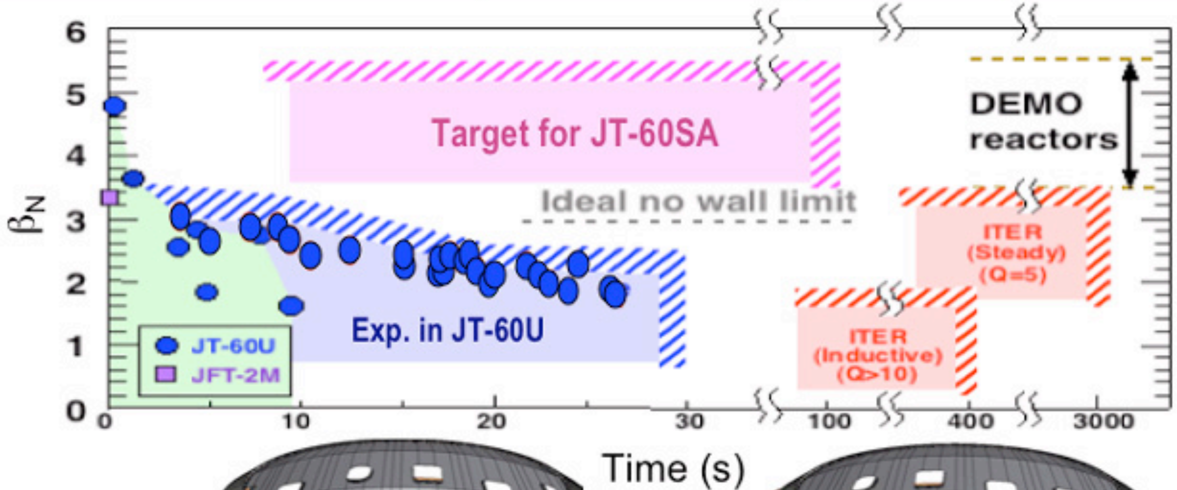
United Kingdom Atomic Energy Authority

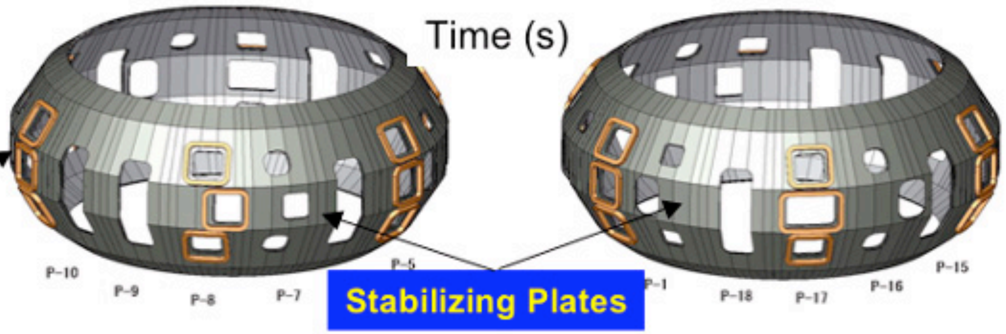
JT-60SA has various features to supplement ITER for DEMO

High beta steady-state operation for DEMO

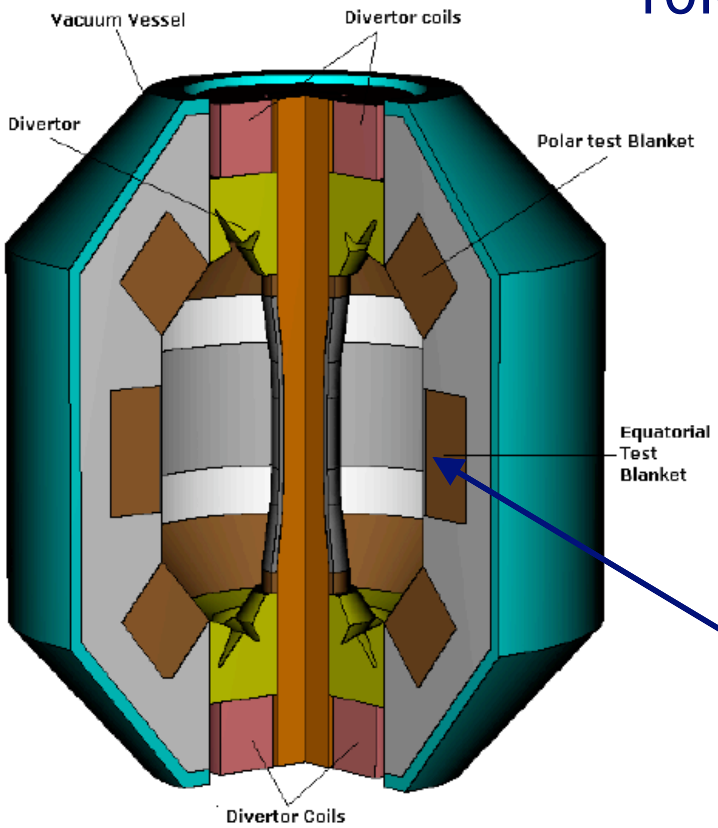
1. Wider shaping opportunities (low A~2.6, DN)
2. Upper divertor to match high triangularity
3. Down-shifted N-NBCD to form reversed shear
4. Stabilizing plates (SP) for RWM control
5. 6 set of 3 poloidal n=1,2 RWM control coils
6. Ferritic steel on SP to simulate DEMO
7. 8 hours of continuous operation as long term target





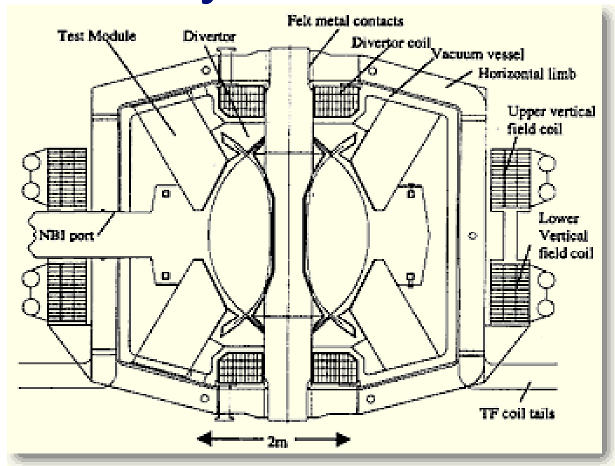


A Hope -- Component Test Facility



10MWyear/m^2 fluence neutrons

12 years



*1.6*MW/m^2 neutron flux

<1kg tritium per year.

Based on MAST (Culham) and NSTX (Princeton).

Develop the IP of fusion.

CCFE
CULHAM CENTRE FOR FUSION ENERGY

Fusion Soon.

- *With ITER we will do fusion at large scale. But commercial fusion needs technology developments.*

  We could get a first fusion reactor online by 2045.

- *It requires considerable investment -- political will is vital.*
- *Fusion at compact scale is more speculative -- but… …*
- *We need ideas, technical help and determination.*

CCFE
CULHAM CENTRE FOR FUSION ENERGY

United Kingdom Atomic Energy Authority