ITER – An Overview

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IAC Student Meeting

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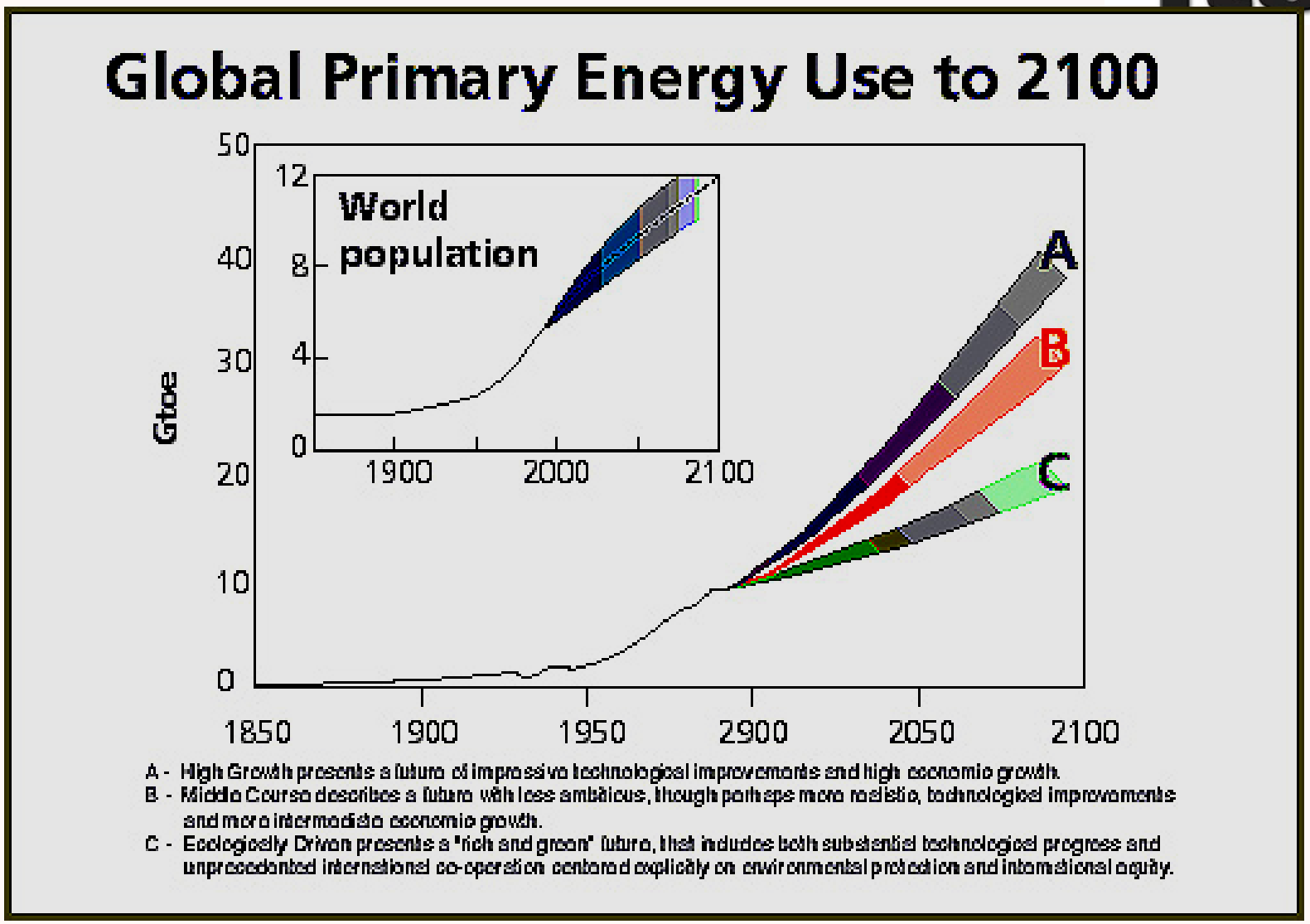
Oak Ridge National Laboratory

Houston, we have a problem

The world needs a lot of energy
Where will it come from?

Foreseen global increase in population and energy consumption ~ x 2 in 50 years



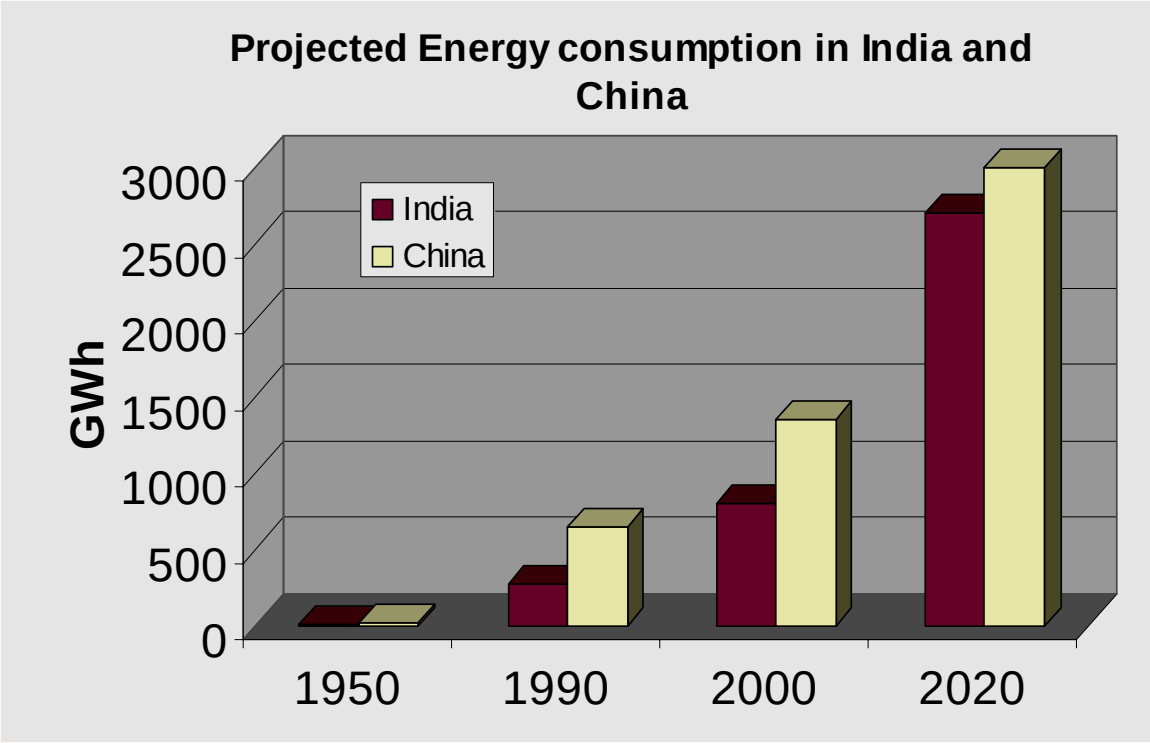
Per capita consumption of electricity (KWh)

COUNTRY	*1990*	*2000**	*2020**
Canada	19000	22000	24000
USA	12000	15000	18000
UK	6000	9000	14000
Japan	7000	10000	13000
Brazil	1850	2500	5500
China	500	1000	2000
India	250	600	1800
WORLD AVERAGE	1500	1900	2300

* estimates

- ***China and India are developing fast***

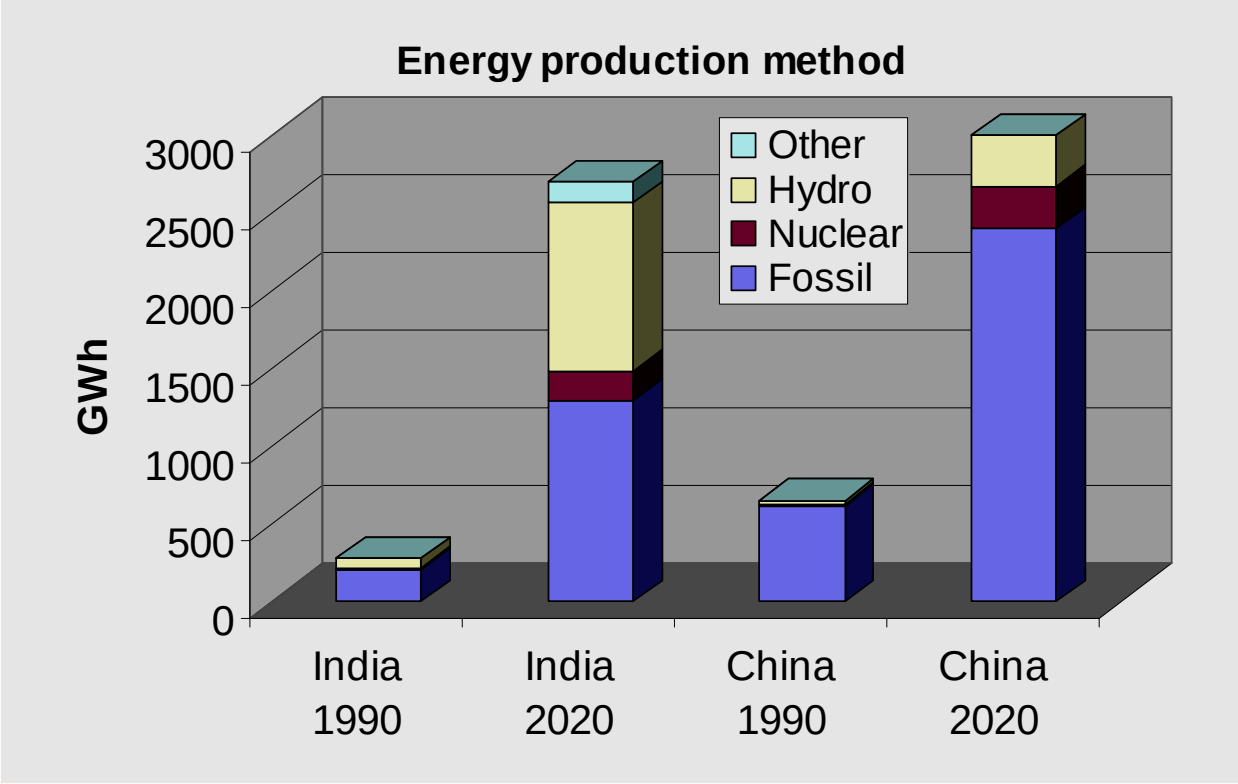
Energy projections for India and China
20% of world's energy total by 2020



- Similar trends are apparent for all developing countries in Latin America, Asia, and Africa.

How is all this "Base" Energy going to be produced?

Power generation mix includes a lot of fossile fuels, produces a lot of CO_2



- By 2020 both India and China will be generating the same amount of CO2 by fossil fuel burn as the USA (2/3 of world total for the 3).

HUGE environmental impact of such CO_2 production

What are the alternatives?

Comparison among foreseen energy production methods – (green is favorable)

	FOSSIL			RENEWABLE	FISSION	FUSION
	Coal	Oil	Gas	(Hydro, Aeolian, Photovoltaic, etc)		(projected)
Economic cost/KWh (main cost factor)	Moder. (fuel)	Mod-High (fuel)	Moder. (fuel)	High (low fuel efficiency)	Moderate (equipment, safety)	Moderate (equipment)
Economic cost trend	⇑	⇑	⇔	⇓	⇑ (safety)	⇓
Generic efficiency of method	Moder.	Moder.	Low-moder.	Very low - low	High	High
Energy efficiency of fuel	Low	Low-moder.	Very low	Very low	High	Very high
Labour intensity	High	Moder.-high	Moder.-high	Low	Low	Low
Environmental Cost/KWh	Very High (CO, CO_2, soot, mines, surface, etc)	Very High (CO, CO_2, etc)	Mod.-high (CO, CO_2 etc.)	Low (some effect on environmental balance, e.g. dams)	High (Moderate-High radioactivity and long-term waste storage)	Low (Short-term waste storage)
Environm. cost trend	⇑	⇑	⇑	⇔	⇑	⇔
Perceived health hazard and danger	**High**	**High**	**Moder.**	**Low**	**High – very high**	Low
Fuel availability, now	High	High	High	High	High	High
Fuel avail. in 50 years	Mod.	Low	High	High	Moderate - high	High
Stage of development	High	High	Moder.	Low - Moderate	High	Moderate
Public acceptance	Moder.	Moder.	High	High	Very Low	? (probably high)
Public acceptance trend	⇓	⇓	⇔	⇑	⇓	? (potentially ⇑)

Red = Negative aspect, Blue = Neutral aspect, Green = Positive aspect

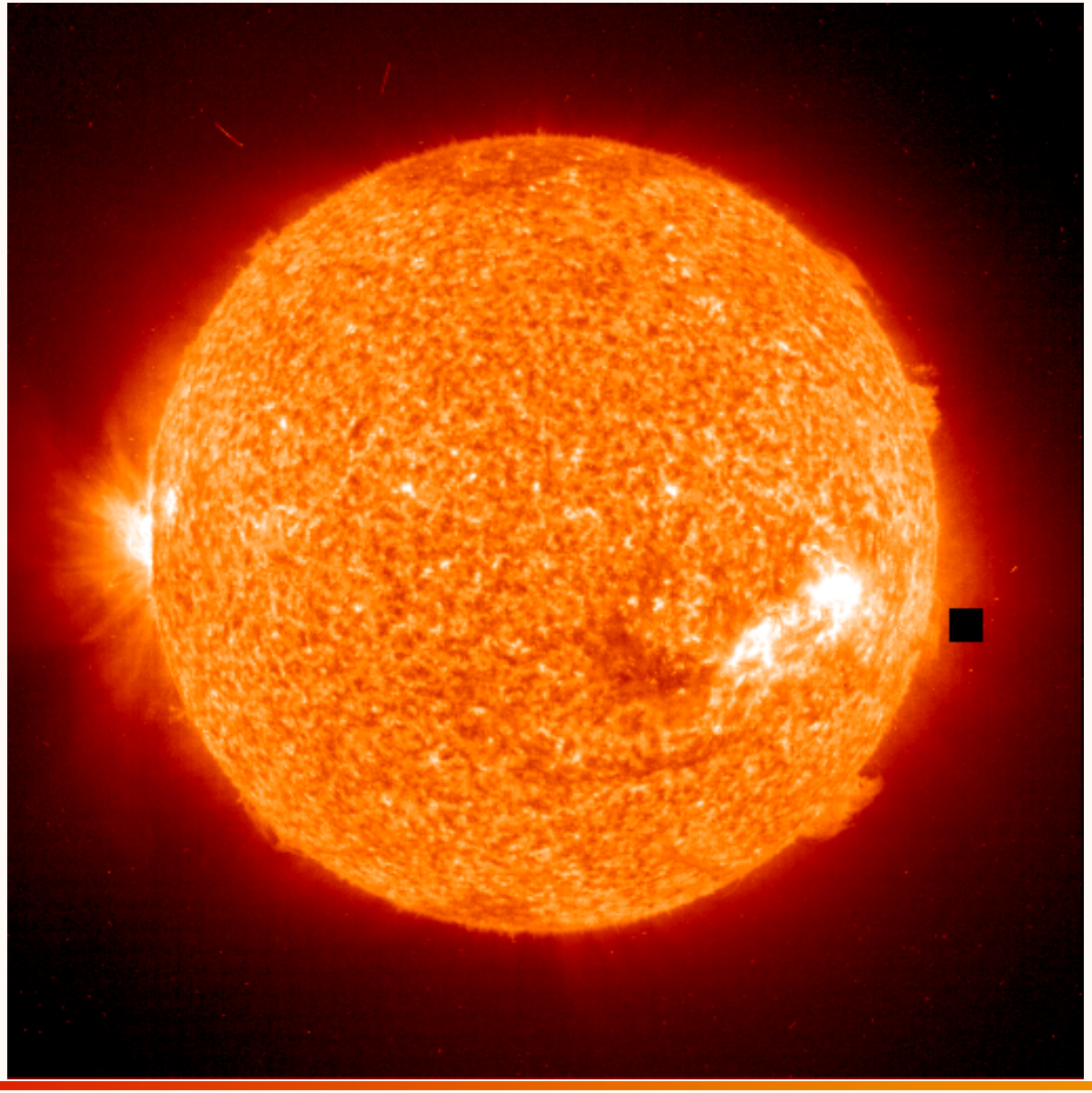
Comparative cost of power generation (mils/kW-e-h)

	Fossil	Fission		Fusion (Tokamak)	
Plant Type	(Coal)	PWR-ME*	PWR-BE*	Aries I	Aries II
Plant size (MWe)	2x500	1100	1100	1000	1000
Capital	22	57	30	53	35
Operation and Maint.	6	13	9	7	7
Fuel	22	8	7	6	6
Decommissioning	0.1	0.6	0.6	0.5	0.5
TOTAL	50	78	46	66	48

(without taking into account direct and indirect environmental costs)

What is Fusion?

Our Sun

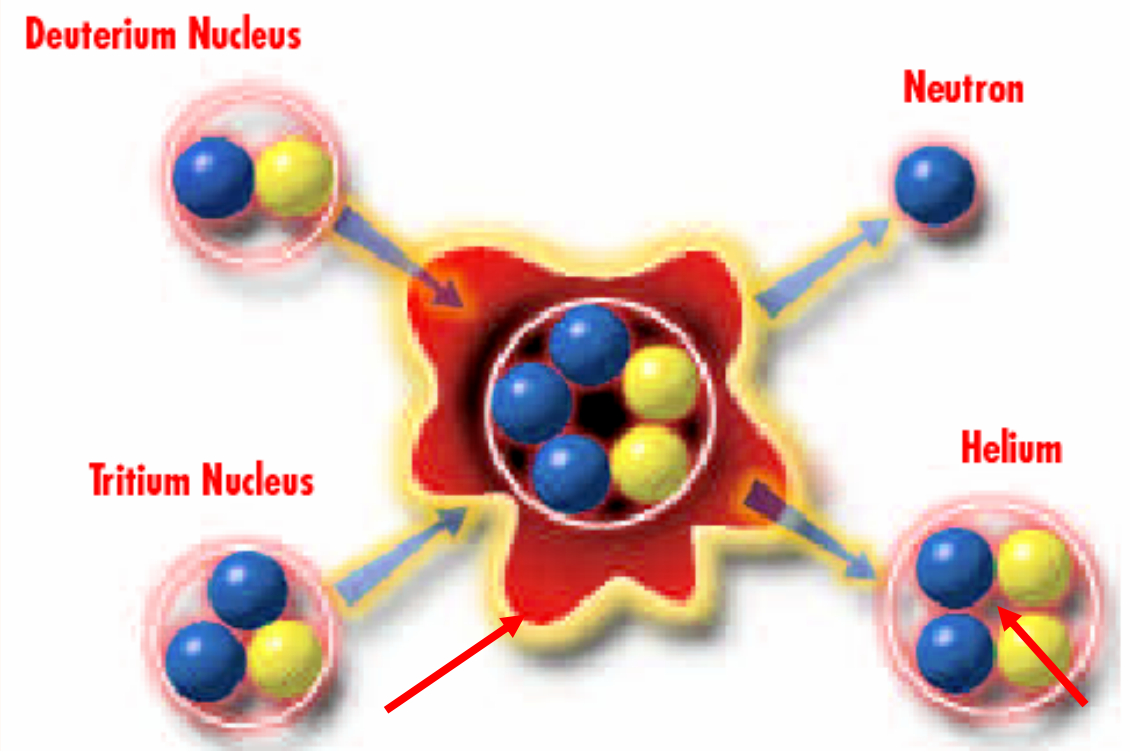


Billions of Stars…

Fusion is apparently part of our future: Back to the Future…

Fusion Background – What is a fusion reaction?

- A fusion reaction takes place when two light nuclei combine to form a heavier nuclei, (the opposite of nuclear fission)



80% of energy release (14.1 Mev)

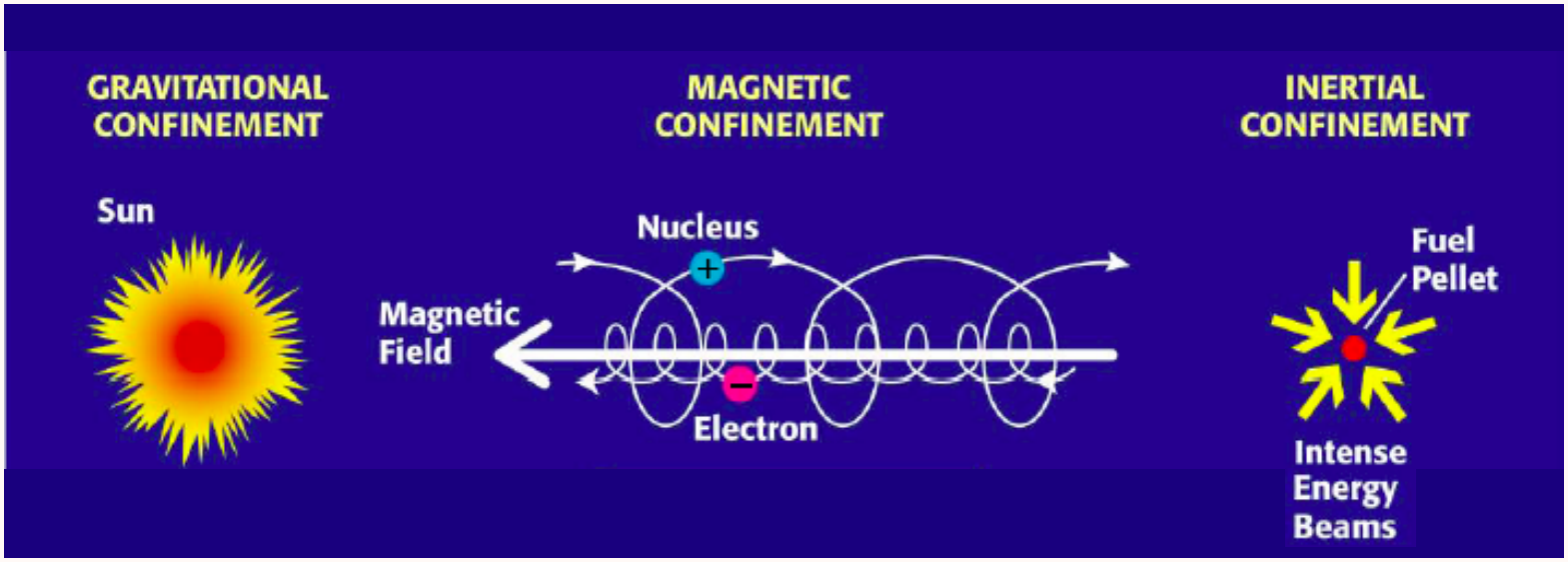
Total = 17.6 MeV

20% of energy release (3.5 MeV)

Illustration from DOE brochure

- The "easiest" fusion reaction to cause is that between deuterium and tritium nuclei

There are several ways to reach fusion conditions – all involve a plasma



High density, high temperature thermonuclear plasmas must be confined long enough for efficient fusion reactions to occur:

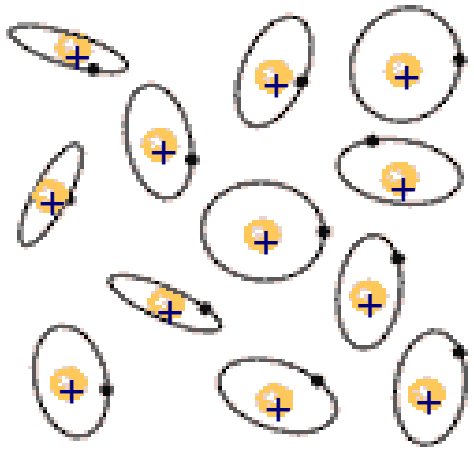
==> Net energy gain

The following plasma conditions need to be maintained (simultaneously).

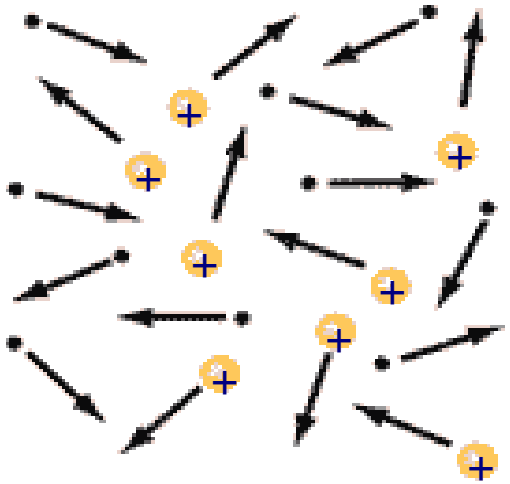
* Plasma temperature: (T) 100-200 million degrees Kelvin (10 x sun)
* Energy Confinement Time: (t) 4-6 seconds
* Central Density in Plasma: (n) 1-2 x 1020 particles m-3

(approx. 1/1000 gram m-3, i.e. one millionth of the density of air)

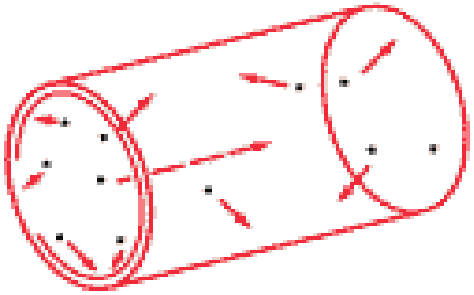
What is a plasma?



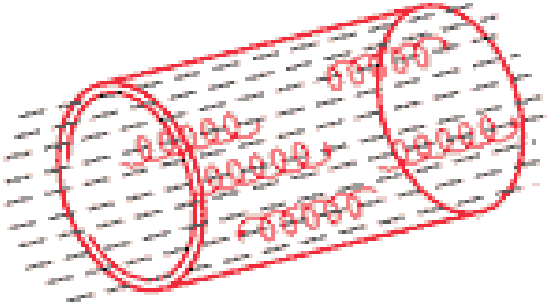
Gas



Plasma



Motion of charged particles without magnetic field.



Motion of charged particles with magnetic field.

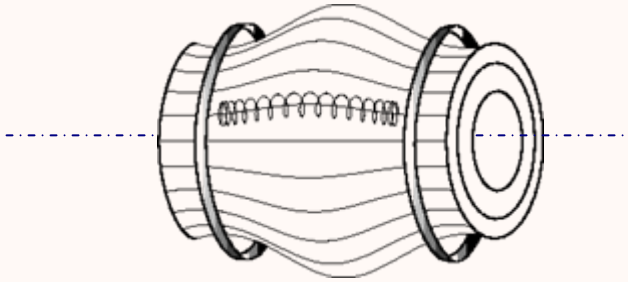
Fusion – Magnetic Confinement

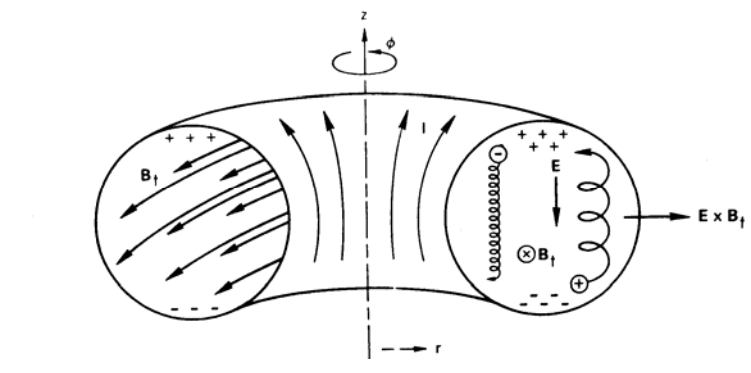
- One of the first ideas was a magnetic mirror, that allowed the charged particles in a plasma to bounce back and forth between regions of high magnetic field (but the ends leaked!)

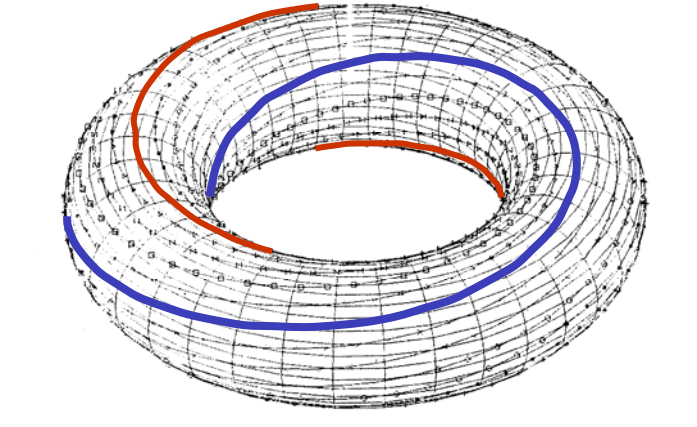
- So they bent the mirror into a donut (no ends!)

- However, this simple configuration is not stable, the field gradient causes charge separation and the plasma is lost due to ExB force

- If the field lines can be twisted around the torus, the charge separation is prevented and confinement is improved



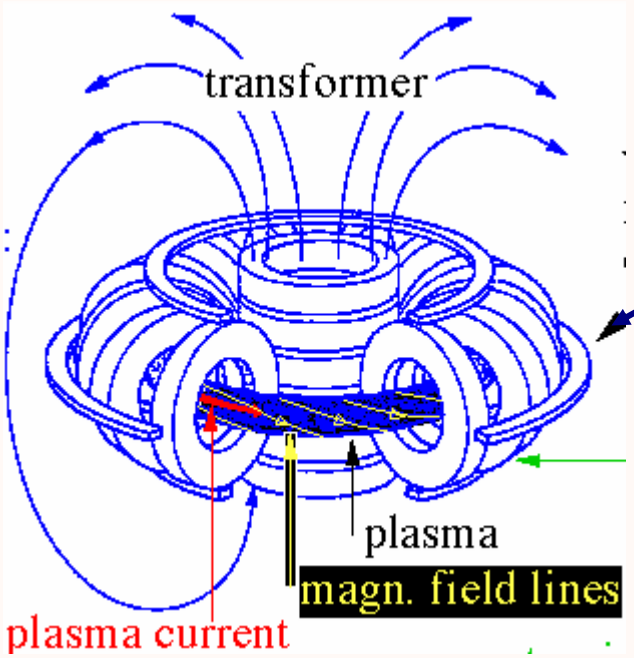




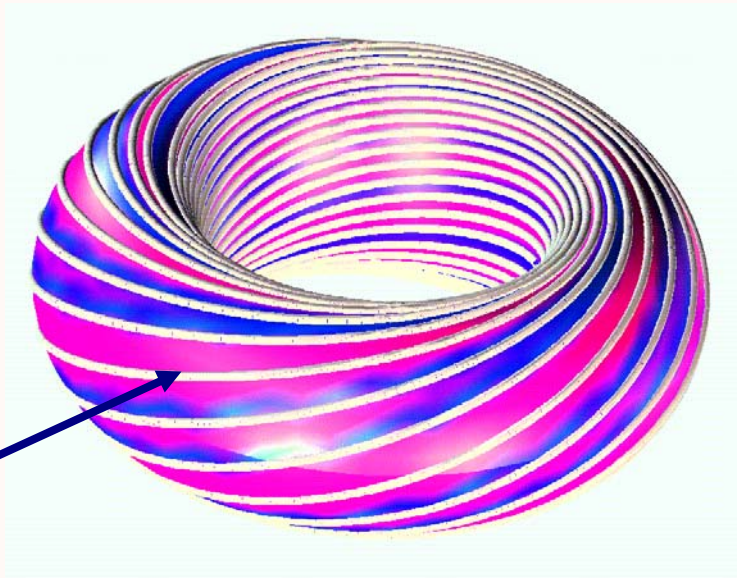
Illustrations from Jassby and Univ of Texas

Fusion – Magnetic Confinement (2)

- The tokamak is the most widely studied configuration, and uses a large current in the plasma to twist the magnetic fields



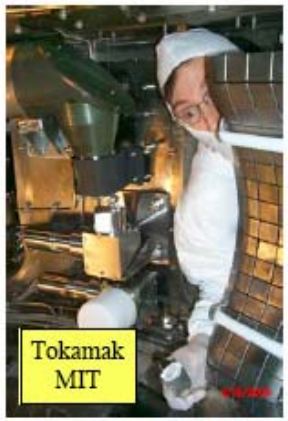
Coils

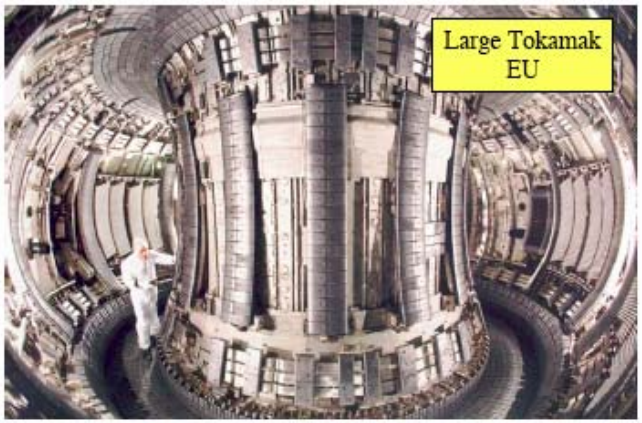


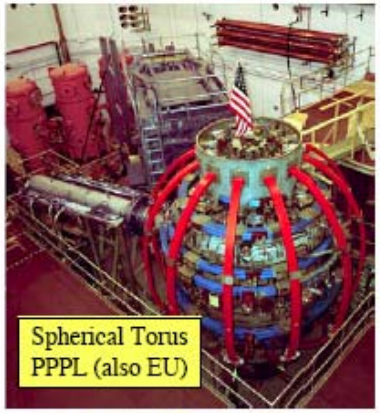
- Holding the plasma with magnetic fields is sometimes likened to compressing jello with rubber bands

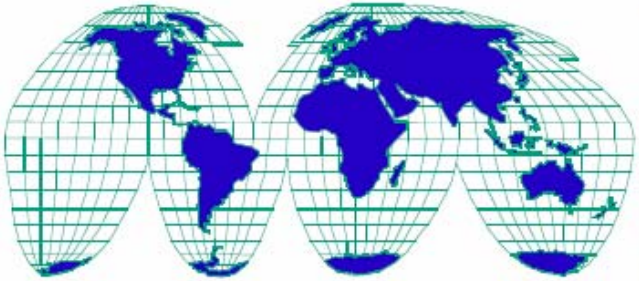
Illustrations from IPP and ORNL

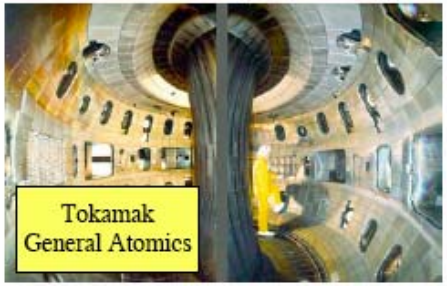
“Everybody” is running experiments in magnetic fusion

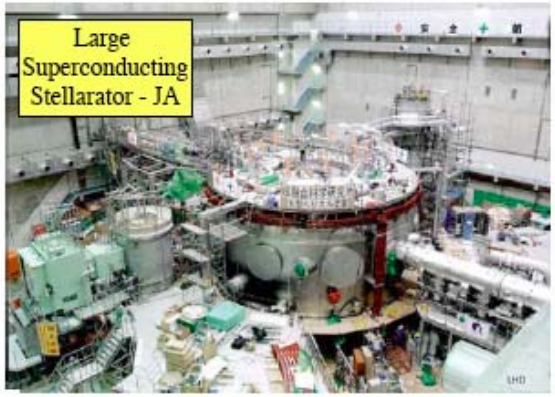




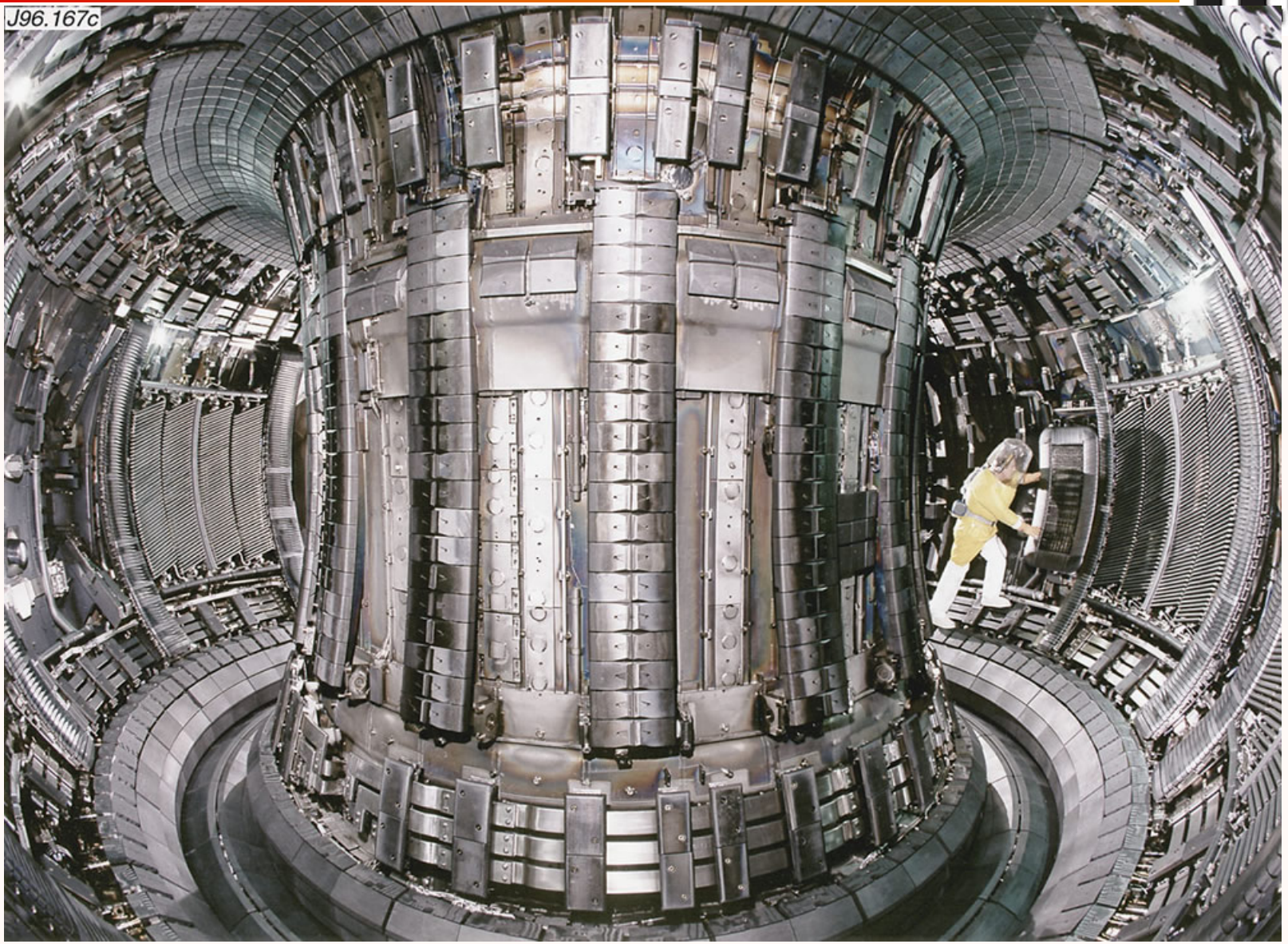




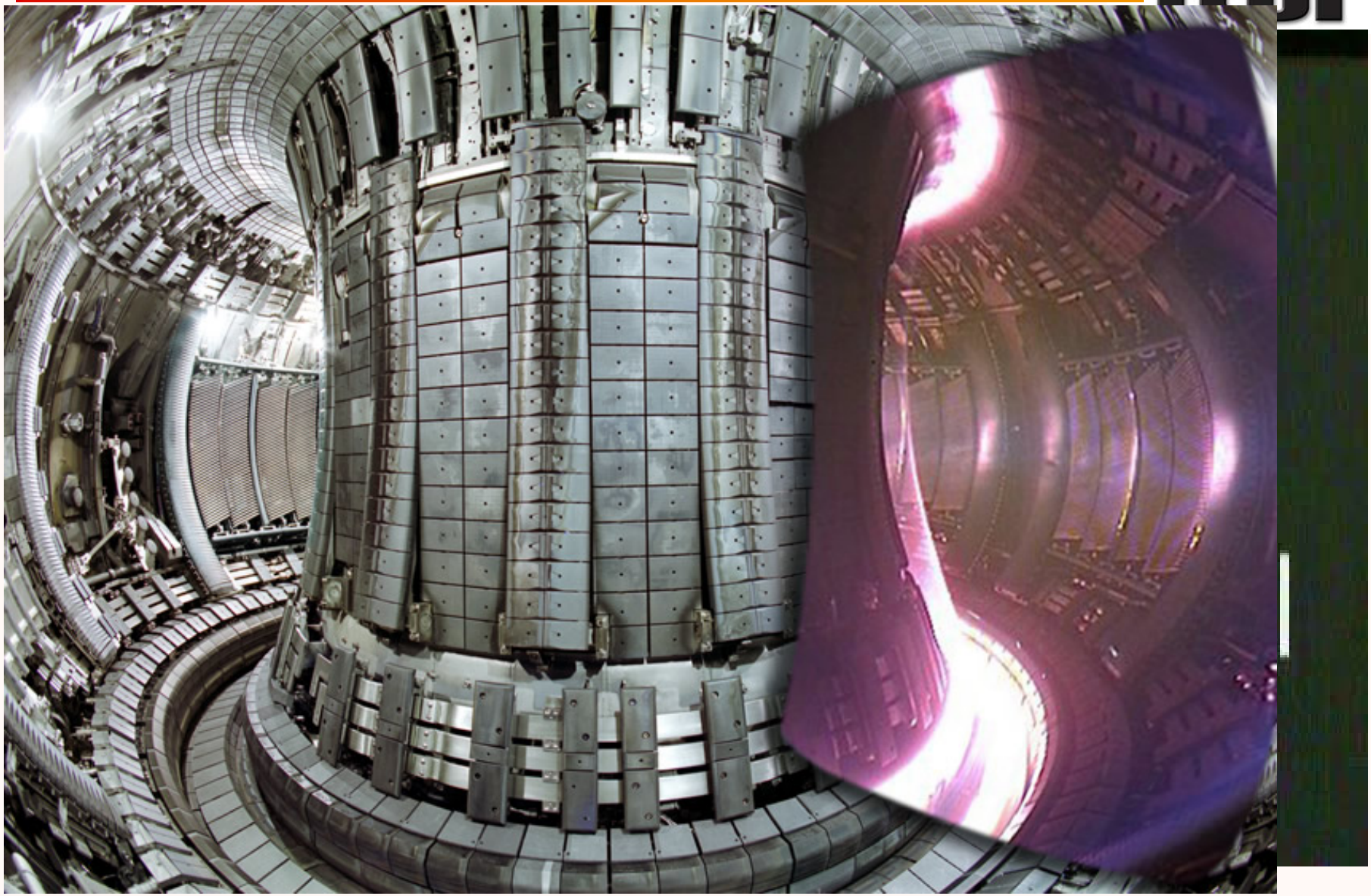




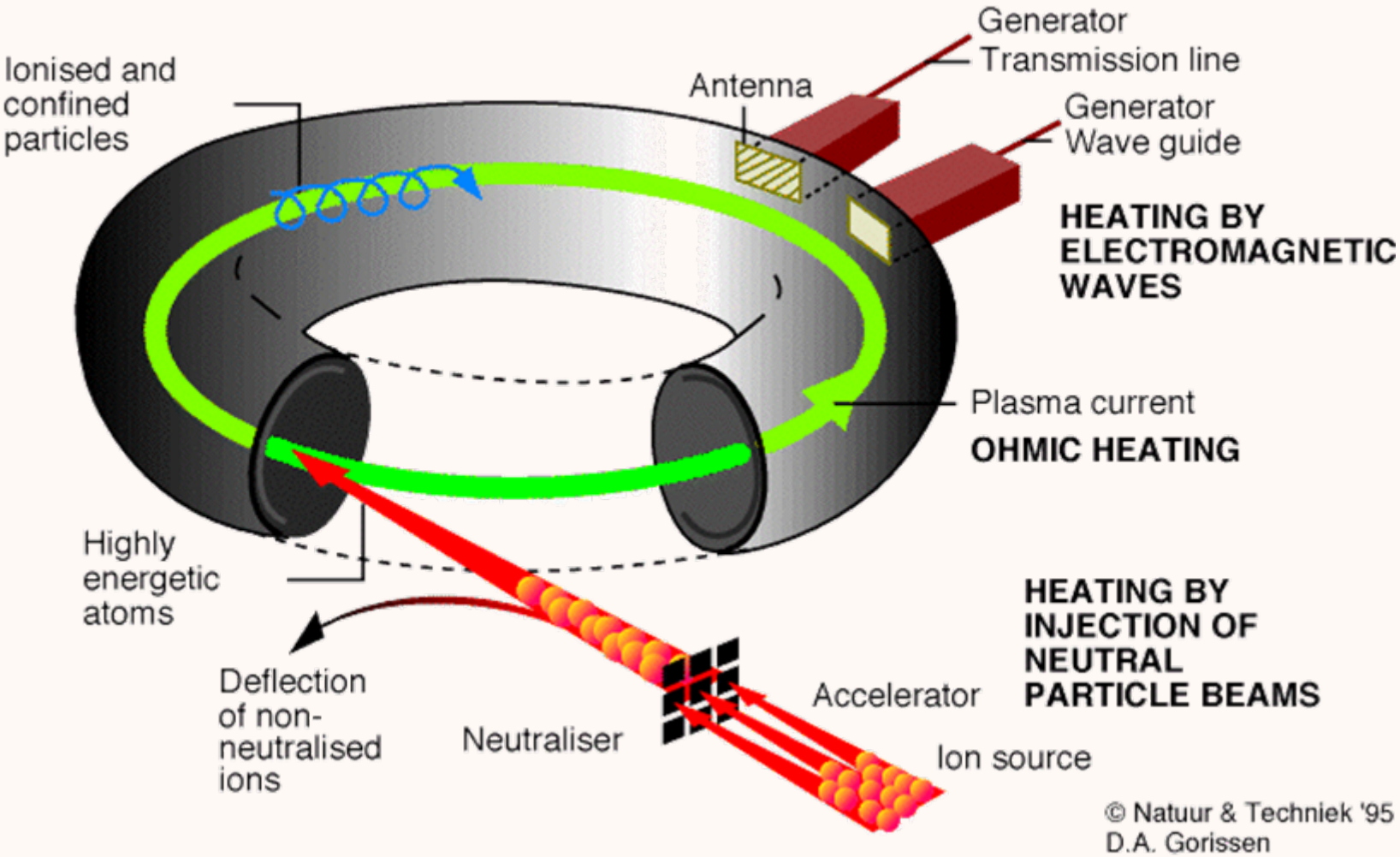
Joint European Torus (JET)



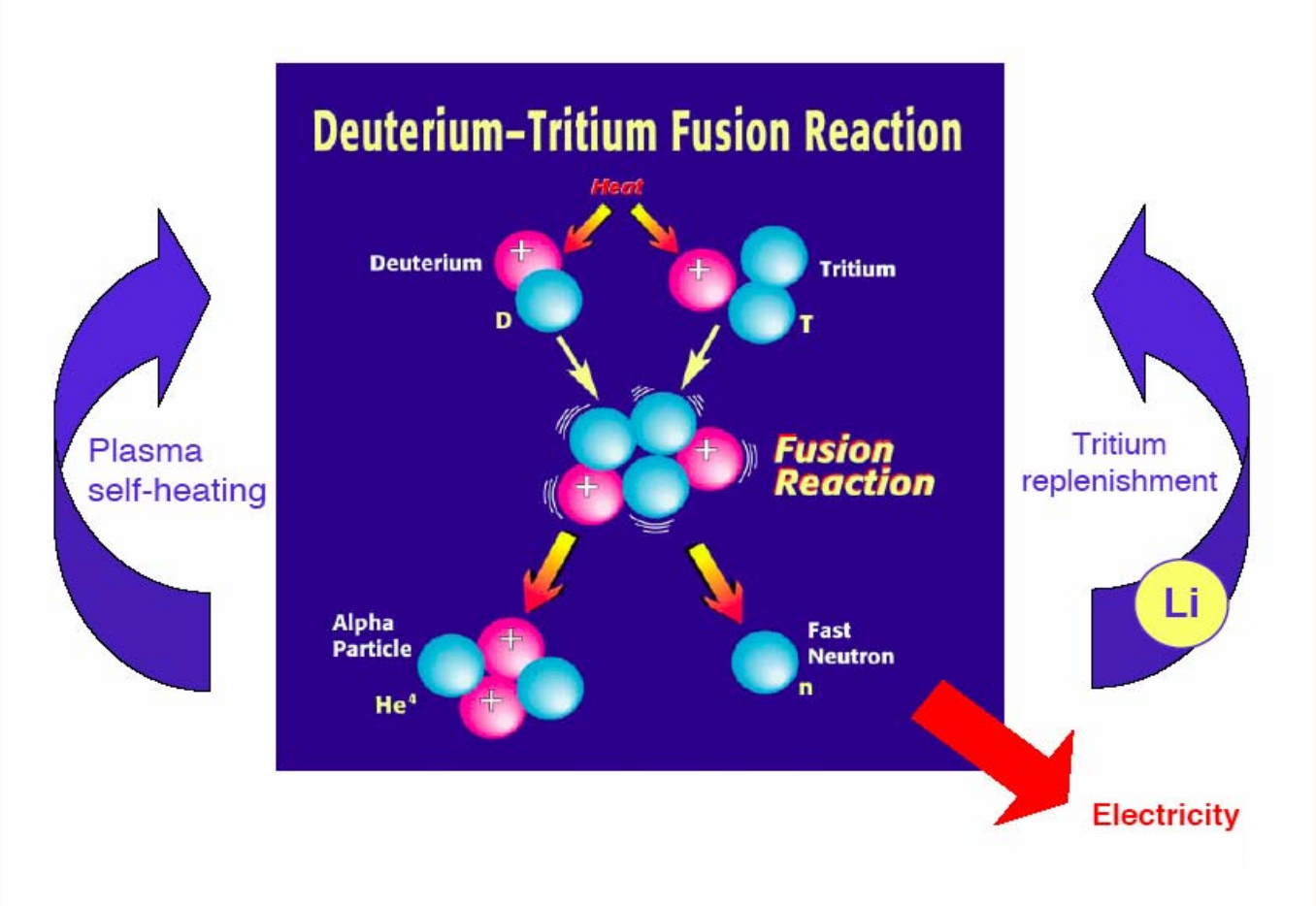
Joint European Torus (JET) is currently world's largest tokamak



Auxillary heating power is required to reach fusion temperatures

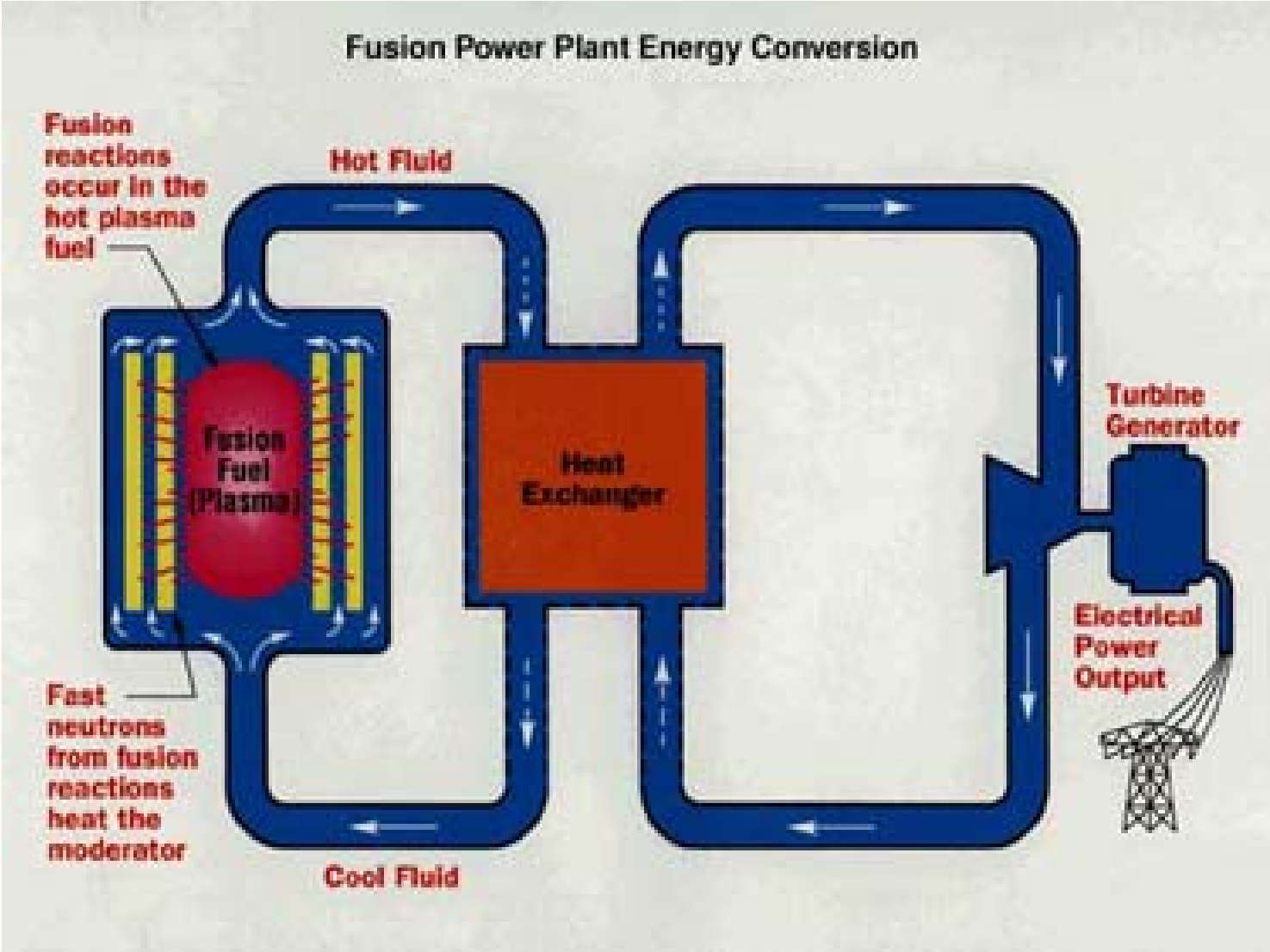


Energy Production Requires a Closed Cycle and High Reliability

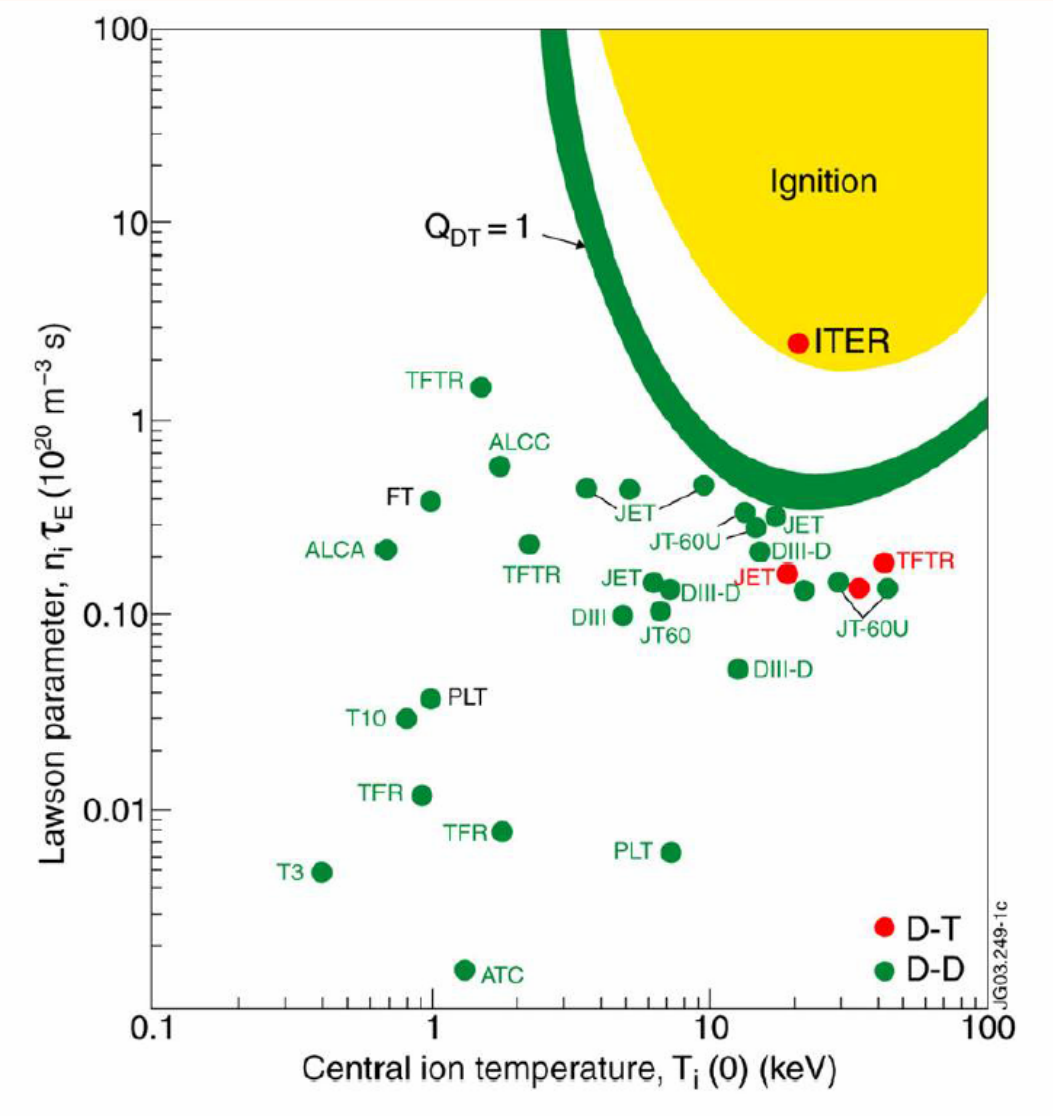


ITER will allow us to study He plasma self heating and control, neutron damage/capture processes and tritium recycling

Ultimate goal is to absorb neutrons, produce heat & generate electrical energy



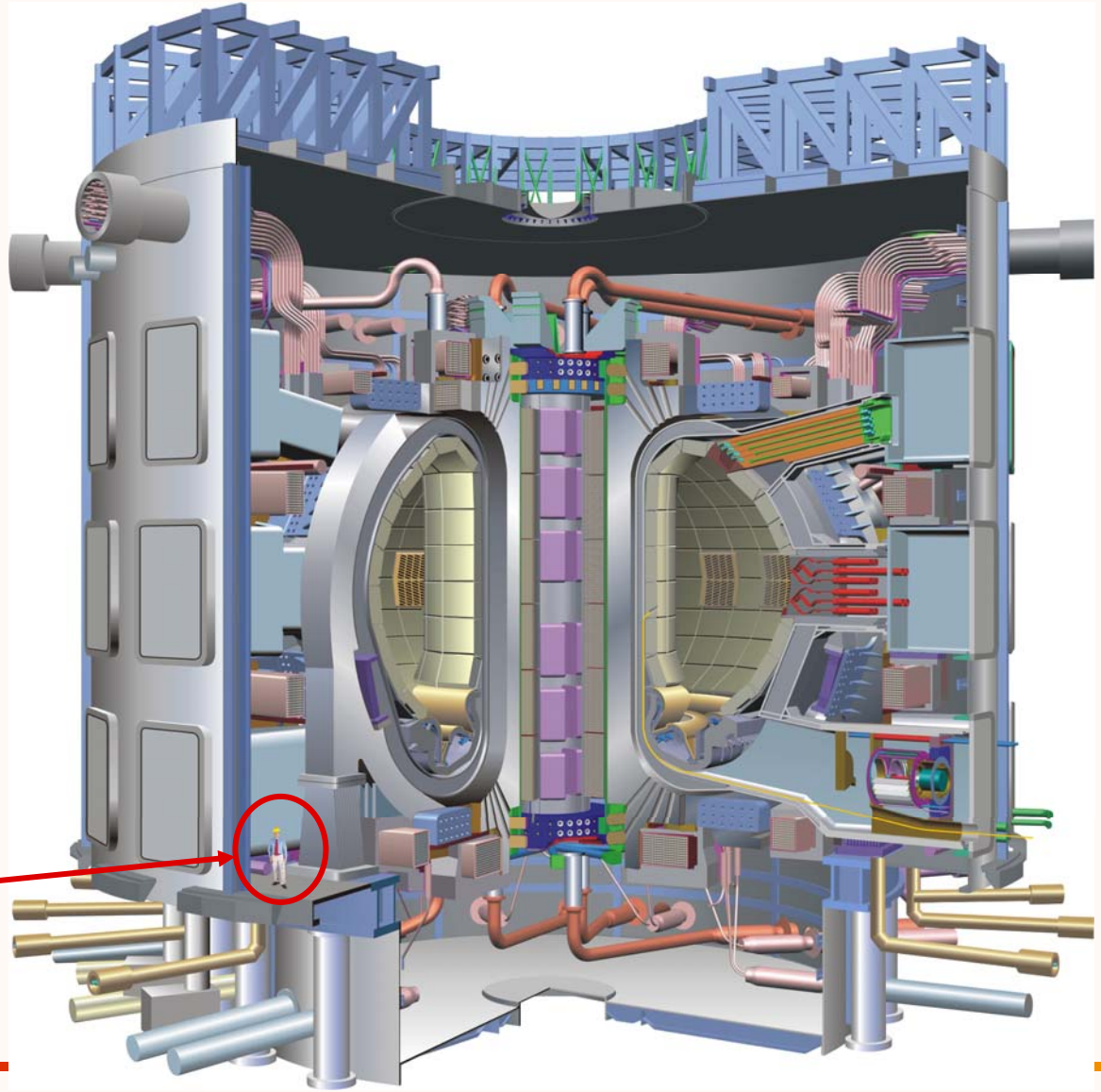
Are we progressing toward the goal?



- YES, but we need to take a major step in scale
- ITER explores the region of high gain (Q>5) and ignition.

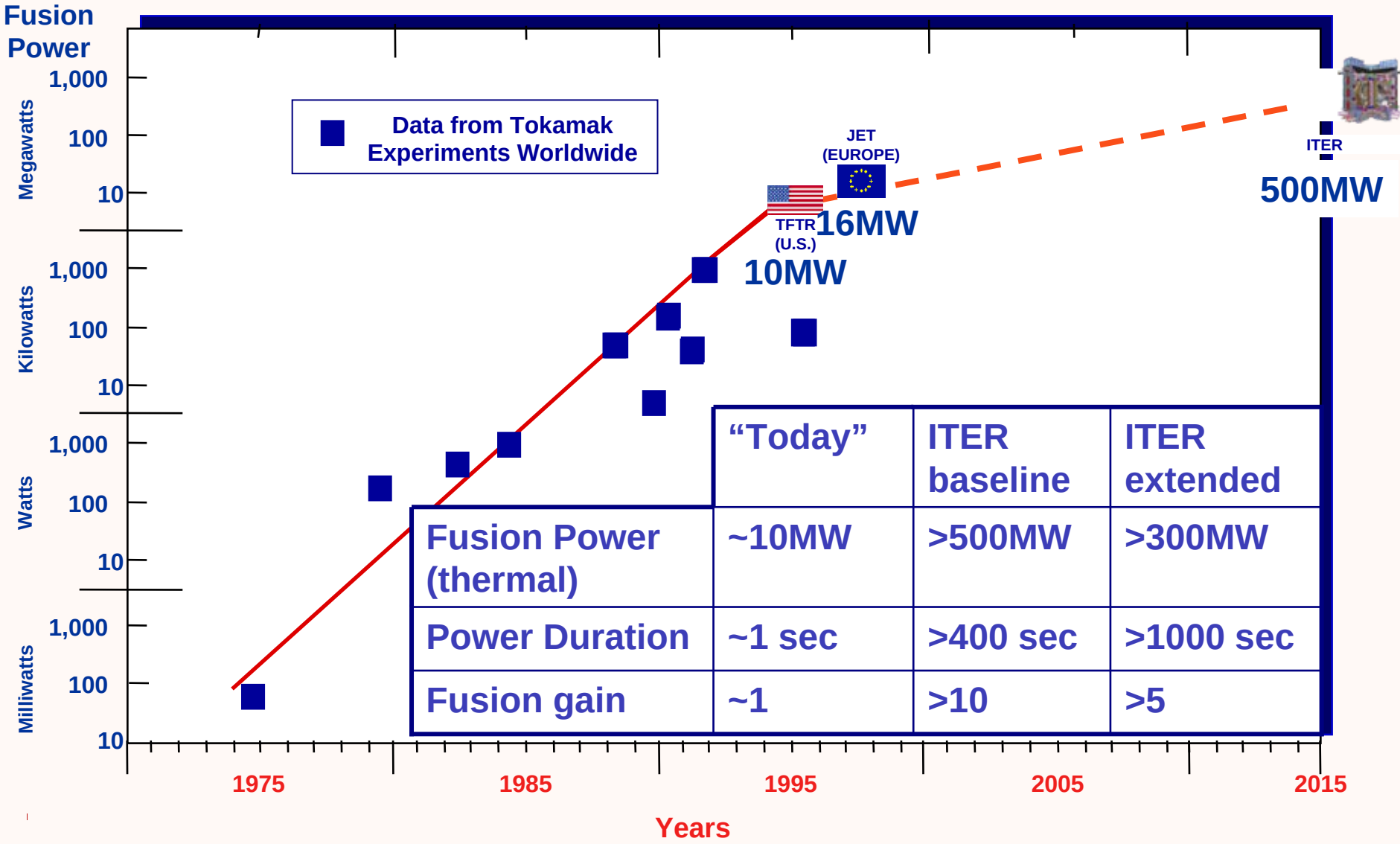
ITER Project Overview

The ITER Tokamak



Where's Waldo?

ITER is major step in power, pulse length plasma is " burning" (self-heated)



	"Today"	ITER baseline	ITER extended
Fusion Power (thermal)	~10MW	>500MW	>300MW
Power Duration	~1 sec	>400 sec	>1000 sec
Fusion gain	~1	>10	>5

ITER – Evolution and Mission

To demonstrate the scientific and technological feasibility of fusion energy

Conceptual / Engineering Design Activities 1988-2001

4 — European Union (1988-)

2 — Japan (1988-)

1 — USSR/Russian Federation (1988-)

1 — United States (1988-1998, 2003-)

Coordinated Activities / Transitional Arrangements (2001-)

1 — China (2003-)

1 — South Korea (2003-)

1 — India (2005-)

ITER engages the governments of over 50% of the world's population

•*Ref L. Baylor*

The Signatories of the ITER Agreement (Elysée Palace, Paris: November 21, 2006)

- with French President Jacques Chirac, in Paris, France on November 21, 2006. From left to right: Vladimir Travin (Deputy Director of the Federal Atomic Energy Agency, Russian Federation), Kim Woo Sik (Vice Prime-Minister, Ministry of Science and Technology, Korea), Takeshi Iwaya (Vice-Minister for Foreign Affairs, Japan), José Manuel Barroso (President of the European Commission), Jacques Chirac (President of the French Republic), Xu Guanhua (Minister of Science and Technology, People's Republic of China), Anil Kakodhar (Secretary to the Government of India, Department of Atomic Energy), Dr. Raymond Orbach (Under Secretary for Science, U.S. Department of Energy), and Janez Potočnik (European Commissioner for Science and Research).

ITER – site and director are selected

- Site is Cadarache, France, adjacent to CEA

Kaname Ikeda (Director General, Dec-2005)

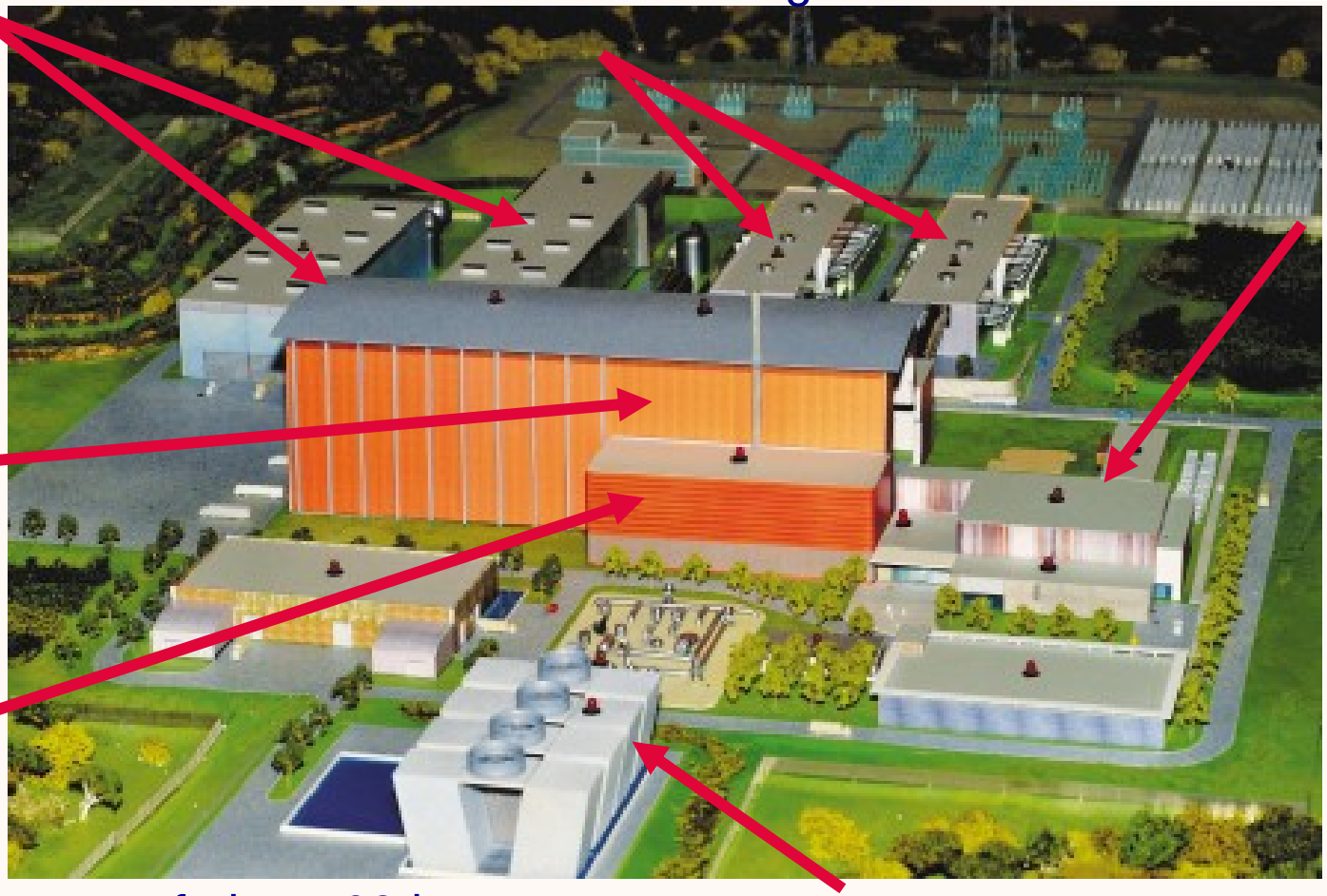
- **Nuclear engineer**
- **Leader in Japanese space and nuclear fuel programs**
-

•*Ref L. Baylor*

The ITER Scope

Magnet power convertors buildings

Cryoplant buildings



Hot cell

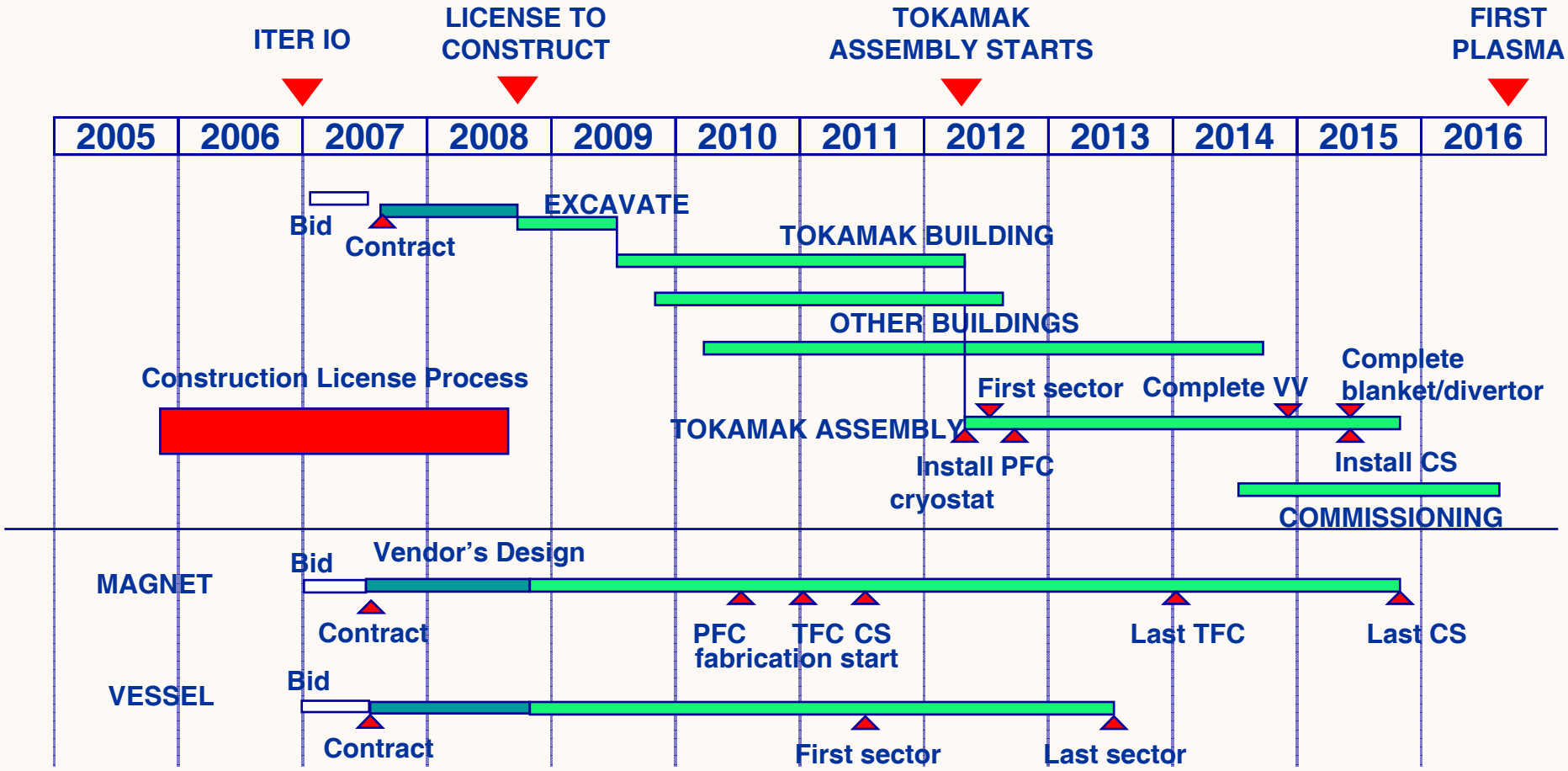
Tokamak building

Tritium building

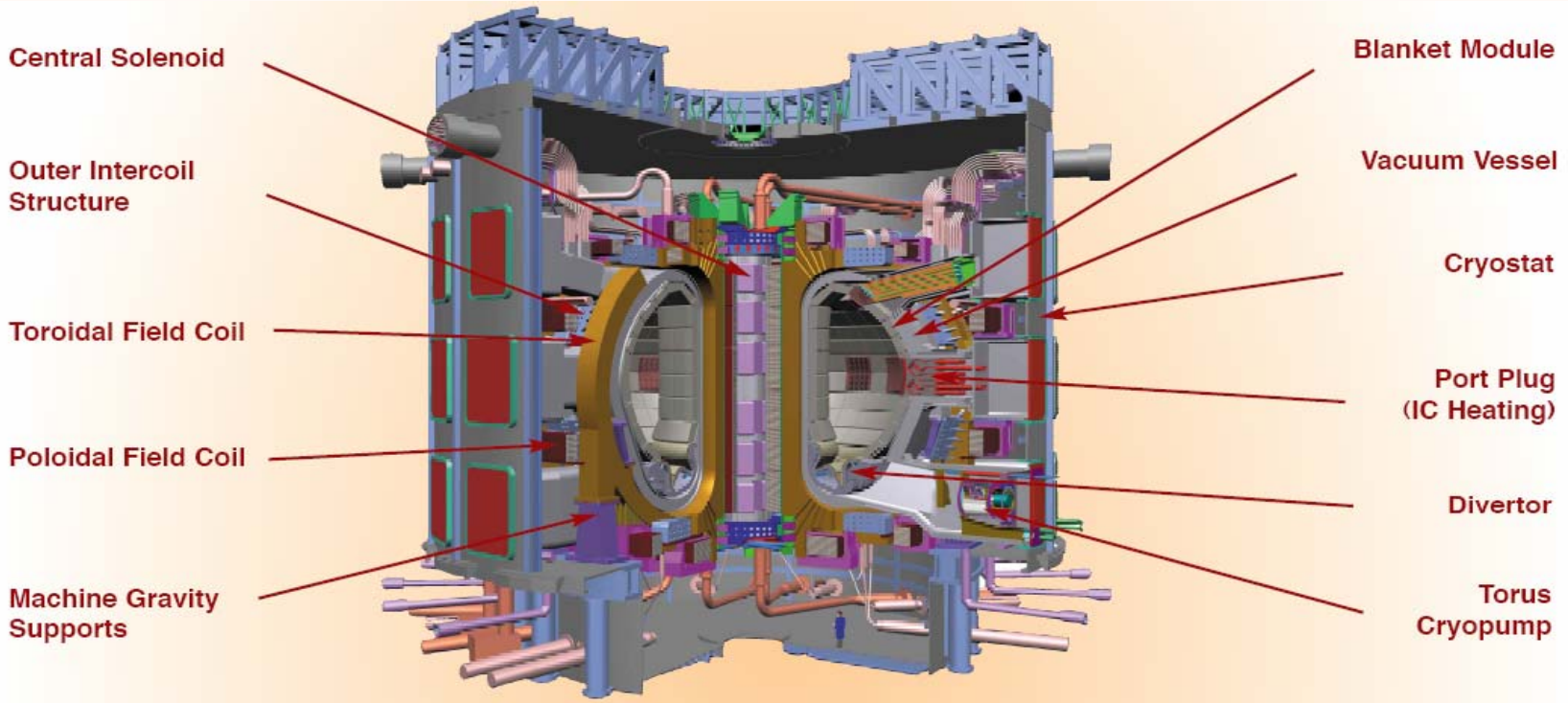
Cooling towers

- Will cover an area of about 60 ha
- Large buildings up to 170 m long
- Large number of systems

Iter will start operation in 2016



ITER is a 500 MW Tokamak Reactor



Main Plasma Parameters and Dimensions	
Total fusion power	*500 MW*
Q — Fusion power/auxiliary heating power	*≥ 10*
Average (14 MeV) neutron wall loading	*0.57 MW/m^2*
Plasma major radius	*6.2 m*
Plasma minor radius	*2.0 m*
Plasma current	*15 MA*
Toroidal field @ 6.2 m radius	*5.3 T*
Plasma Volume	*837 m^3*
Installed auxiliary heating/current drive power	*73 MW*

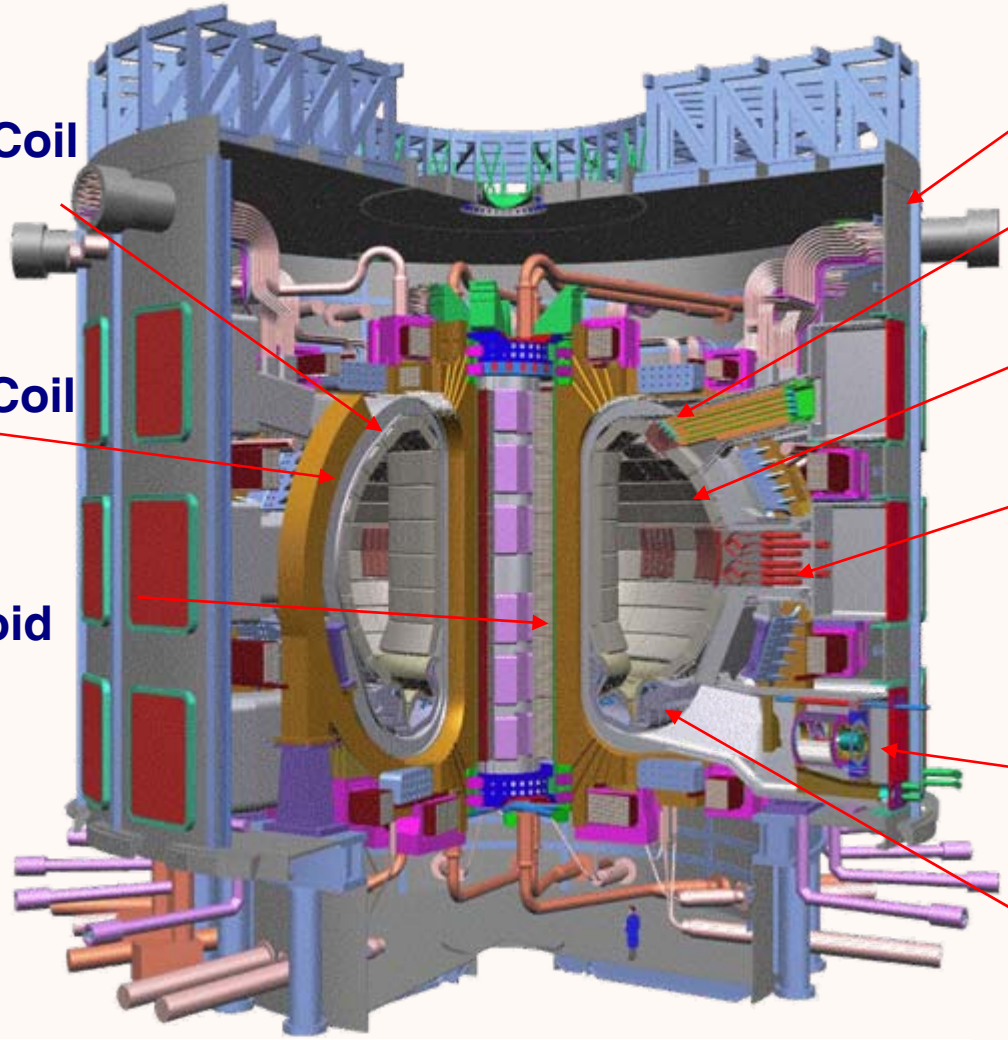
•Ref DOE

The Core of ITER weighs 23350 tonnes

Toroidal Field Coil
Nb_3Sn, 18, wedged

Poloidal Field Coil
Nb-Ti, 6

Central Solenoid
Nb_3Sn, 6 modules



Cryostat
24 m high x 28 m dia.

Vacuum Vessel
9 sectors

Blanket
440 modules

Port Plug
heating/current drive, limiters, diagnostics [test blankets]

Torus Cryopumps 8

Divertor
54 cassettes

Machine mass: 23350 t (cryostat + VV + magnets)
- shielding, divertor and manifolds: 7945 t + 1060 port plugs
- magnet systems: 10150 t; cryostat: 820 t

US will contribute ~ 10% “in kind”

Central solenoid windings

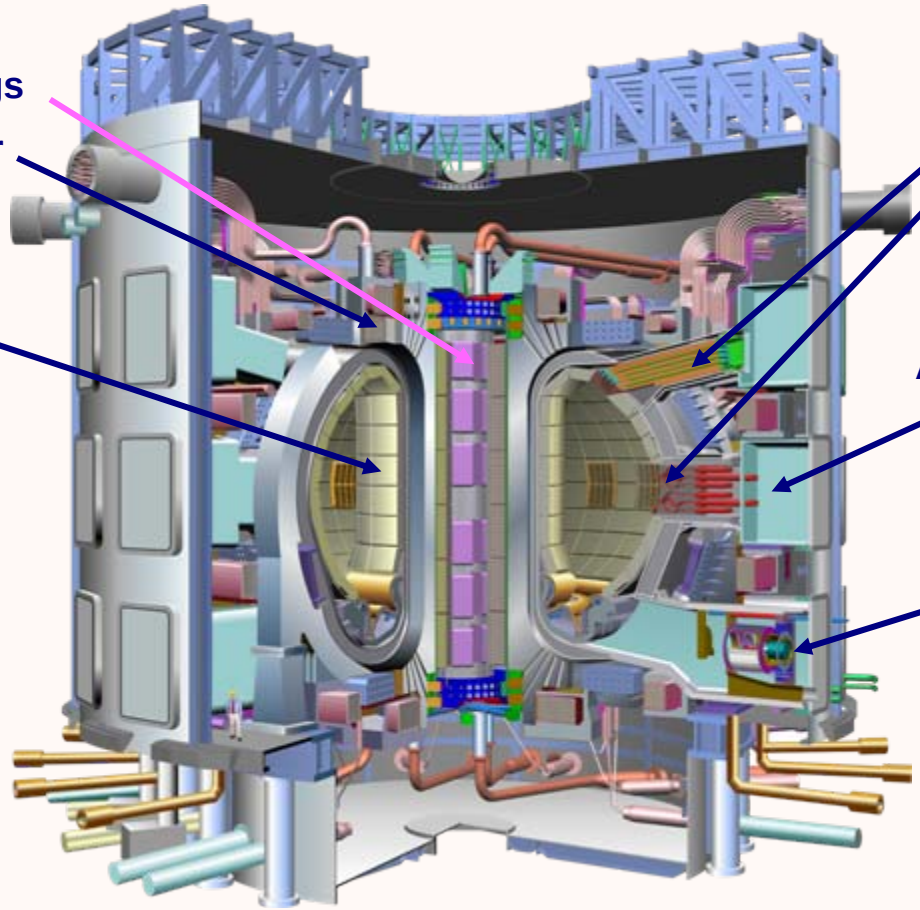
8% of TF coil conductor

20% of FW/shield

Moveable port limiters

Steady state electrical power

Tokamak cooling water system



16% of port based diagnostics

All ICH transmission lines

All ECH transmission lines

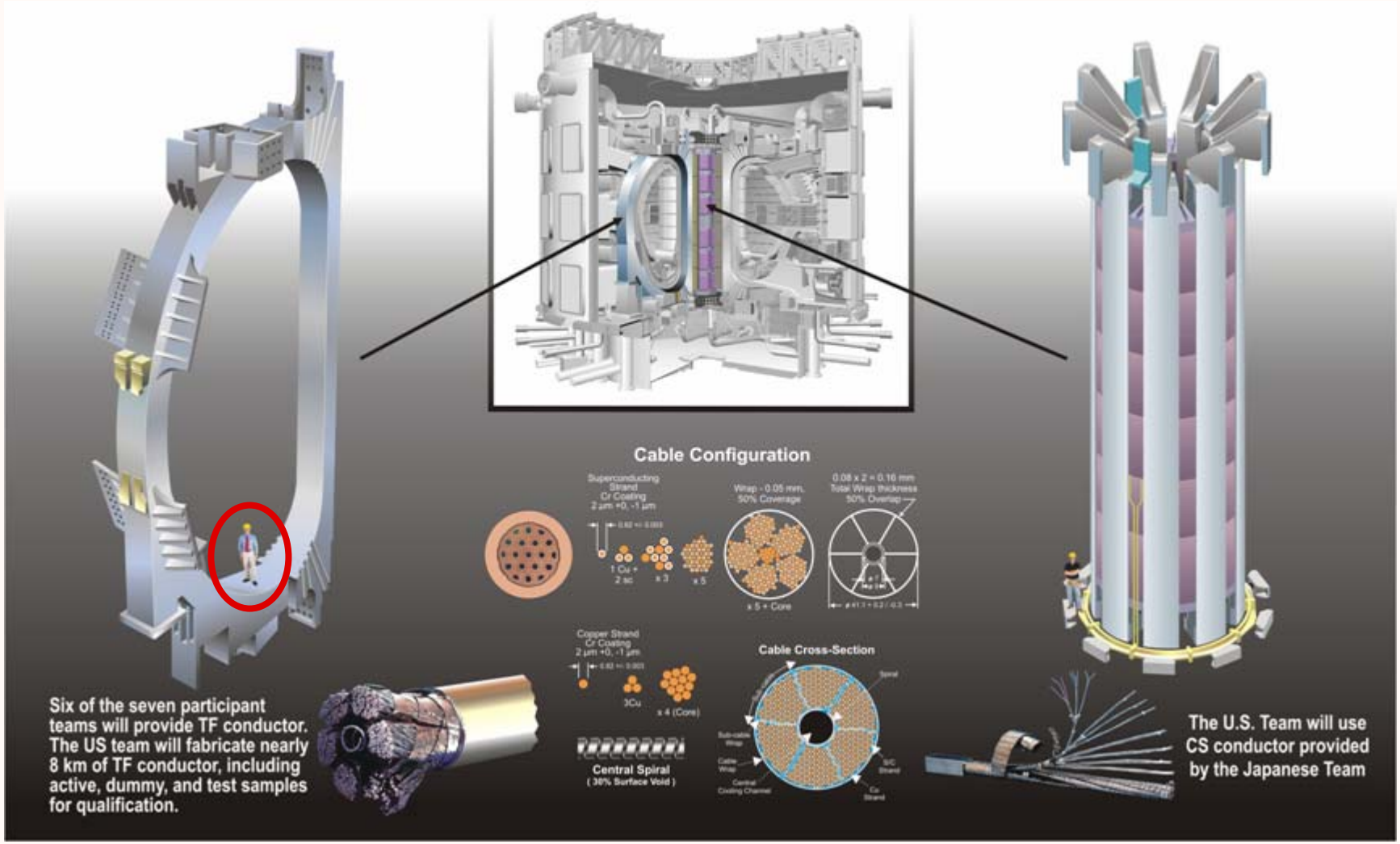
Standard vac. components, roughing pumps Pellet fueling

Tokamak exhaust processing (tritium separation) system

Some Engineering Challenges for ITER

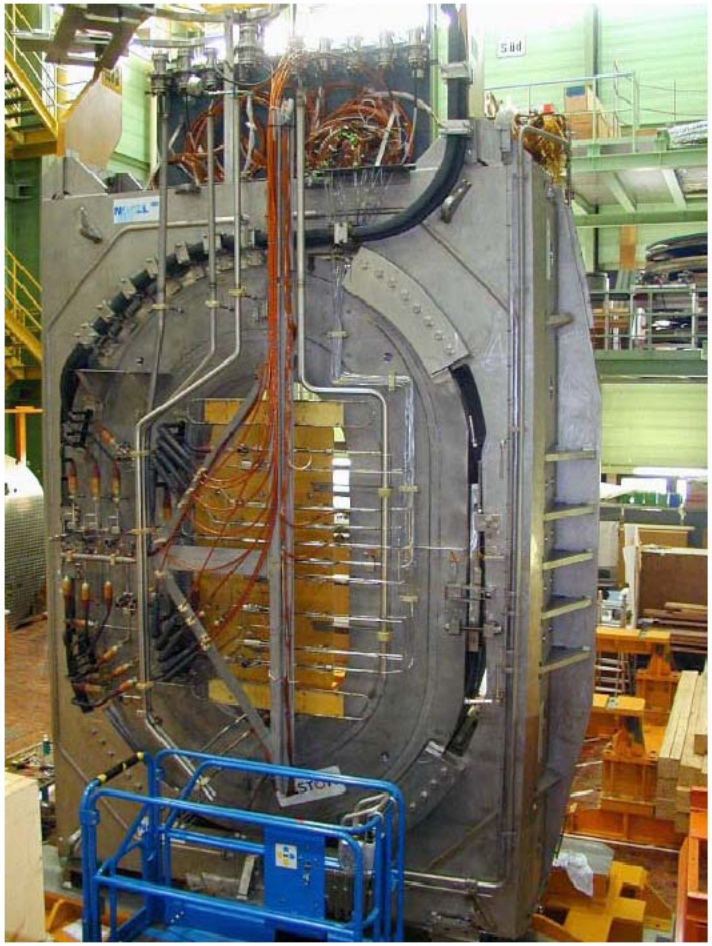
- **Magnets**
- **Diagnostics**
- **Heating and fueling systems**
- **Materials**
- **Many more …**

Magnet systems
TF Coil, Central Solenoid



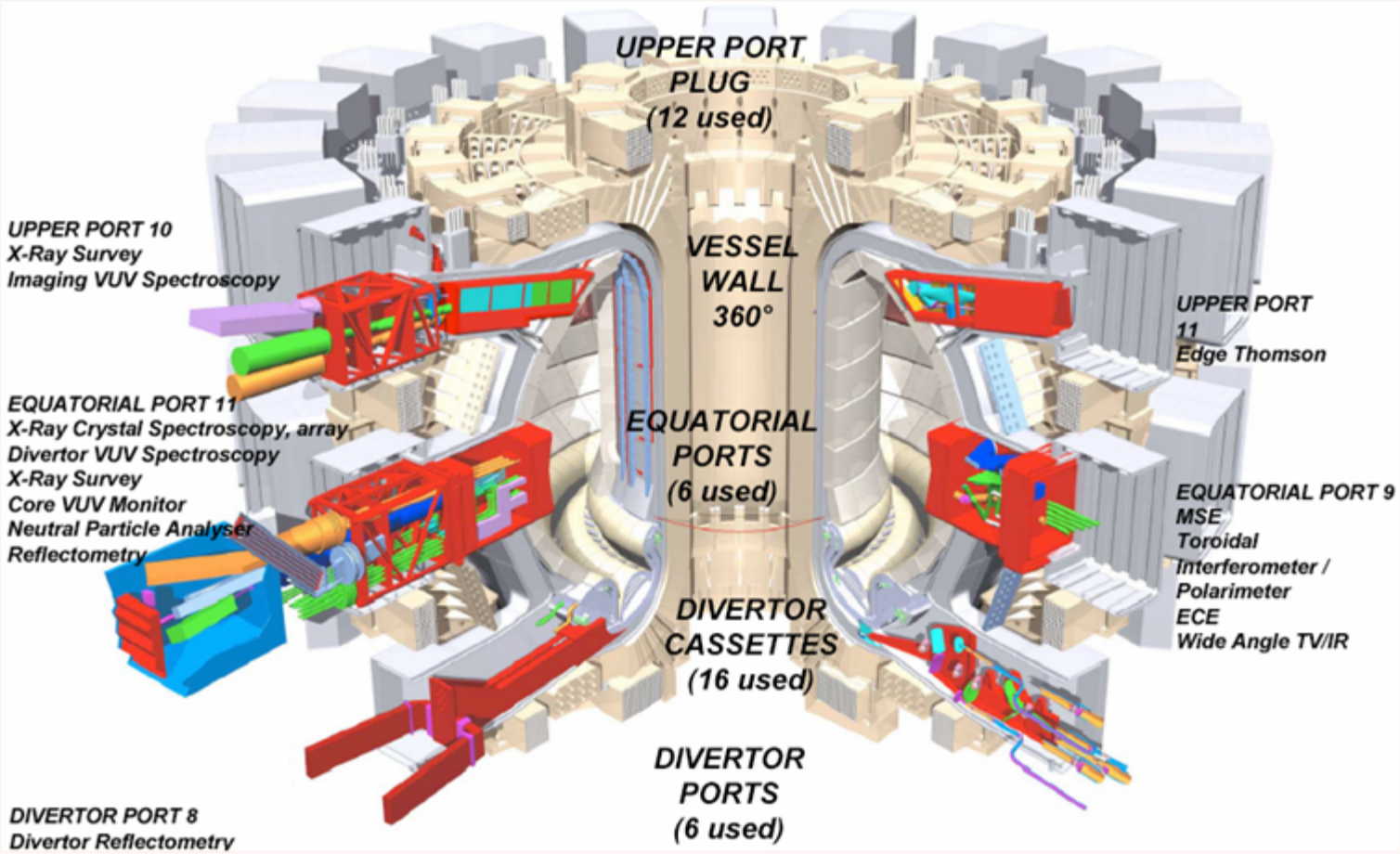
Magnet R&D prototyped superconducting central solenoid (CS) and TF coils

CS Model Coil



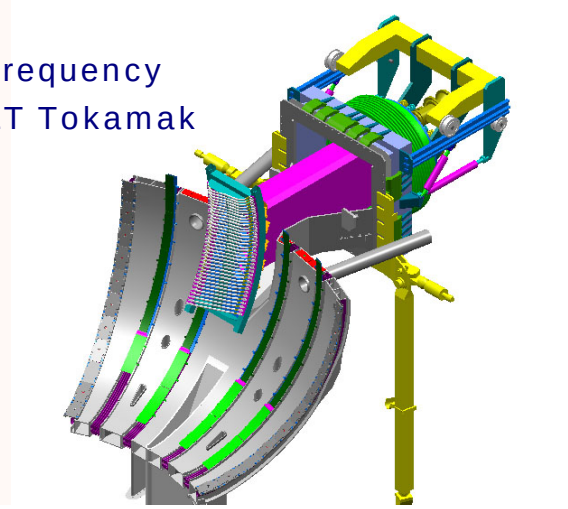
TF Model coil

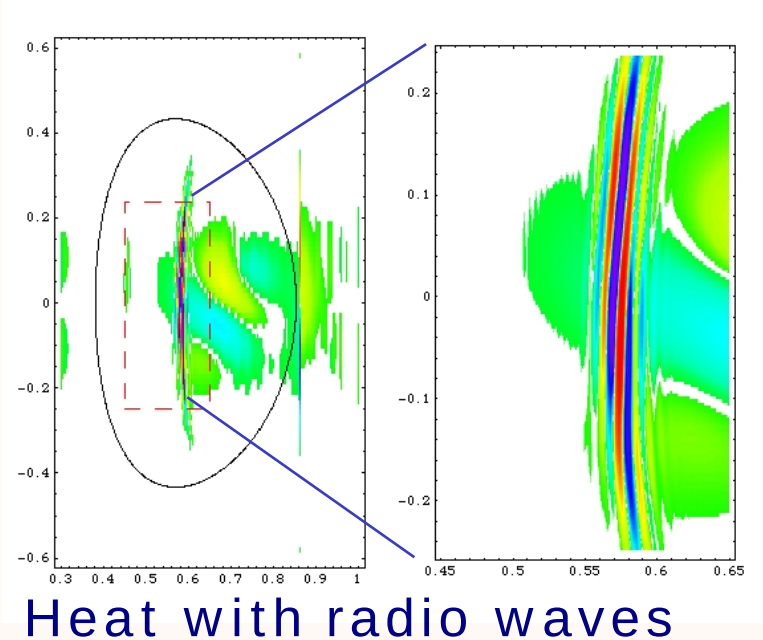
Diagnostics monitor plasma behavior and must survive in harsh environment



High power radio frequency (ICH) heating and H/D/T pellet injector fueling

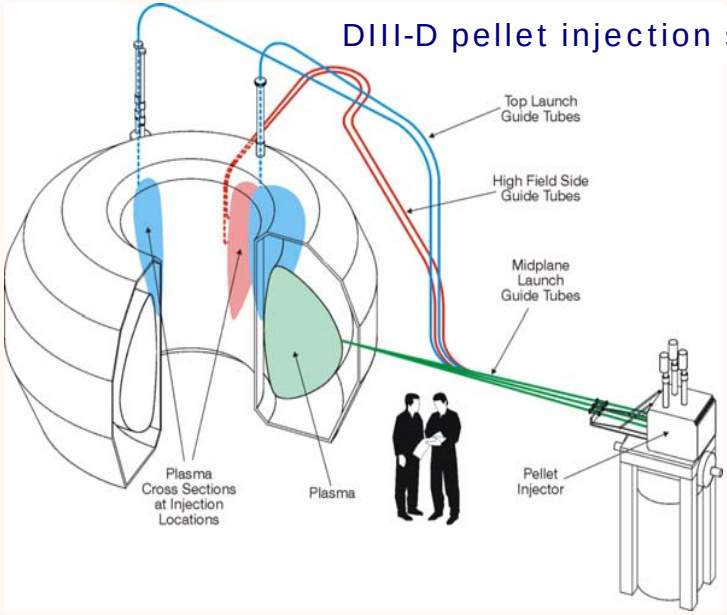
High power radio frequency antenna for the JET Tokamak





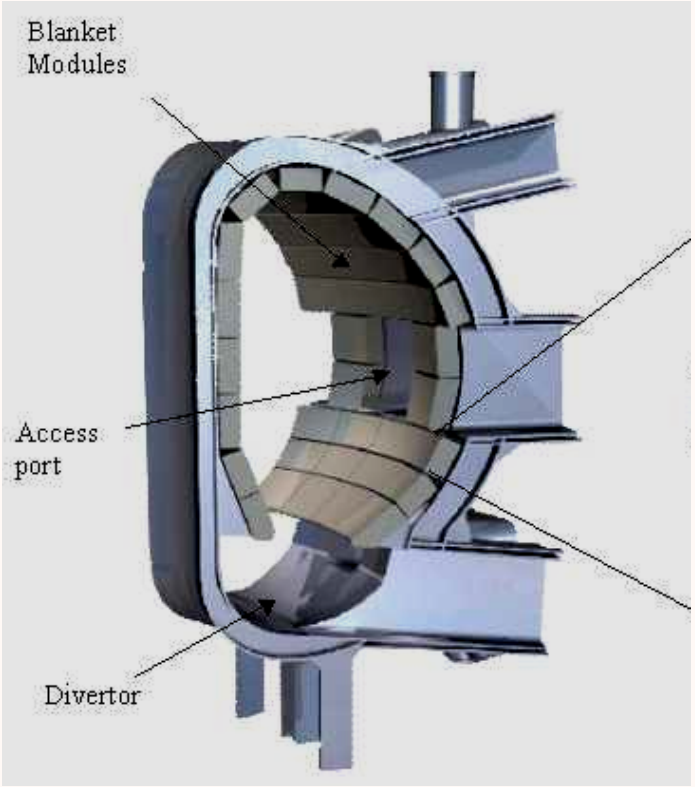
Heat with radio waves

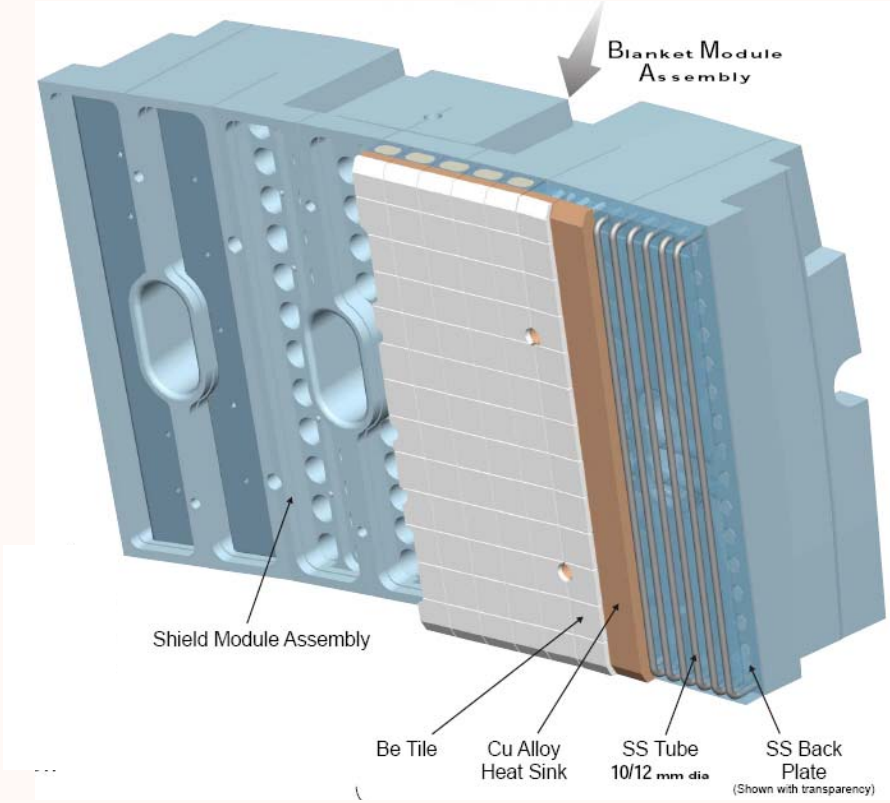
DIII-D pellet injection system



Fuel with frozen pellets

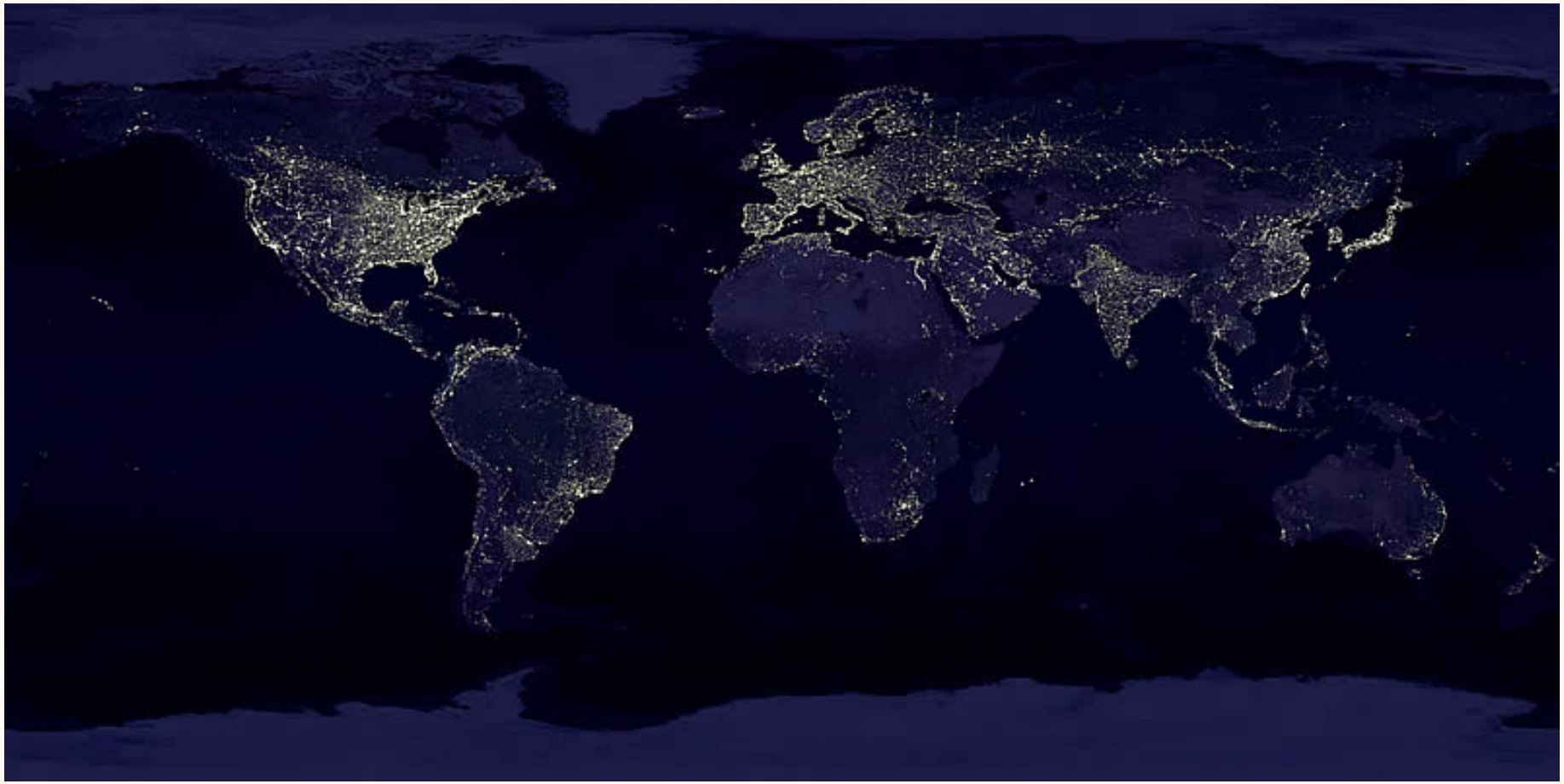
First Wall and Blanket take brunt of radiation and heat load





The Blanket serves three main functions:

- To remove the useful neutron power and most of the particle power in the plasma
- To provide shielding of the vacuum vessel structure and S/C coils
- To help in passive stabilization of the plasma

Conclusion

- We need to find a way to keep the lights on
- ***ITER is the next step toward fusion energy***