ITER and Fusion Technology Development in India

Vigyan Samagam, New Delhi
22 January 2020

P. I. John

- **ITER: International Thermonuclear Experimental Reactor**

- **Fusion: Thermonuclear Fusion between light Elements to create heavier elements**

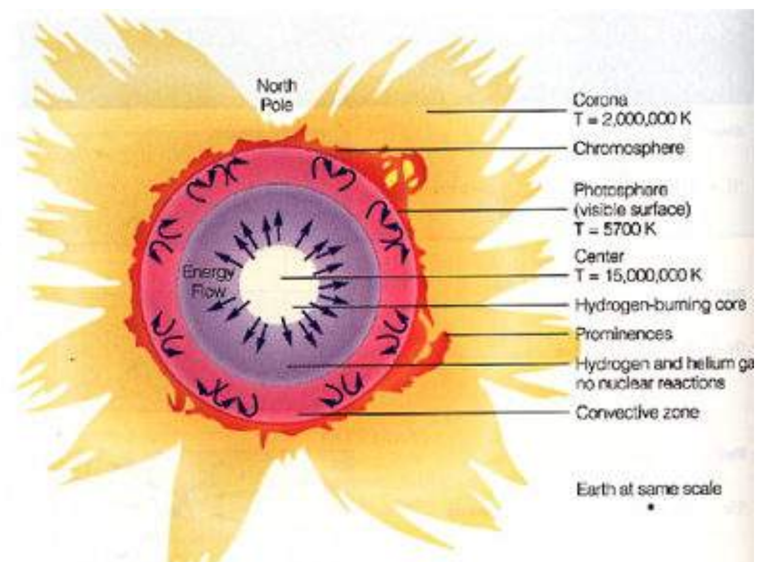
- **Technology Development: Learning how to do this on Earth**

Fusion in the Sun

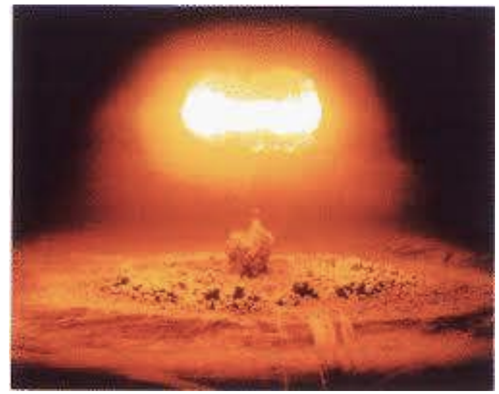
Density ~160 gm/cc

Temperature ~ 15 MK

Pressure 340 Billion atm

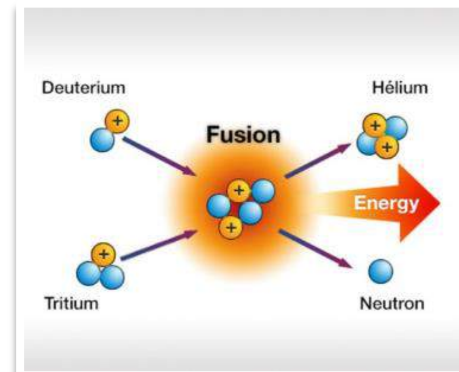


Fusion on Earth: H-Bomb



In the Hydrogen Bomb, High Temperature to fuse Dueterium + Tritium created by exploding an atomic bomb.

DT Fusion in Lab

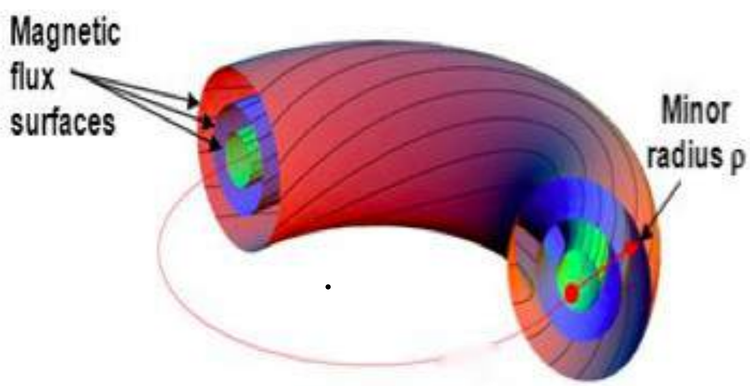


Temperature: 100-150 million °K. To reach this temperature and to hold the plasma together for sustained reaction is the challenge.

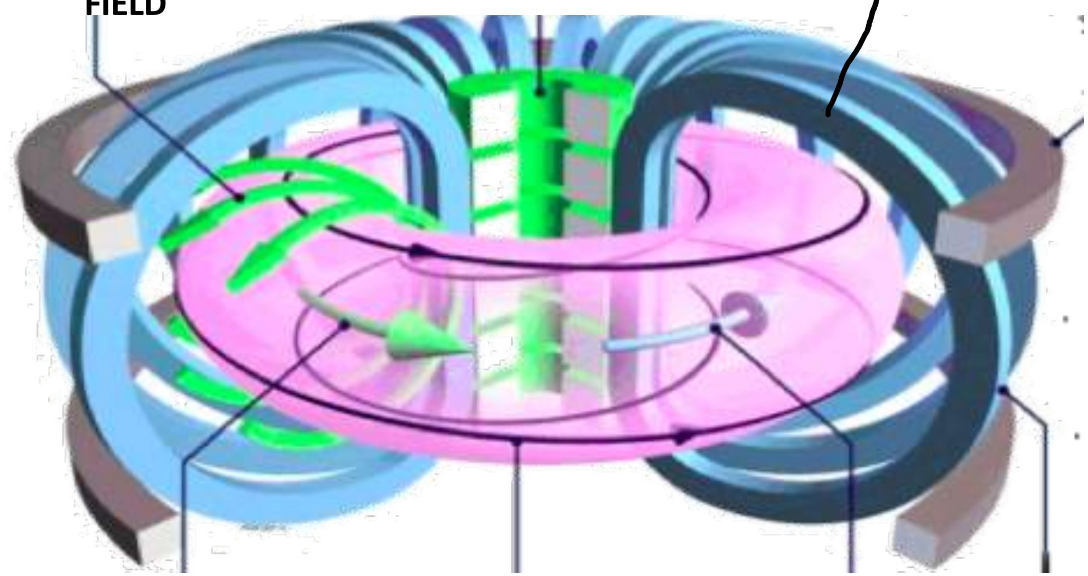
Magnetic Traps confine the hot plasma away from material walls: TOKAMAK

The Tokamak Concept

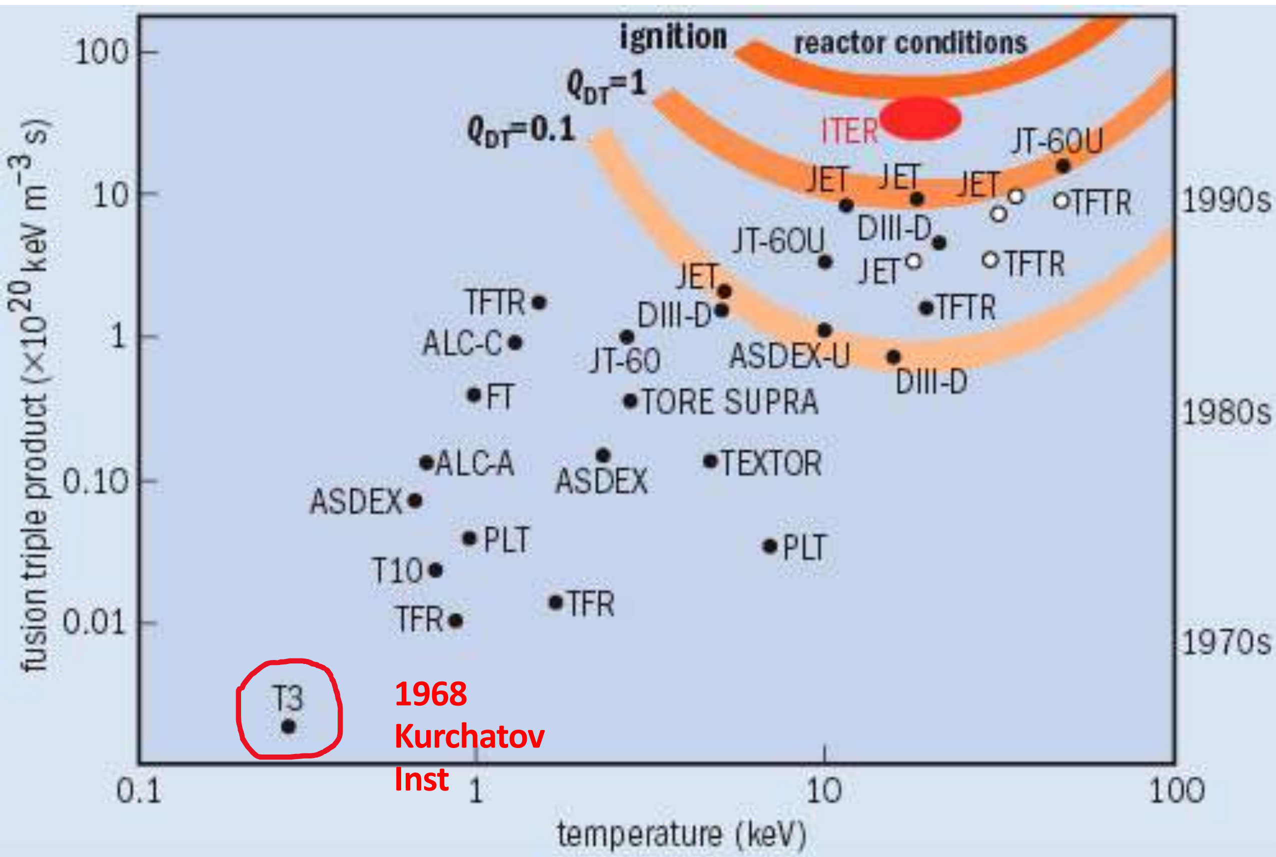
Plasma made of Electrons +ve Ions
Charged particles stick to Magnetic Field lines



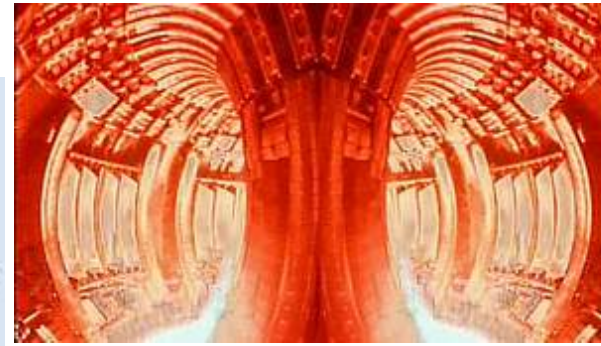
HELICAL FIELD LINES WIND AROUND TORUS TO WEAVE NESTED MAGNETIC SURFACES



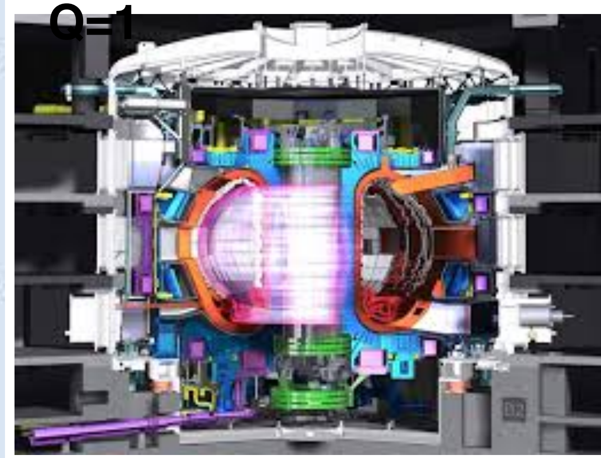
1950: 70 years of progress



JET, CULHAM LAB, UK



JET D-T Fusion 1991
Q=1



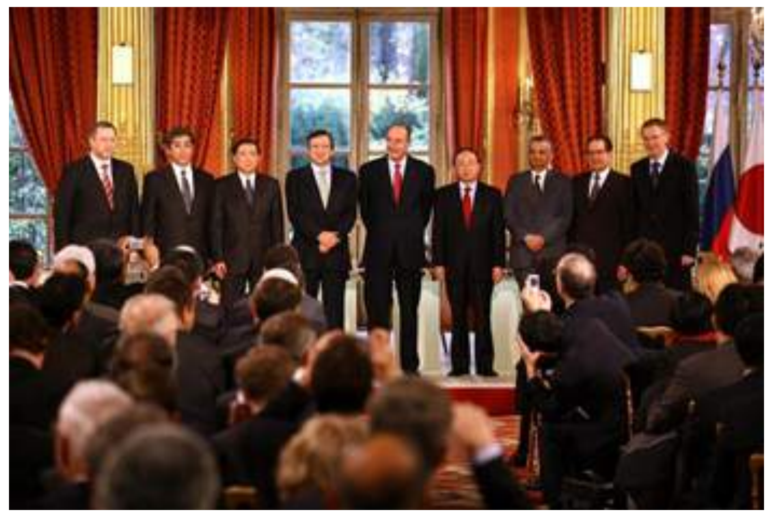
ITER Q=10 2025?

ITER: A Brief History

Genesis: Geneva Summit in 1985: General Secretary Gorbachev of the Soviet Union proposed to U.S. President Reagan an international project to develop fusion energy for peaceful purposes.

INTOR DESIGN
Toronto 2001

China, S. Korea, India by 2006



Cadarache site, South France 2005

ITER Agreement Signed 2006

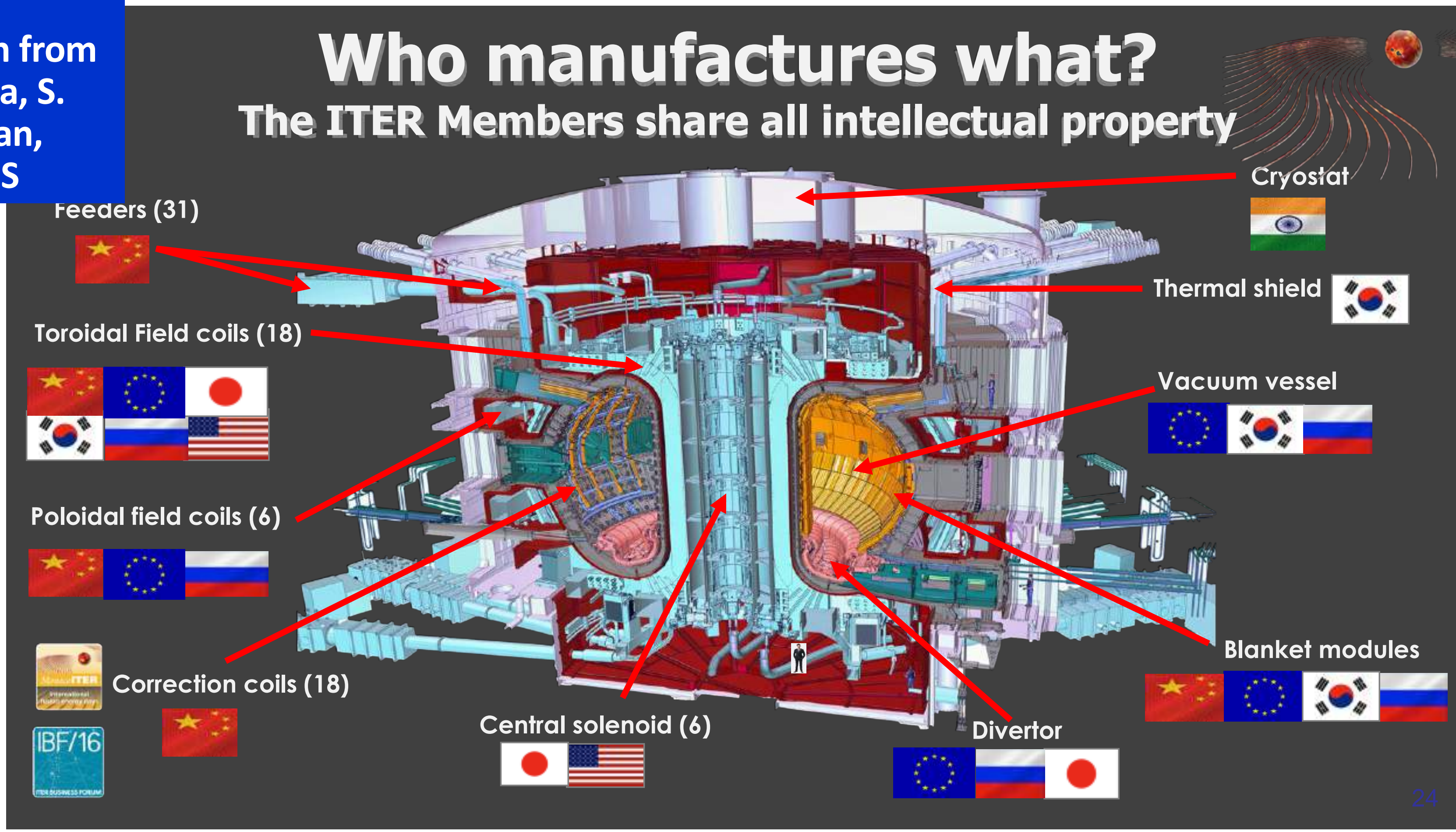
ITER Organization created 2007

ITER Project is funded by the Department of Atomic Energy (DAE)

Implemented by the Institute for Plasma Research (an autonomous aided institute of (DAE), Gandhinagar

Executed by a special project within IPR, called ITER-India (also called the Domestic Agency) for delivering India’s in-kind commitments

- 45.46% from EU
- 9.09% each from China, India, S. Korea, Japan, Russia & US



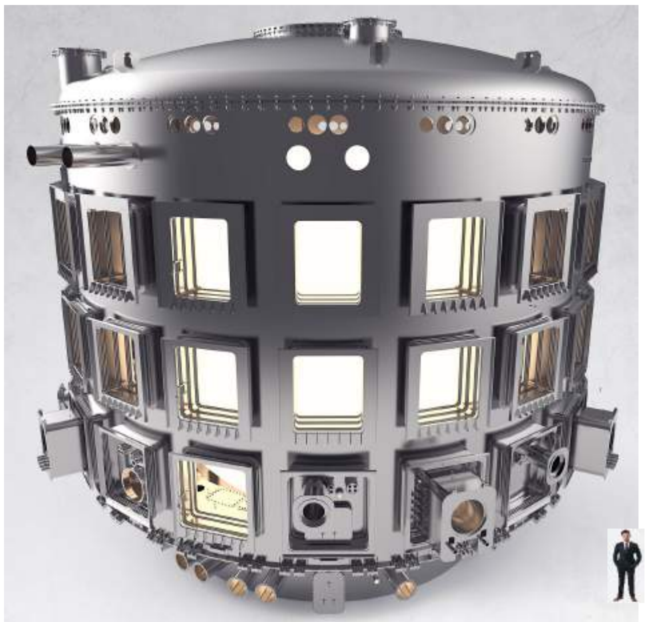
Scal
e

Slide credits: DG, Bernard Bigot's talk at ITER Business Forum IBF-2016

INDIA'S IN-KIND CONTRIBUTION TO ITER

4 Types, 9 Packages, Mix of technologies		
Heavy & precision engineering – material and manufacturing intensive	Cryostat (BTP)	Machine jacket to ensure vacuum environment for SC magnet
	In Wall Shields (BTP)	Neutron shielding
R&D oriented and technology intensive	RF sources: Ion Cyclotron Frequency (FS)	Plasma heating, current drive, wall conditioning
	RF sources: Electron Cyclotron Frequency (FS)	Startup, heating, current drive, instability control
	Diagnostic Neutral Beam (BTP + FS)	Energetic neutral beam in plasma to detect He ash
	Power supplies (FS)	Power ITER heating and beam systems
	Diagnostics (FS + BTP)	Diagnosing ITER plasma
Technologically challenging & Integration intensive	Cryolines and Cryodistribution (FS)	Cooling some ITER components to sub zero temperatures
Interface & integration intensive	Cooling water systems (FS)	Removal of heat load from ITER components

ITER Cryostat



29 m

Ø 29.4 m

Vacuum Vessel enclosing the entire Tokamak: Ensures vacuum environment for SC Magnets to minimise loss of cooling

- **Shell Thickness : 50 mm**
- **Max. Thickness : 200 mm**
- **Total Weight : ~3550 MT**
- **Material : Dual Marked SS 304/304L**
- **Vacuum : 10^{-6} Torr**
- **Largest SS vacuum vessel ever built: 16000 m^3 volume**

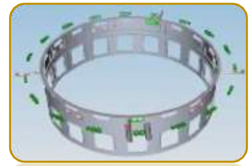
Material used: SS 304, SS 304L dual;
Co content <0.1% ; Suppliers: JINDAL steel, Industeel (France) & L&T Forging (Hazira)

ITER Cryostat PA signed – 6th Sep 2011
Contract to M/s L&T – 17th Aug 2012

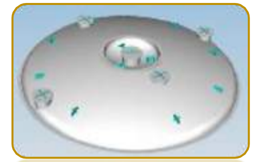
MANUFACTURING CHALLENGES

Manufacturing of Cryostat in one piece or even in four sections is not feasible

- Segmented approach
- Special handling of large pieces ~ 100 tons
- Structure requires welding Tolerance control : 0.3% of the dimension post joining of pieces
- Special welding techniques developed
- Special jigs and fixtures (to hold the piece while welding and handling) made



Upper

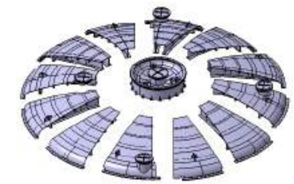


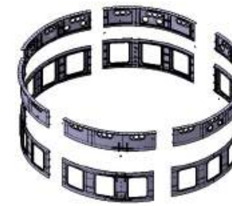
Top Lid

Base Section

Lower Cylinder

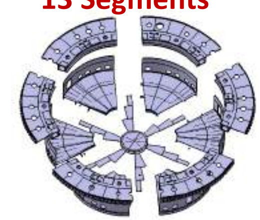
13 segments including central Lid





12 Segments

13 Segments



12 Segments

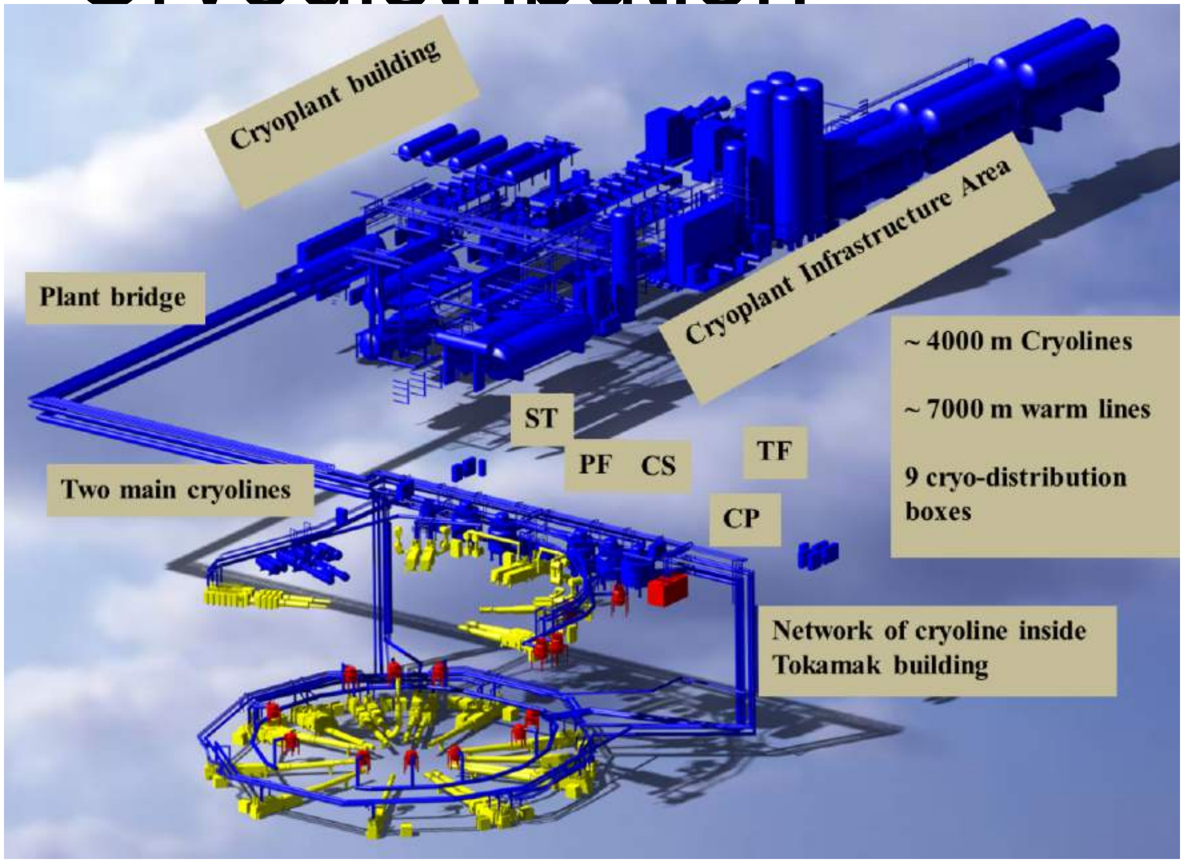
Manufacturing Status

Upper Cylinder Sectors Received. Fabrication going on at ITER Site workshop.

Lower Cylinder Assembly Completed and stored by IO

Base section Assembly Completed and handed over to IO

Cryolines & Cryodistribution



ITER magnets cooled with supercritical helium at 4 K

Surrounded by a thermal shield with a forced flow of helium at 80 K

Cryoplant produces the required cooling power

Distribution through a complex system of cryolines and cold boxes that make up the cryo-distribution system.

Principal challenge: cold circulators having mass flow rate ~ 3 kg/s at 4.3 K and 0.15 MPa pressure head.

Diagnostics Neutral Beam (DNB): measures He ash

Challenges

- Intense physics R&D
- Beam source of the largest size,
- High precision manufacturing
- Heavy engineering

Source development:

RF based negative ion source optimization & operation

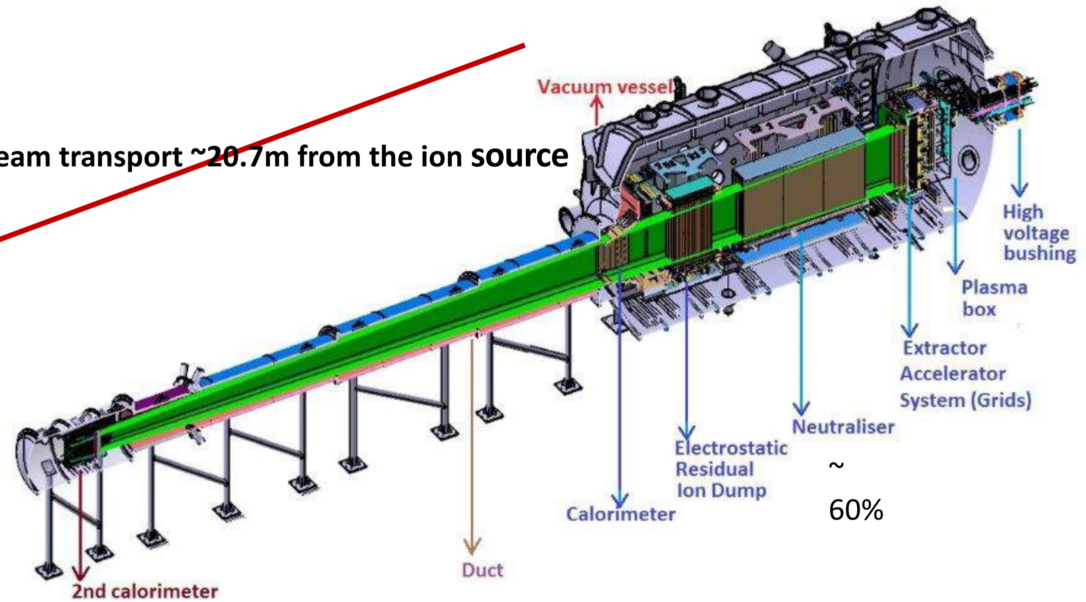
Material & engineering aspects

Development of material
Similar & dissimilar metal joining
Several precision machining techniques

100 keV, 60 A beam of H^-

8 RF negative ion source

Beam transport ~20.7m from the ion source



~ 60%

100 keV, 20 A beam of H^0

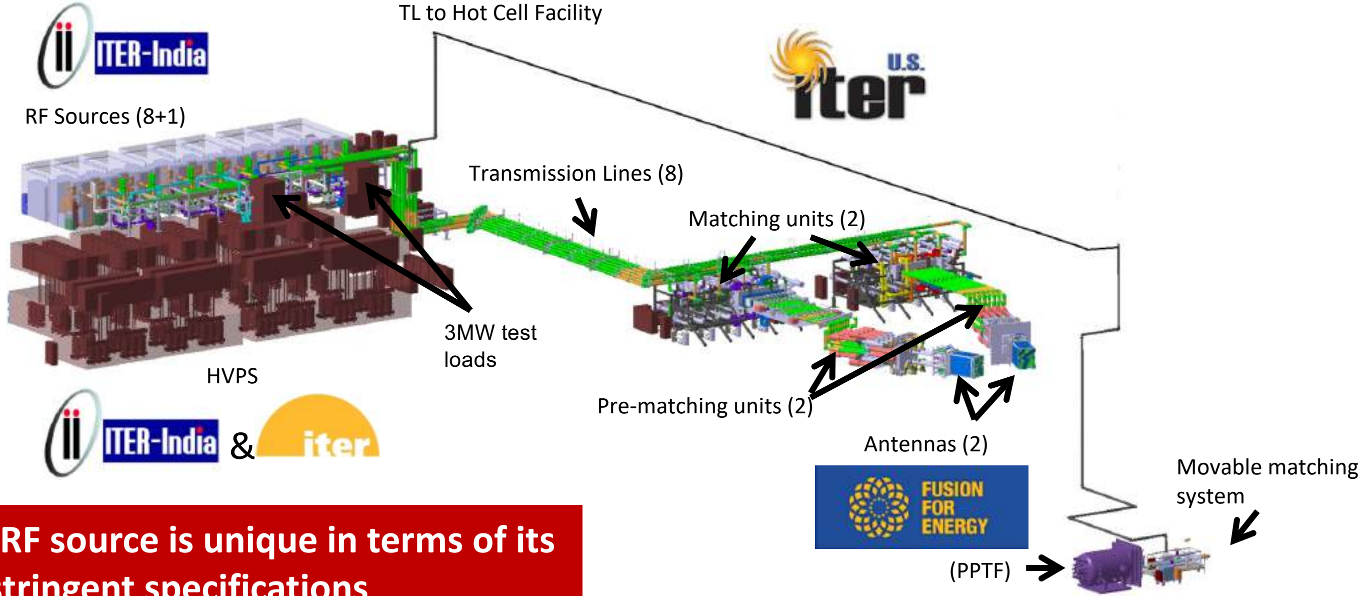
Achieved current density ~ 27 mA/cm2, against required 35 mA/cm2

Radio Frequency Power Sources: Ion Cyclotron Resonance Frequency (ICRF)

Functionality:
- **Heating**
- **Current drive**
- **Wall conditioning**

ICRH: Resonant heating of ions at Ion-Cyclotron Frequency

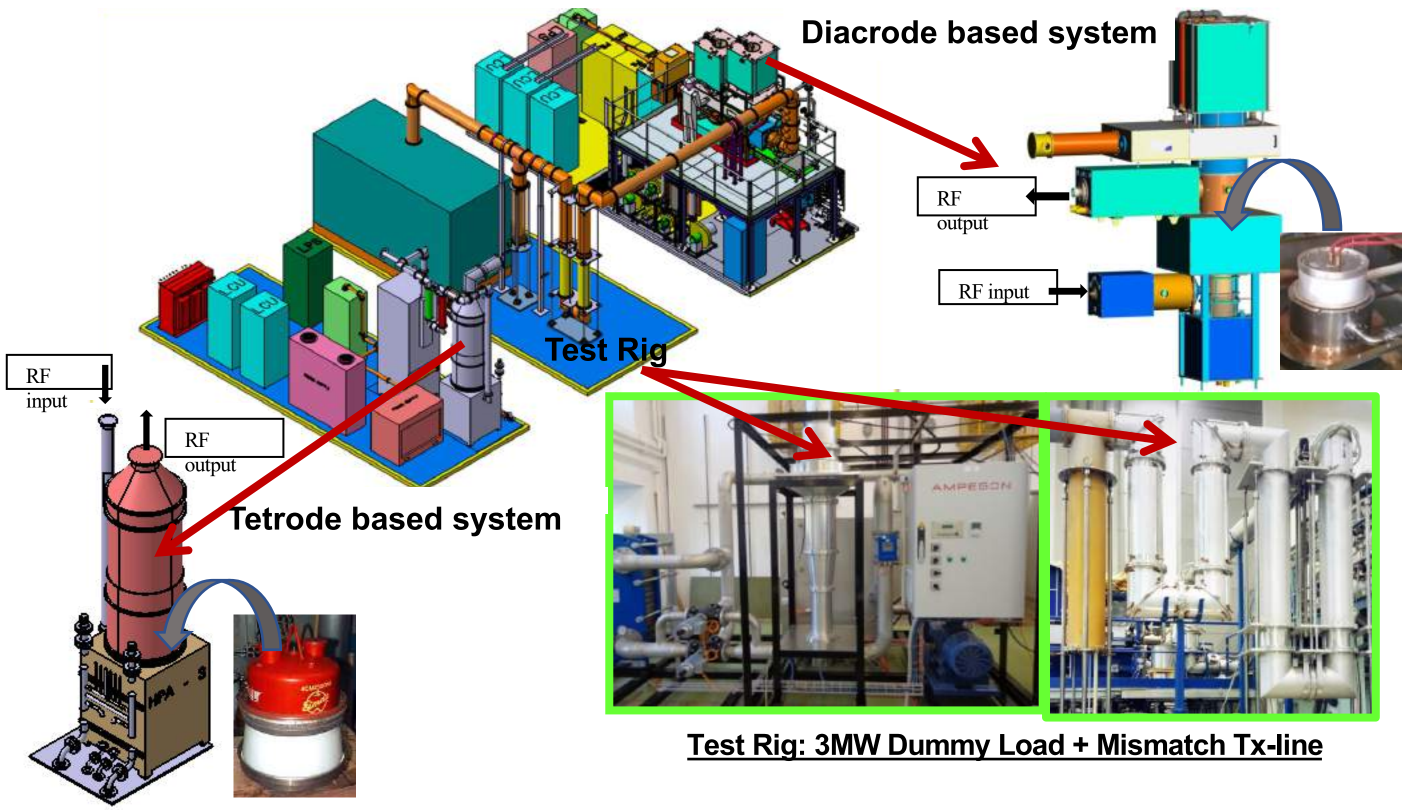
9 ICRF sources: (8 for operation + 1 spare)
- **2.5 MW/VSWR 2:1/35-65 MHz/CW**
- **3.0 MW/VSWR 1.5:1/40-55 MHz/CW**



This kind of RF source is unique in terms of its stringent specifications

ICRF Sources: Test Facility developed at ITER-India

Dedicated test facility comprises of Low power RF section, SSPA, Controls, High Voltage & Auxiliary Power Supplies, Tx-line system, Test Rig, Cooling etc.



Test Rig: 3MW Dummy Load + Mismatch Tx-line

Power Supplies: for RF & DNB systems

Multi-MW power supplies developed to drive the RF based plasma heating systems and the Diagnostic Neutral Beam system

Power supplies for DNB system

100 kV, 7.2 MW acceleration system power supplies for ion source manufactured in India and working in Padua Italy on ion source dev. Test bed

Pulse Step Modulation based HVPS for ICRF/EC system

ICRF:
27kV/190A Dual power supply

ECRH : **55 kV, 110 A**

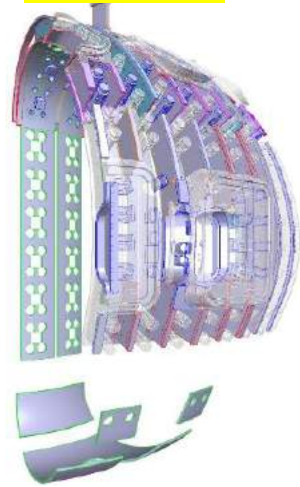
Design successfully tested, Exceeds ITER specifications

In Wall Shields: Neutron shielding

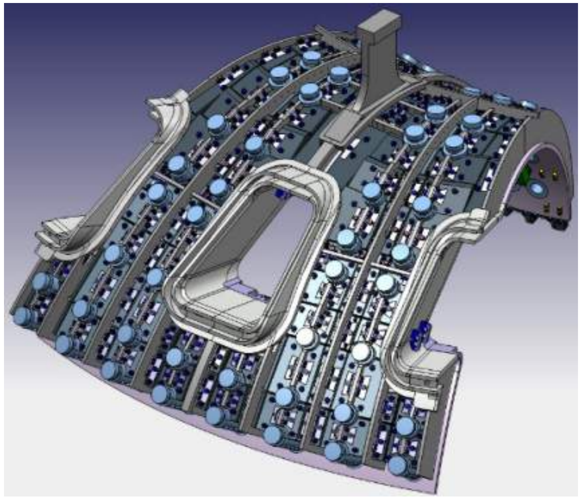
- Provide **shielding from neutron radiation for components situated outside of the vacuum vessel** (such as the magnets) as well as for **environmental safety**
- Contribute to **plasma performance** by limiting perturbations due to toroidal field ripple
- **Occupy 55 % of the space** between the double walls of the vacuum vessel
- **Modular** structure **9000 blocks made of 72000** borated (1-2% boron) or ferritic steel plates (each 40mm thick)

40° Sector

Without Shielding



Only Shielding



The peculiar shape of the blocks of IWS is a result of the surrounding space constraints.

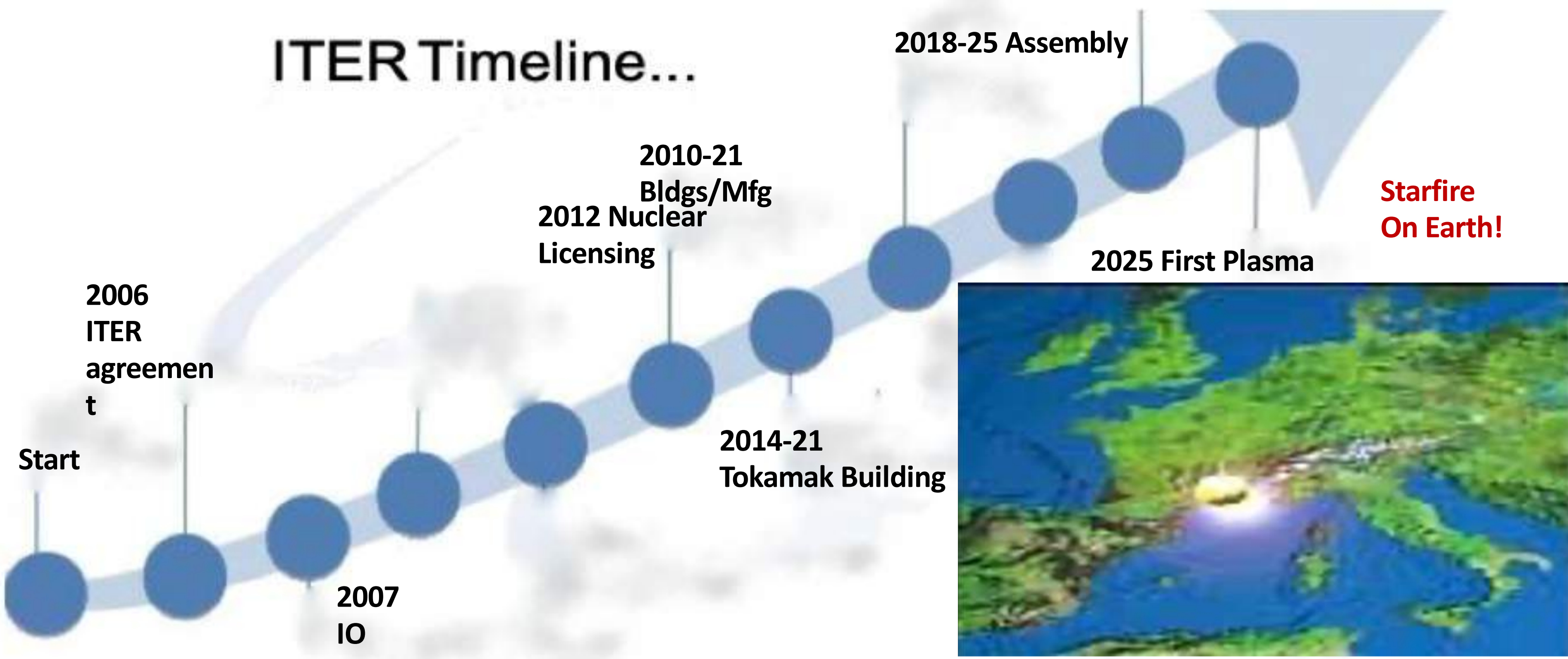
Slide courtesy : Mr. Laban Coblentz, IO, France

Manufacturing Progress

Total average component manufacturing through First Plasma is >65% complete.

Courtesy: Mr. Laban Coblentz (ITER Org.), Vigyan Samagam Mumbai

ITER Timeline...



Site progress

Dec 2010

Oct 2019

SUMMARY

- 75-year old quest for Starfire fulfilled
- Cutting edge technology, extreme environment
- materials, machining, joining, electrical, RF, hydraulic and cryogenic engineering addressed
- Control of Burning Plasma
- Novel Nuclear Technologies: Tritium breeding
- Capacity and competence building in R&D institutions and industry being achieved
- Acquiring state of the art Fusion technology knowhow

Slide Credits: VS Kolkata talk by Aparajita Mukherjee