# Vacuum system for fusion devices

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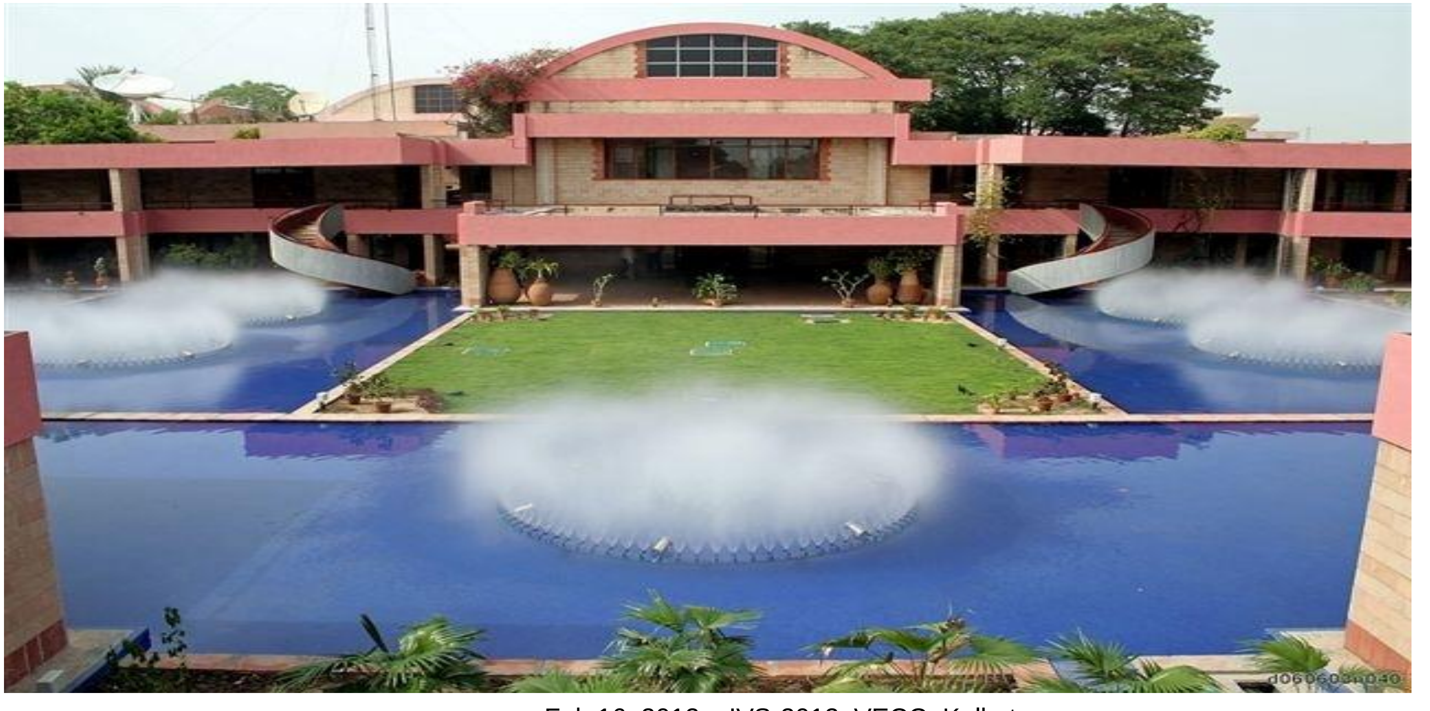


# Introduction

- Vacuum
- Fusion

# Fusion

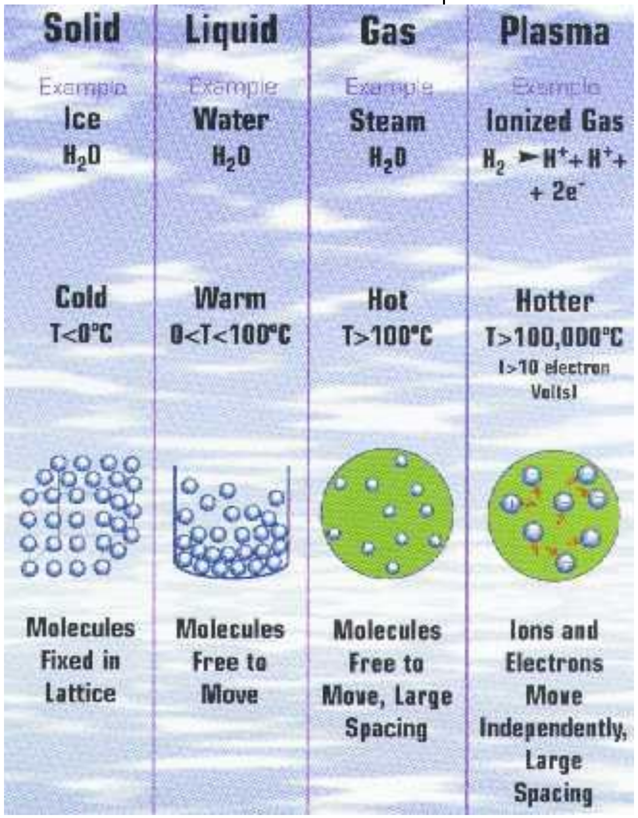
- Fusion is the reaction in which two atoms, e.g., hydrogen, combine together, or fuse, to form an atom of helium.
- In the process some of the mass of the hydrogen is converted into energy.
- Fusion has the potential to be an inexhaustible source of energy.
- Fusion is the process that powers the sun and the stars.

- To make fusion happen, the atoms of hydrogen must be heated to very high temperatures (100 million degrees) so they are ionized, forming a plasma and have sufficient energy to fuse, and then be held together i.e. confined, long enough for fusion to occur.

# Plasma

Electrons are knocked off from Neutral Atom

- Ionized gas
- Combination of ions and electrons
- Good conductor of electricity
- Affected by magnetic fields

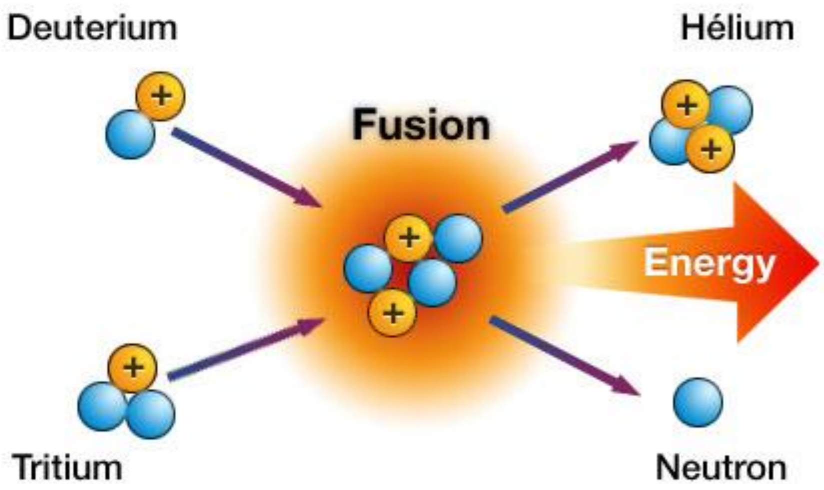


- The easiest fusion reaction

D-T reaction

Deuterium (or “heavy hydrogen) with Tritium (or “heavy-heavy hydrogen”) to make helium and a neutron, release 17.5 MeV energy.

# Fusion



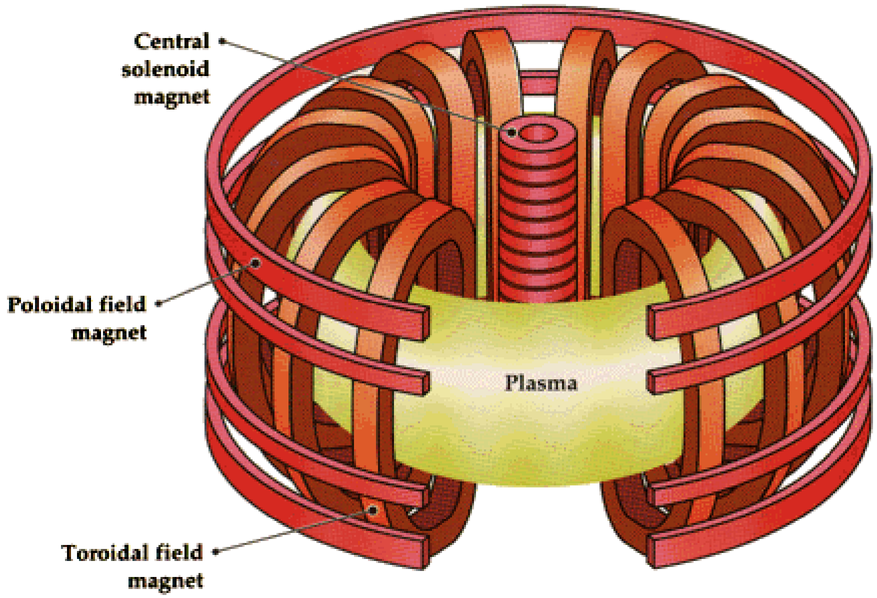
- For Fusion reactor

  Tokomak is a very strong candidate

# Tokamak

- **TOROID – KAMERA- MAGNETIC- KATUSHKA**
  (Acronym derived from Russian)
- A toroidal chamber in magnetic field
- Based mainly on Magnetic Confinement device
- Most successful plasma confinement and heating device.

# Tokamak



Central solenoid magnet
Poloidal field magnet
Plasma
Toroidal field magnet

# Tokamak Research and India

- SINP Tokamak
- ADITYA Tokamak
- SST1 Tokamak
- ITER

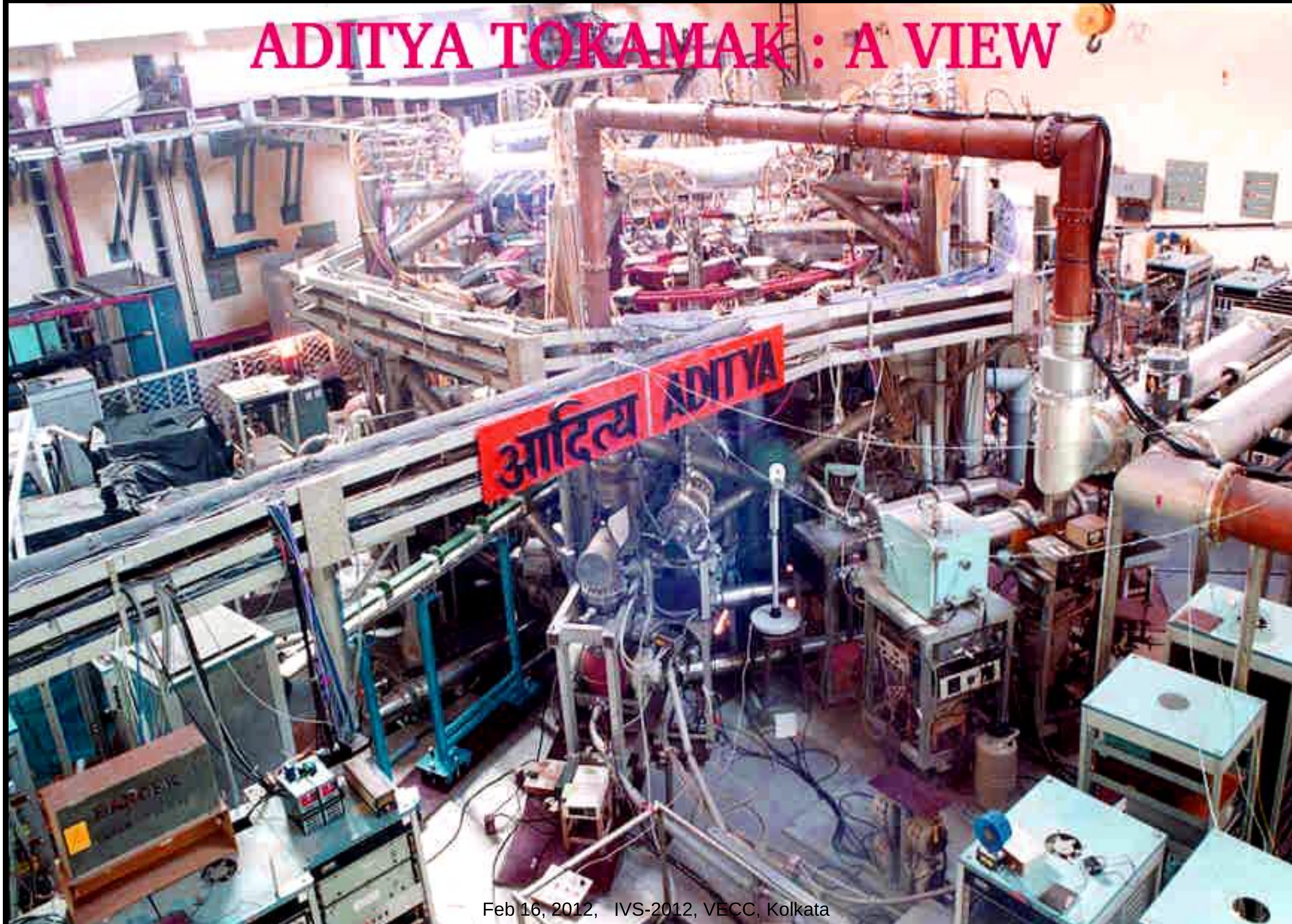
# ADITYA Tokamak
# First Indigenous Indian tokamak

- Plasma Physics studies identified by Ministry of Science and Technology as **High priority thrust area in 1982 and started as** Plasma Physics Programme

- In 1986, an Institute (IPR) fully devoted to Plasma science and magnetic fusion is established.

- Recognizing the importance of fusion research, its natural affinity to nuclear energy and urgency for its development, the Institute was taken over by Department of Atomic Energy in 1996

# ADITYA TOKAMAK : A VIEW



# TOKAMAK SUB-SYSTEMS

- **Vacuum system**
- **Magnetic field coils**
- **Power system**
- **Plasma Diagnostics**
- **Data acquisition and control**
- **RF heating and current drive**

# Tokamak Vacuum System

- UHV
  - Low outgassing rate
  - Withstand Electromagnetic Forces
  - Non-magnetic material
  - Withstand bombardment of energetic particles
    Plasma-wall interaction
  - Less Impurity introduction
  - Lower Recycling

# UHV Vessel

- **Design**

- Selection of materials for chamber,
- Metal seals – Conflat, wire seals, Viton seals (rare)

- **Fabrication**

- Heat Treatment, Machining, Welding, Flanges

- **Pre - Assembly**

- Cleaning with mild acid, soap solution, distilled water
- Electropolishing
- Ultrasonic cleaning

- **Assembly**

- Clean Environment,
- Use of gloves, apron

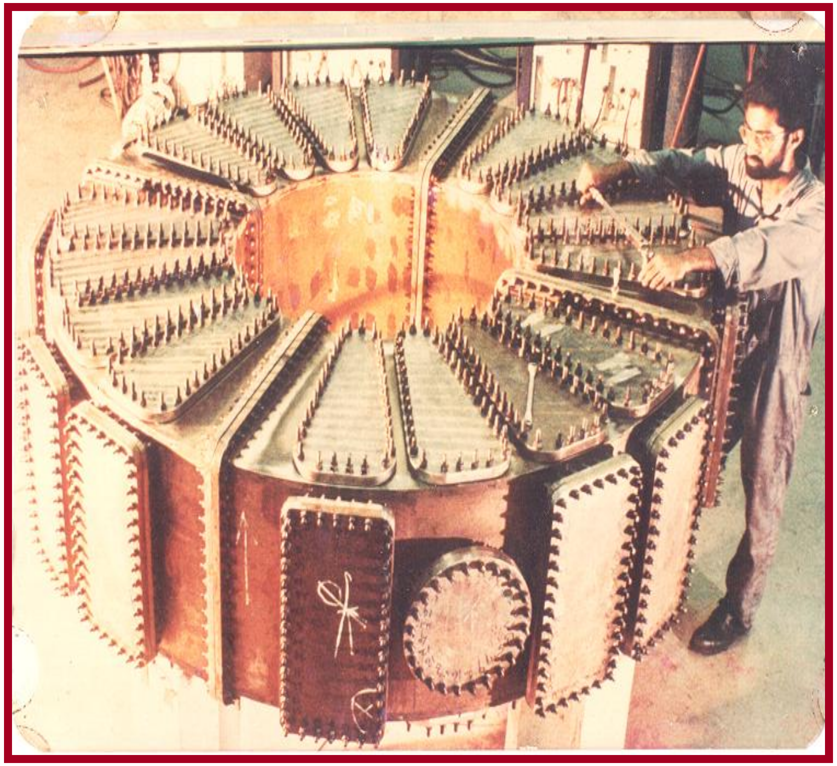
In-situ wall treatments

- Baking
- Discharge cleaning

- Wall coating

# ADITYA TOKAMAK VACUUM SYSTEM

- Toroidal Chamber-Four Quadrants
- Rectangular cross-section of 0.6 m X 0.6 m
- Material : SS 304 L
- Minor Radius: 0.25 m
- Major Radius: 0.75 m
- 16 Top, Bottom & Radial Ports
- Volume ~ 2 $m^3$
- Surface Area ~ 20 $m^2$
- Pumping System: 4 UHV Lines
- 3 TMPs (2000 l/s each) &
- 1 Cryopump (2000 l/s)
- Pirani, B-A IG
- RGA and eH Leak Detectors
- Ultimate Vacuum: ~1 x $10^{-9}$ torr
- Base Pressure ~ 1 x $10^{-7}$ torr
- Working Pressure: $10^{-3}$-$10^{-5}$ torr



# In Situ Wall Conditioning Systems

- Automated Glow Discharge Cleaning System
- Pulse Discharge Cleaning System
- ECR Discharge Cleaning System
- Wall Coating – lithium, boron

# GLOW DISCHARGE CLEANING SYSTEM

- Discharge Current : ~ 3.5 ampere
- Discharge Voltage : ~ 350 Volts
- Fill Pressure : ~ 1 X $10^{-3}$ Torr
- Fuel Gas : Hydrogen
- Duration : Automated (12 Hours)
- No magnetic field

# PULSE DISCHARGE CLEANING SYSTEM

- Ohmic Voltage : ~ 5.0 KV
- Toroidal Magnetic Field : ~ 0.09 T
- Pressure : ~ 3 X $10^{-5}$ torr
- Fuel Gas : Hydrogen
- Pulse duration : 4 ms
- Pulse Repetition Rate : 900 Pulses/ Hour

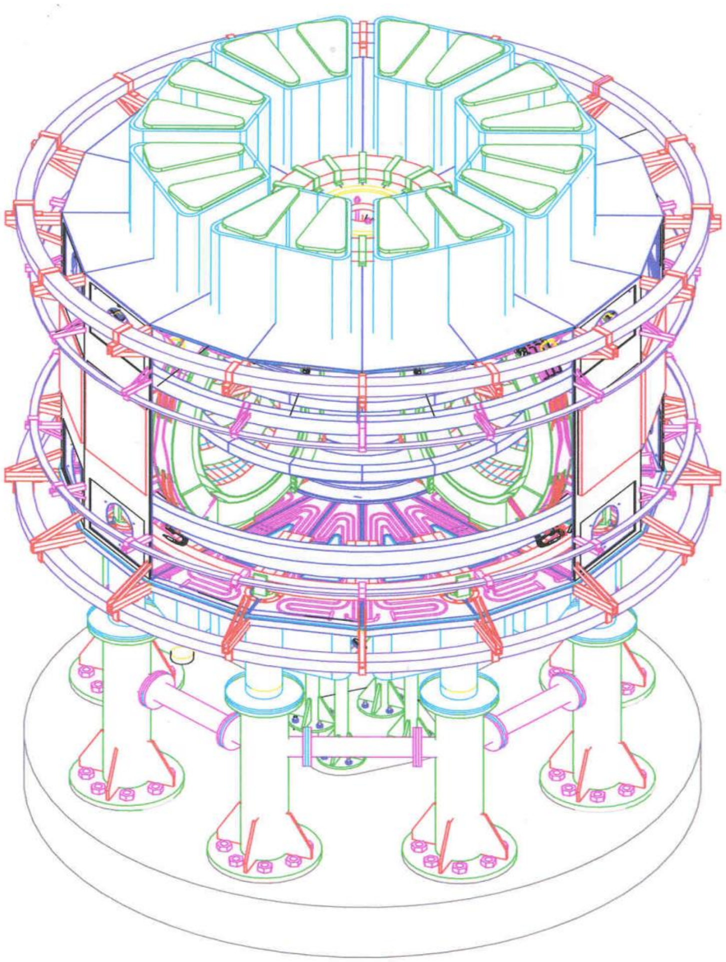
# ECR DISCHARGE CLEANING SYSTEM

- Frequency : 2.45 GHz
- Toroidal Magnetic Field : ~ 0.05 T
- Pressure : ~ 3 X $10^{-5}$ torr
- Fuel Gas : Hydrogen
- Power : ~ 750 Watt

# SST1 Tokamak

- Steady State Tokamak
- Superconducting Magnets for longer plasma pulse

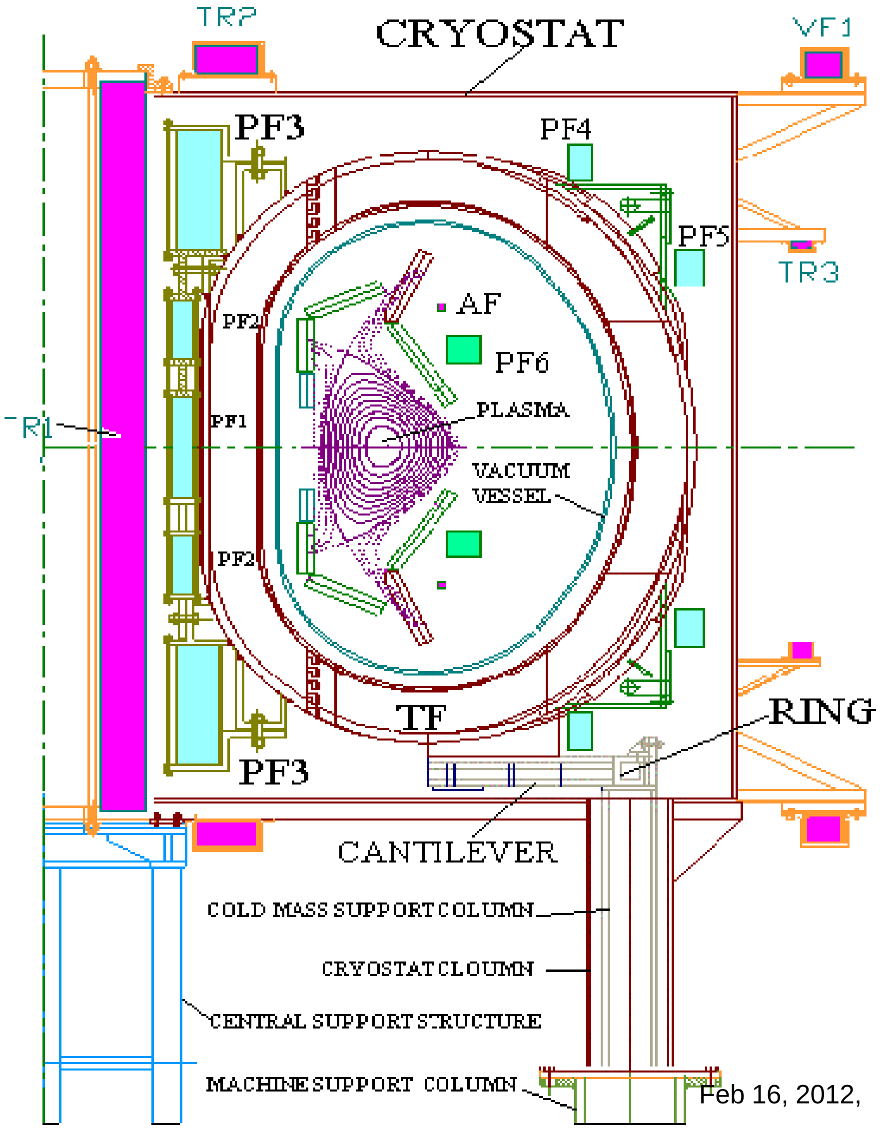
# SST 1 TOKAMAK



**SST1 TOKAMAK PARAMETERS**

| | |
|---|---|
| MAJOR RADIUS | : 1.1M |
| MINOR RADIUS | : 0.2 M |
| ELONGATION | : 1.7-2 |
| TRIANGULARITY | : 0.4-0.7 |
| TOROIDAL FIELD | : 3T |
| PLASMA CURRENT | : 220 kA. |
| ASPECT RATI | : 5.2 |
| SAFETY FACTOR | : 3 |
| AVERAGE DENSITY | : 1X $10^{13}$ $cm^{-3}$ |
| AVERAGE TEMP. | : 1.5 keV |
| PULSE LENGTH | : 1000 s |

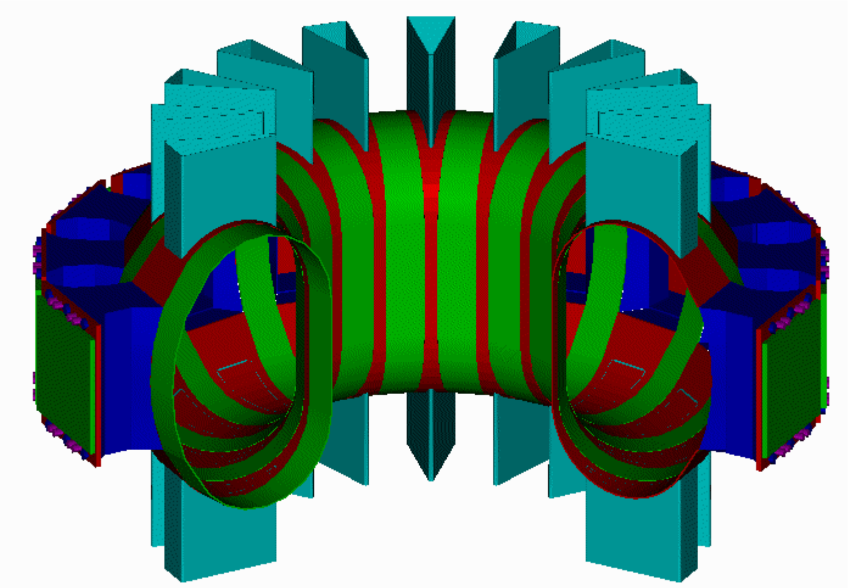
# SST 1 Tokamak Vacuum System

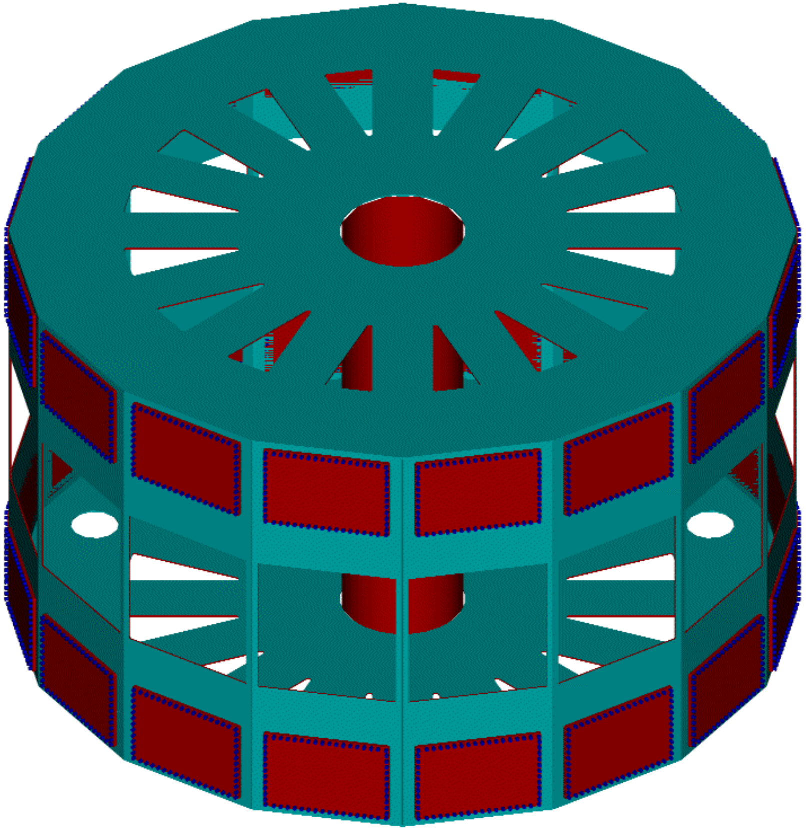



- Material : SS 304 L
- Major Radius : 1.3 m
- Vertical Semi-axis : 0.8 m
- Radial Semi-axis : 0.5 m
- 16 Top, Bottom & Radial Ports
- Volume : ~ 16 $m^3$
- Surface Area : ~ 68 $m^2$
- Pumping System : UHV Lines
- 16 TMPs (5000 l/s each)
- Ultimate Vacuum : ~1 x $10^{-9}$ torr
- Base Pressure :~ 1 x $10^{-7}$ torr
- Working Pressure : $10^{-3}$-$10^{-5}$ torr

**Cryostat**

- Height : 2.6 m
- Mid plane width : 4.4 m
- Volume : ~ 40 $m^3$
- Surface Area : ~ 72 $m^2$





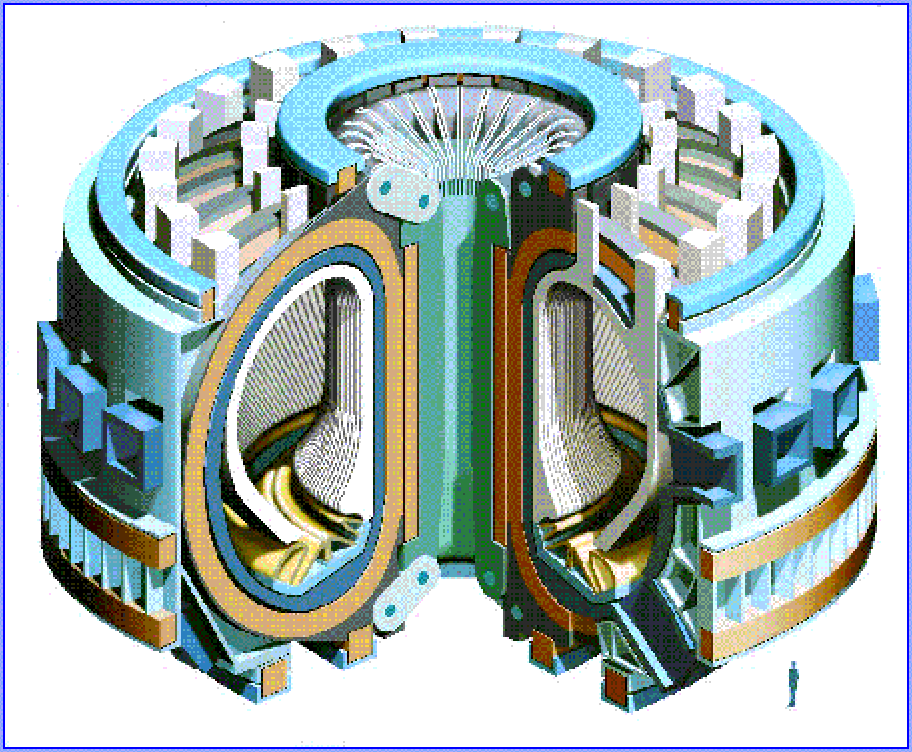
- For more details

Please refer to posters presented on various aspects of SST1 by my colleagues, Raval, FirozKhan and Prashant, in the poster session

# ITER

- International Thermonuclear Experimental Reactor
- Joint International Research Project for fusion devices, The European Union,Japan,China, India, Korea, Russian Federation and USA
- Next Generator tokamak type Fusion device
- Stage between today's tokamak and fusion power plants
- Caderache, France

# ITER
## (International Thermonuclear Experimental Reactor)



30 meters diameter
30 meters tall

62

## ➢ Vacuum Vessel

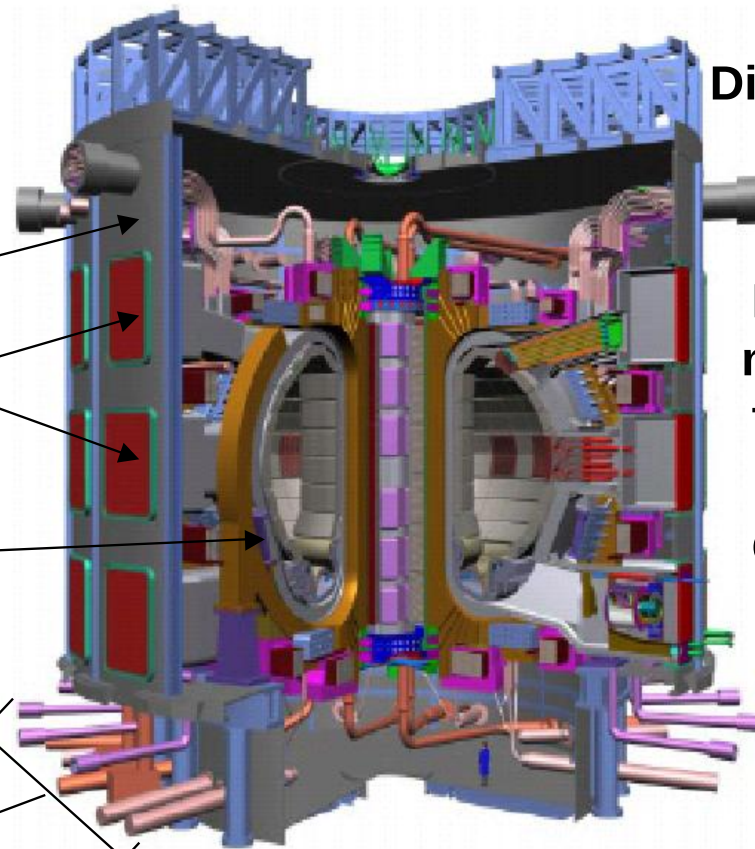
- Material : SS 316L
- Major Radius : 6 m
- Vertical Semi-axis : ~11 m
- Radial Semi-axis : 3 m
- 16 Top, Bottom & Radial Ports
- Volume : ~ 1400 $m^3$
- Surface Area : ~ 10000 $m^2$
- Ultimate Vacuum : ~1 x $10^{-8}$ torr
- Working Pressure : $10^{-3}$-$10^{-5}$ torr

## ➢ Cryostat

- Height : 30 m
- Mid plane width : 30 m
- Volume : ~ 8500 $m^3$
- Vacuum : ~1 x $10^{-6}$ torr

✓ Please refer : Talk by Dr. Kimihiro Ioki, IO, France

# Indian Contribution to ITER



Diagnostic Neutral Beam (DNB)

Cryostat

Diagnostics

RF sources, monitoring and control for IC H&CD

Vacuum vessel in wall shields

Gyrotrons for plasma start up

Power supplies for DNB, RF, Gyrotrons

ITER heat removal, component cooling and chilled water system

Cryo-distribution and Cryo-line system

# THANK YOU