Fusion Power- a survey
IEEE Delaware Bay Section, 2-23-2021

Purpose of this presentation

What are the engineering challenges??

Look at where we are with Fusion Power and where we might be going

Review efforts to date
Efforts prior and concurrent to ITER

Engineering Challenges:

For Physicists: Plasma, magnetic fields, superconducting magnets

For Mechanical Engineers: design, manufacture assembly, metallurgy, project management

For Electrical and Instrumentation Engineers: measure and control, high current

Civil Engineering: large facility; earthquake proofing foundation

Bio Engineering: personnel safety

Previous IEEE Delaware Bay Section Programs

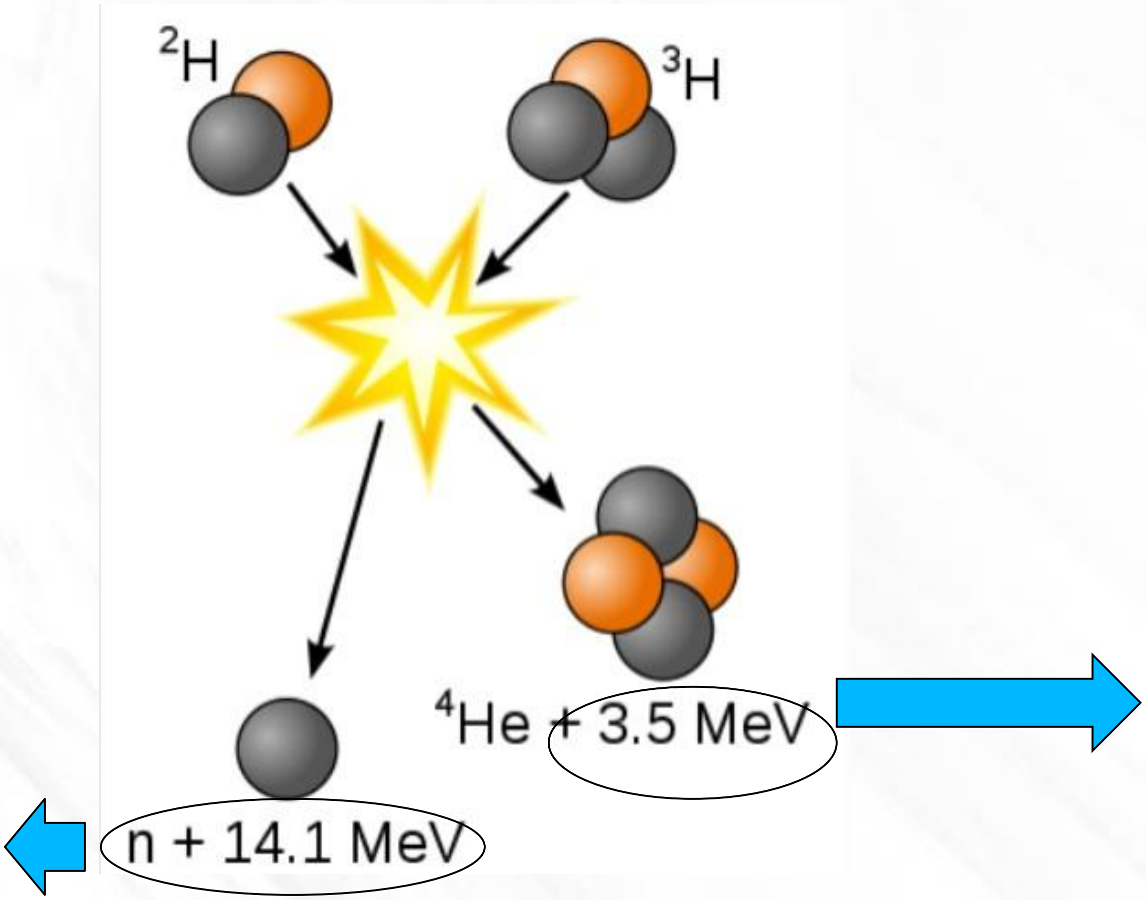
Fusion Energy Research and Development: Star Building on Earth;

Dr. John Glowienka Deputy ITER Program Manager,

9-22-2009

So..what has happened in the last 12 years??

Review – Fusion energy from fusion of Deuterium and Tritium; What's all the fuss about??



HEAT

LITHIUM
TARGET
TO FORM
TRITIUM

Advantages of Fusion

1. **Nuclear fusion doesn't create harmful waste. (No Nuclear Hazard signs/Waste storage)**
2. **There is an infinite?? amount of fuel for nuclear fusion.**
3. **It is incredibly inexpensive to create.**
4. **It is a low risk form of energy.**
5. **Global warming can still be negated without energy loss. May be only practical alternative**

Disadvantages of Fusion

1. **Presently almost as much energy is required to create nuclear fusion as the energy it creates.**
2. **Creating the infrastructure for nuclear fusion is expensive.**
3. **There may be unanticipated consequences to using nuclear fusion.**
4. **This industry still requires innovation.**
5. **Heat can be just as deadly as radiation.**
6. **Are large amounts of He a problem??**

How hard is fusion power to obtain?

How complicated is the problem?

Fusion Technology for power “Way more complicated than Moon Landing”

Need to demonstrate “break-even” fusion

Cost of the ITER through demo of “break-even”, present forecast is ~$15 B.

Schedule For ITER First Plasma 2019 ->2025.

First ITER DT operation 2040

So..what's the big problem??

A free plasma needs to be at 100 million degC on Earth.

(The Sun is “only” at 10 million degC, but high gravity helps)

Containment of the hot plasma for extended times—until atoms fuse-> Tokamak

Handling of high energy neutrons

Superconducting Magnets

A demo Tokamak needs to be BIG

What is needed for fusion power:

A plasma of high velocity deuterium+tritium atoms; heat to near 100 million degC

Contain the above for a relatively long time

have plasma ions going on a circle line in a helix until they “get the idea” to fuse

use magnetic fields to establish the circle and helical path

Pinch electron lines away from the torus walls using Polloidal magnetic field

Methods toward Fusion Power

Atomic bomb- but we need containment

Laser inertial confinement - pulsed laser power
Lawrence Livermore

Magnetic field-– continuous power
Tokamak configuration
German- Stellerator Configuration
Lockeed Martin configuration

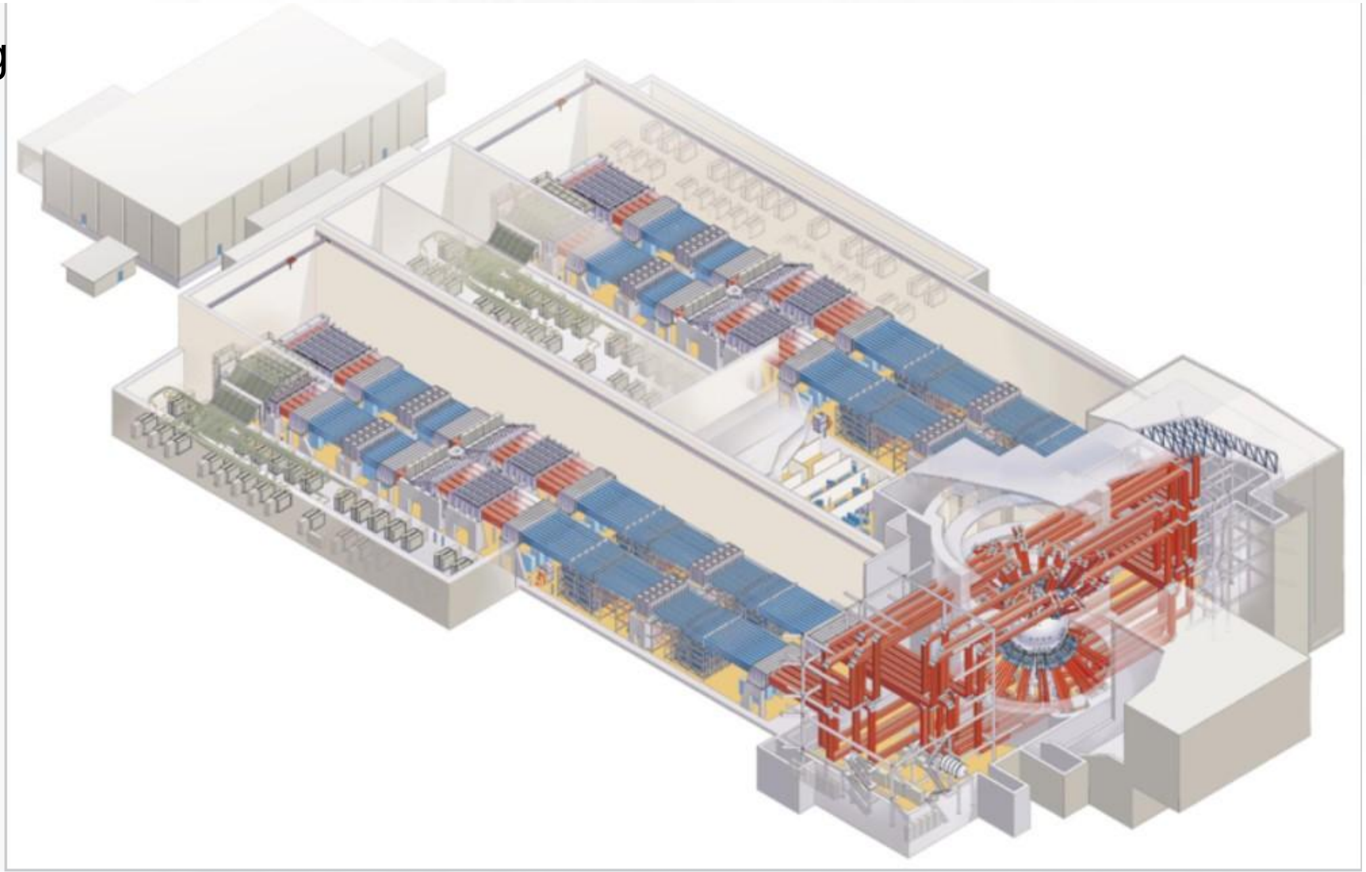
Laser Inertial Confinement

1.06 NdYag
Converted
To 0.351

1.7 MJ
Pulse
Reduced
to
10 KJ at
Target

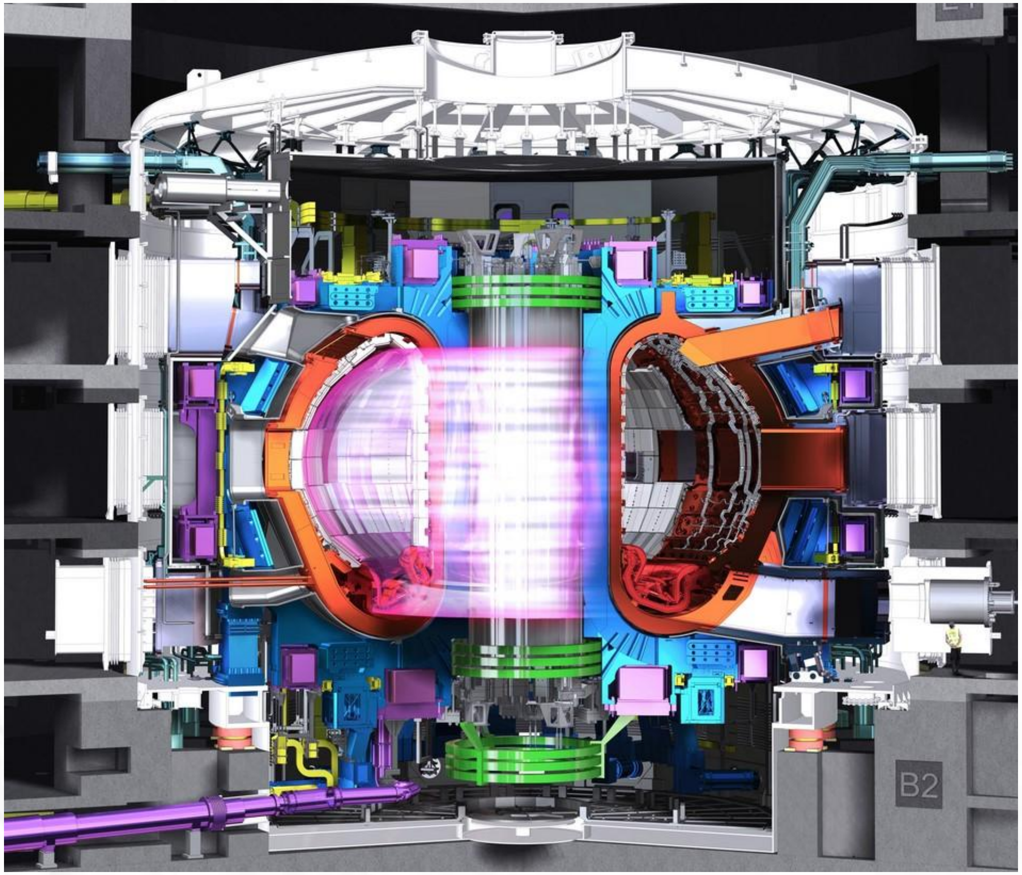
192 laser
Beams

1 TW
Peak
5 ns
pulse



Lawrence Livermore National Ignition Laboratory

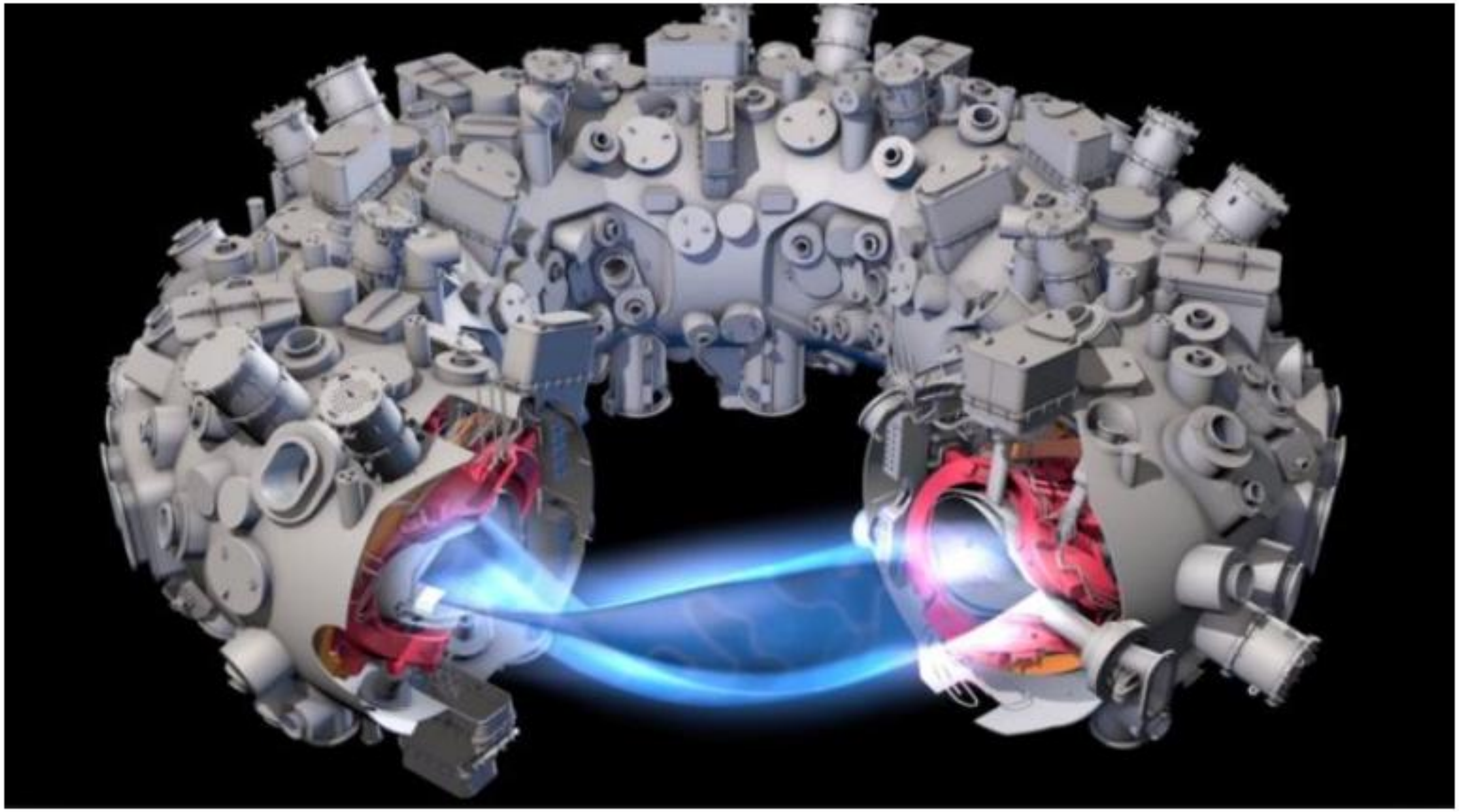
Magnetic Confinement, Tokamak



ITER Tokamak

History of Tokamak Research

Magnetic, Stellerator



Invented in US, Now a German Project
May be easier to control-but difficult to build

LOCKEED MARTIN PATENTED CONFIGURATION FOR COMPACT REACTOR

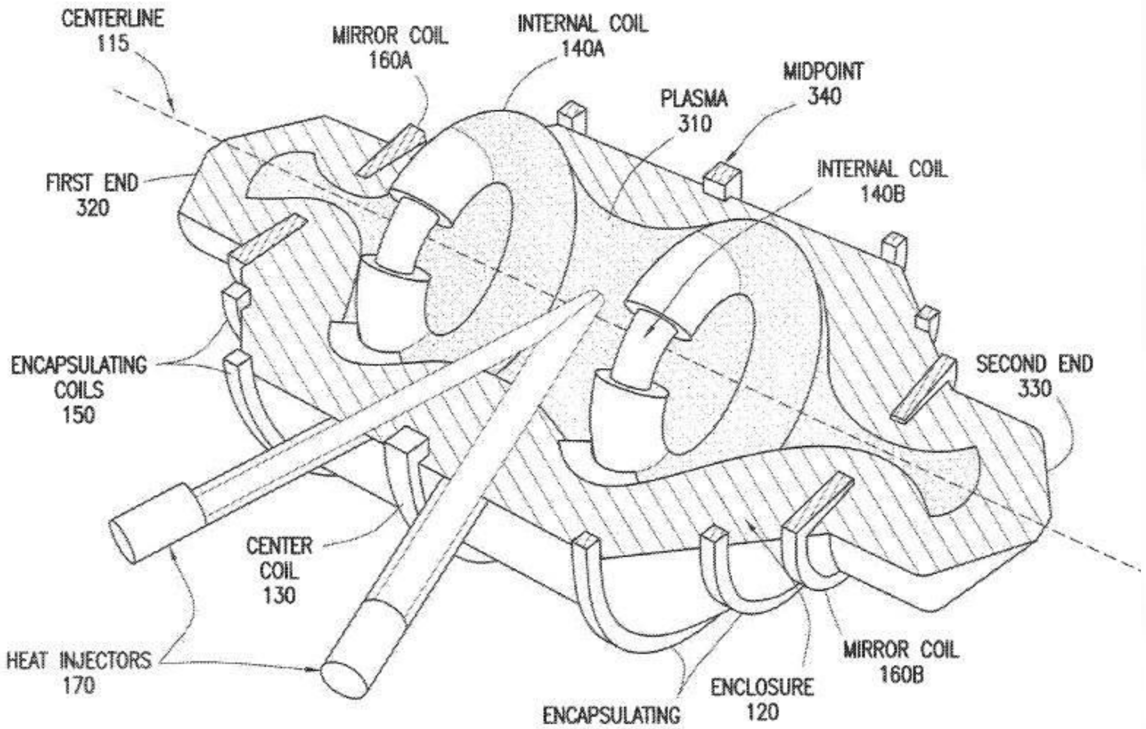


FIG. 3B

Tokamaks

200 around the world, ITER largest

KSTAR (Korea Superconducting Tokamak Advanced Research)

JET (Joint European Torus, EuroFusion)

ITER large enough to pass break even power

Instabilities; Edge Localized Mode (ELM)

Progress on Tokamaks

What has happened since 2009? Where are we now? (Are we there yet?)

ITER - First Plasma; In 2009->forecast for 2018; -> 2025-2030; DT operation -> 2040

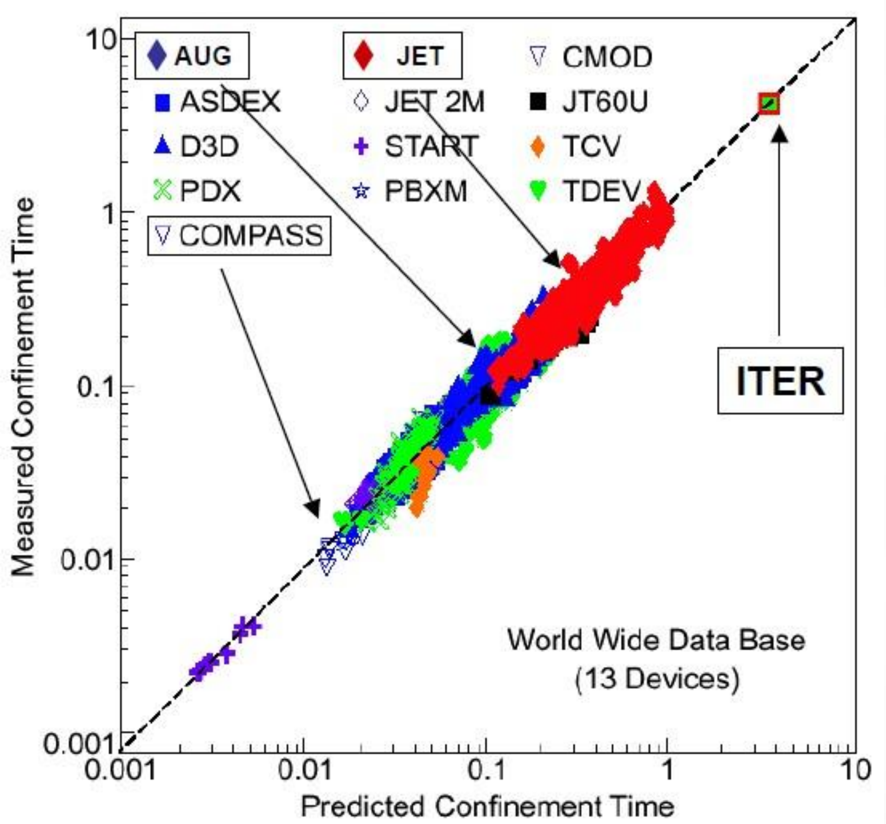
Tokamaks-JET and Korean; Achieved Hot plasma in the 100 million degC area. JET achieved 0.7 break-even for a few seconds

MIT developed “warmer” magnet operation leading to smaller configuration

Synergy of all Tokamak projects

ITER Tokamak

Why so big?



More confinement time, instabilities easier to control; time scale is in seconds

Unlimited Raw Materials??

How much Deuterium/How much Tritium, how to get them

33 gms DT/cubic meter of seawater (264 gallons)

neutron plus lithium ->He plus Tritium

1000 MW fusion plant (at 100% efficiency)→ 125 kg DT + 125 kg TR per year;this would be 125 / .033 = 3800 cubic meters of seawater/ year = 1 million gallons/year

Raw Materials-2

A typical standpipe water tower in this area is 500,000 gallons

How much Tritium on hand?—practically none. Must be generated.

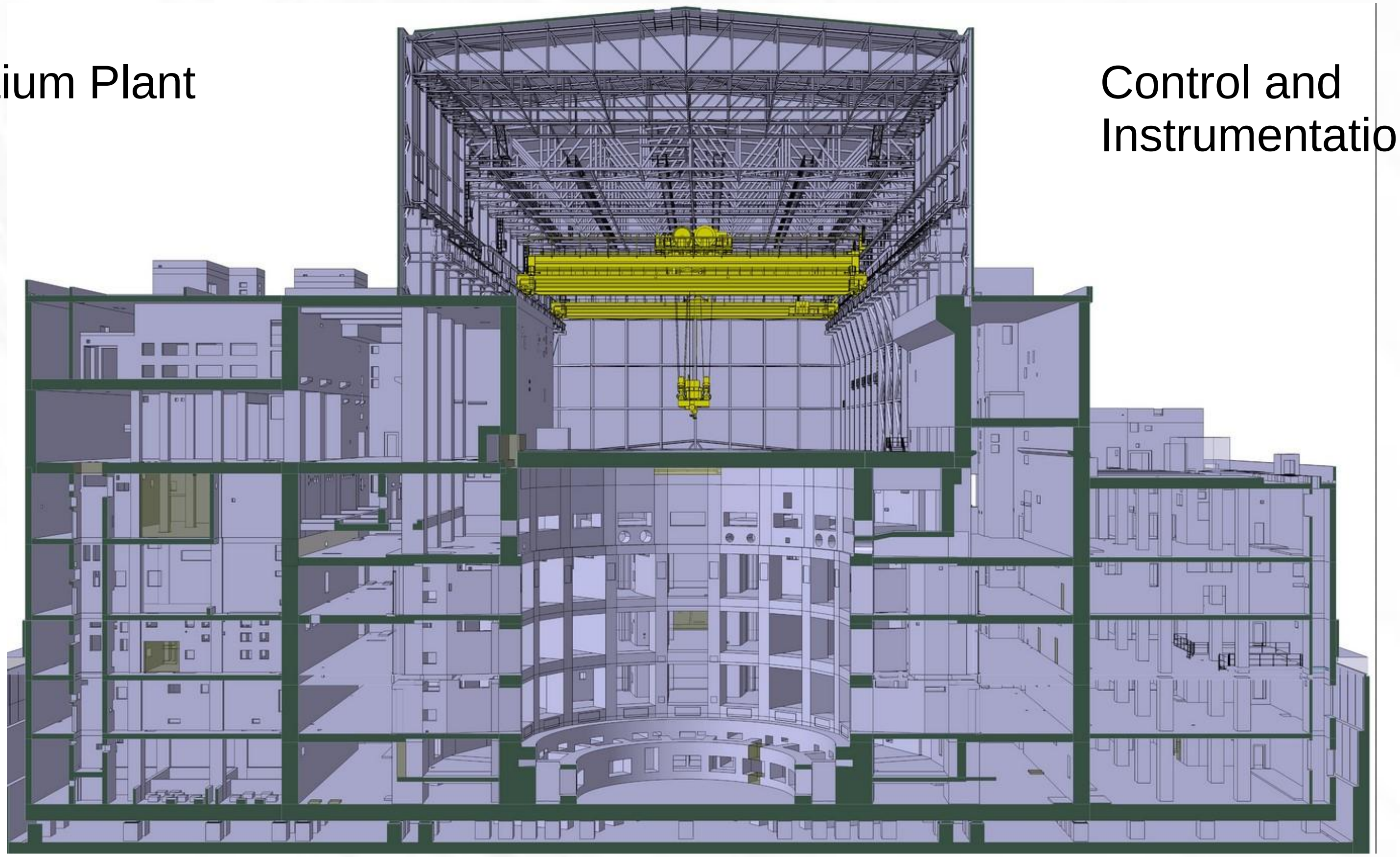
Compare- coal fired 1000 MW ->10,000 tons/day; by weight DT-TR has 3 x 10E+9 more energy

Plasma Measurements

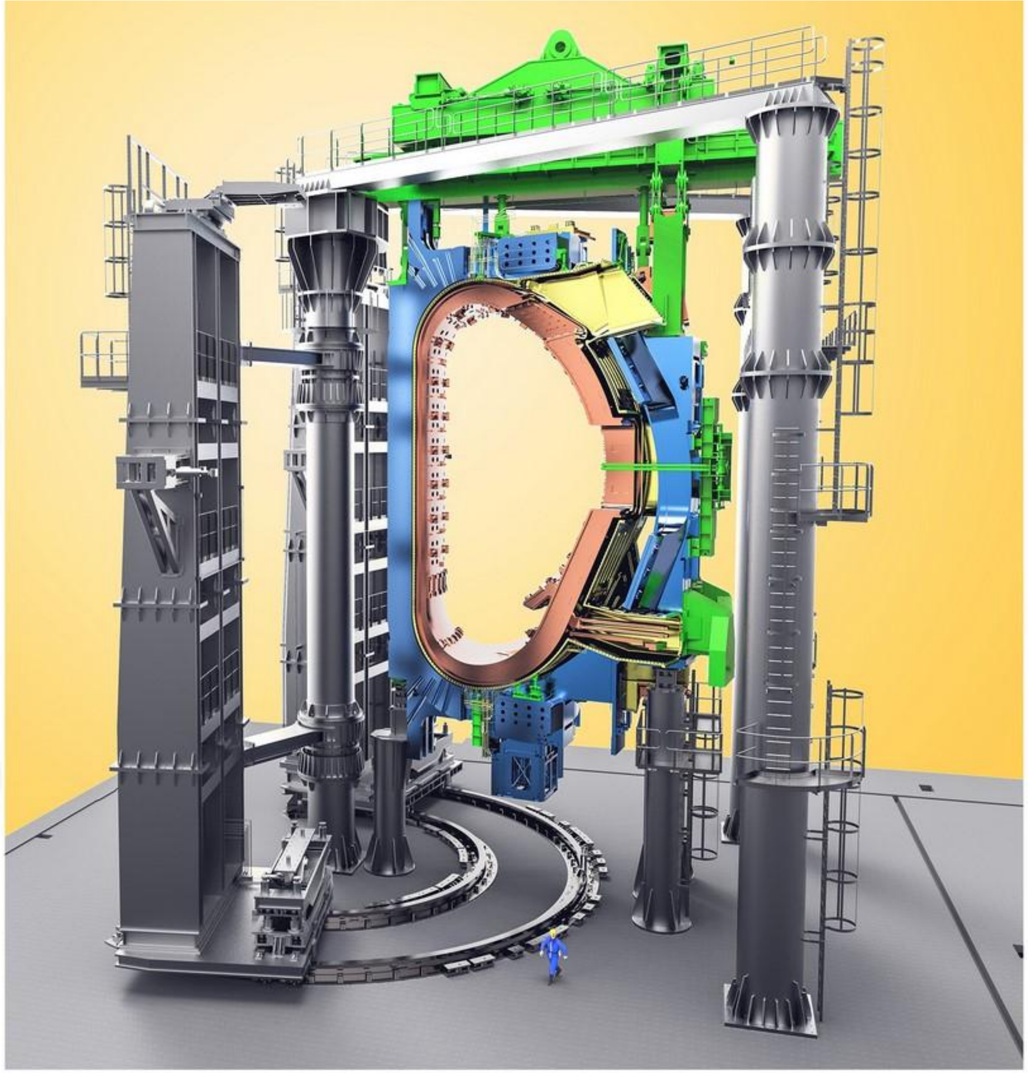
100,000,000 degC temperatures. Theory is that T is atom velocity, so shoot laser beam and measure Doppler broadening of laser pulse.

Particle Count. Use photon counters.

ITER Reactor and Construction Building

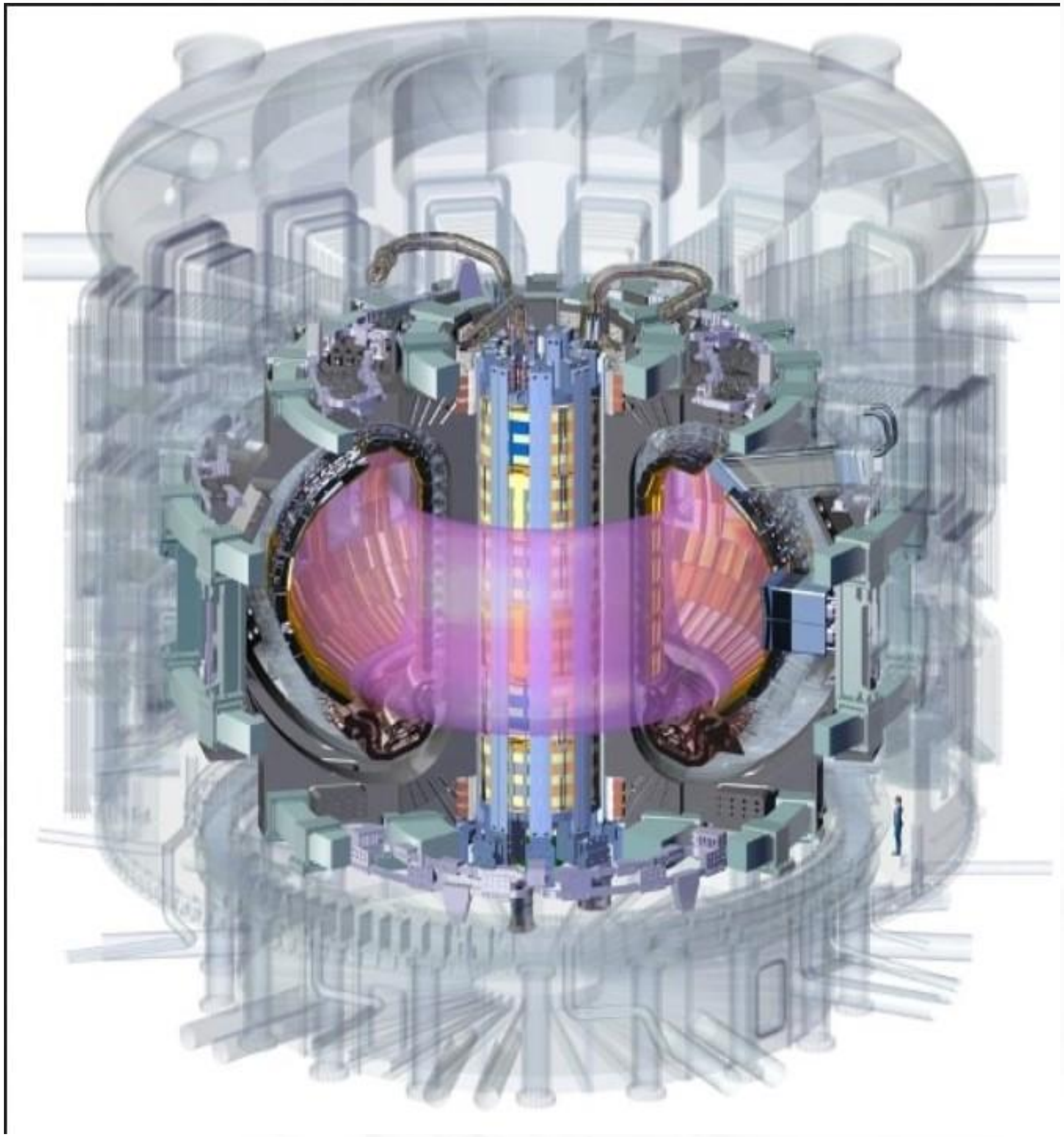


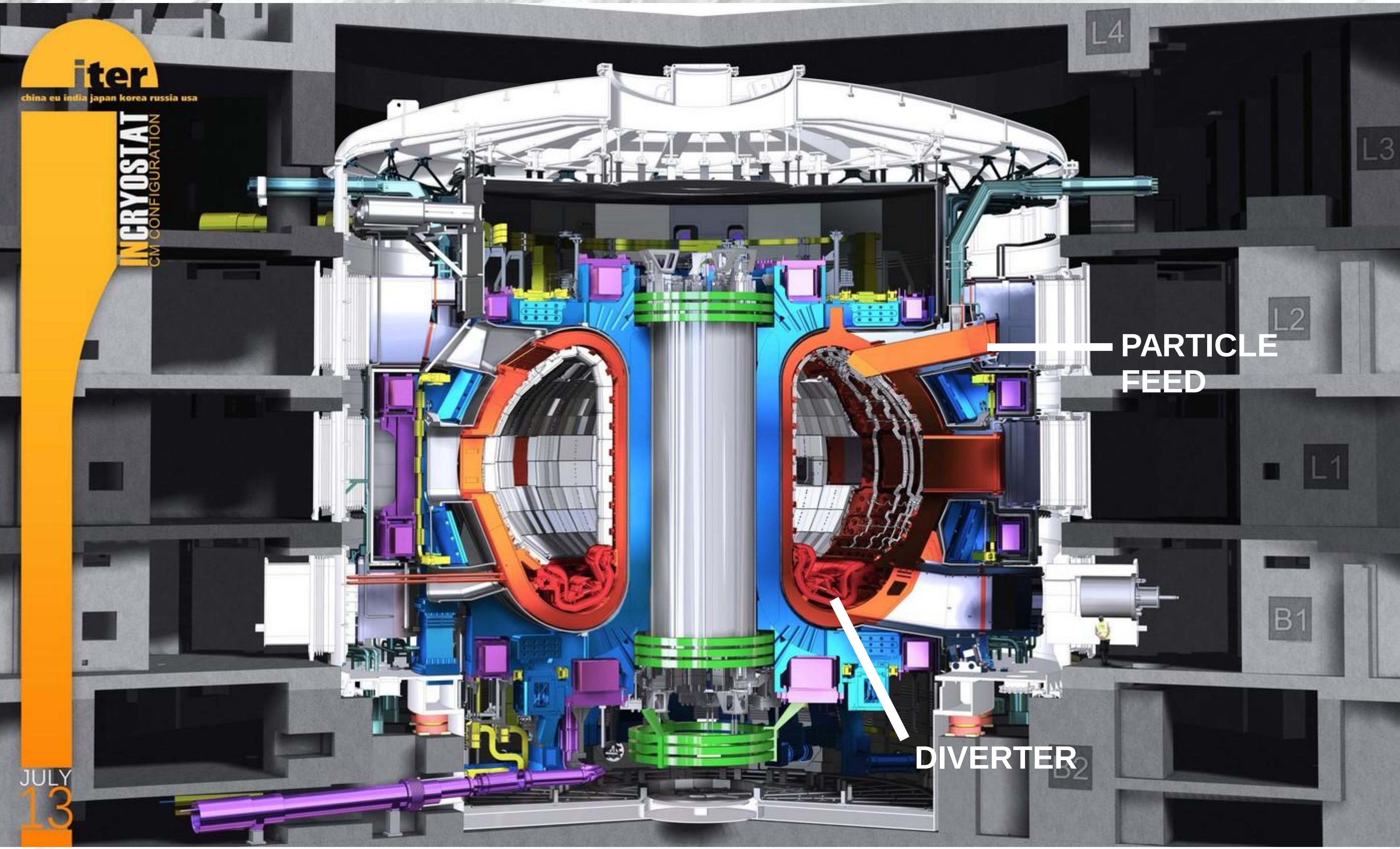
ITER Tokamak



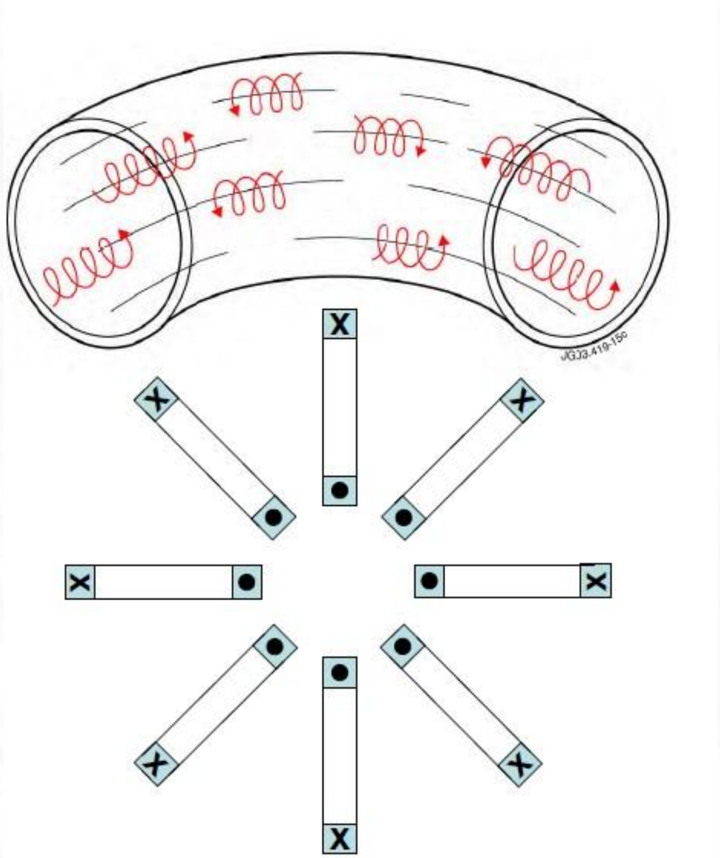
World's Biggest Tools?

ITER Tokamak showing central solenoid magnet and plasma



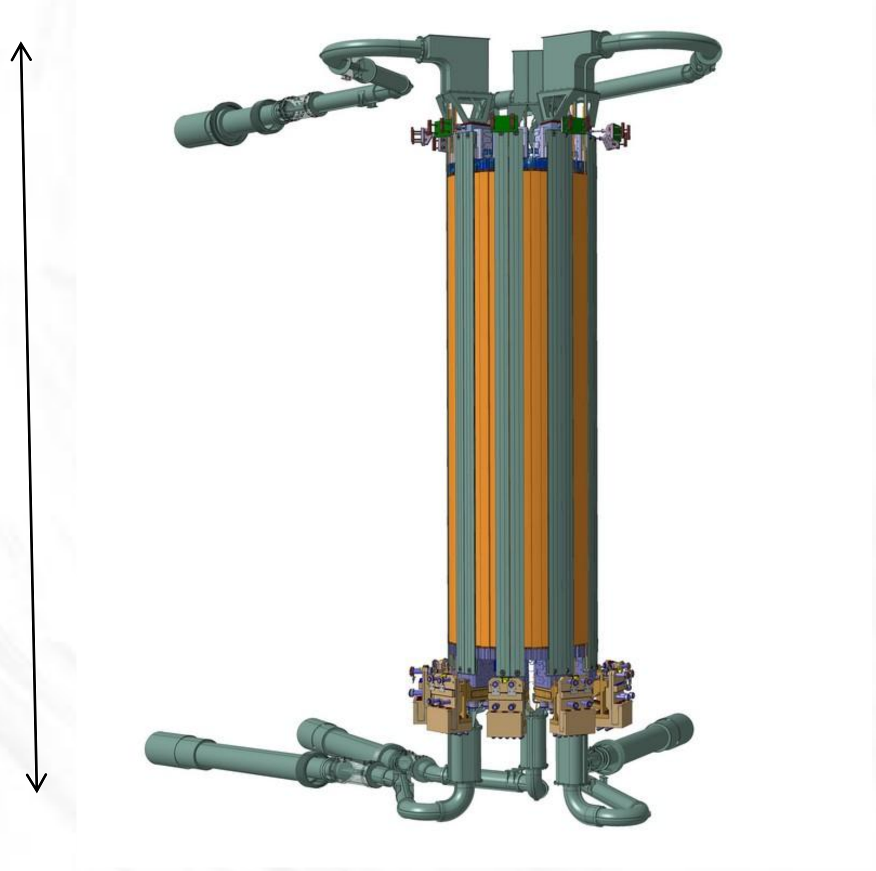

iter
china eu india japan korea russia usa
INCRYOSTAT
CM CONFIGURATION
L4
L3
L2
L1
B1
B2
JULY
13
PARTICLE
FEED
DIVERTER

Action of the Central Magnet and Toroid Magnet on the Plasma

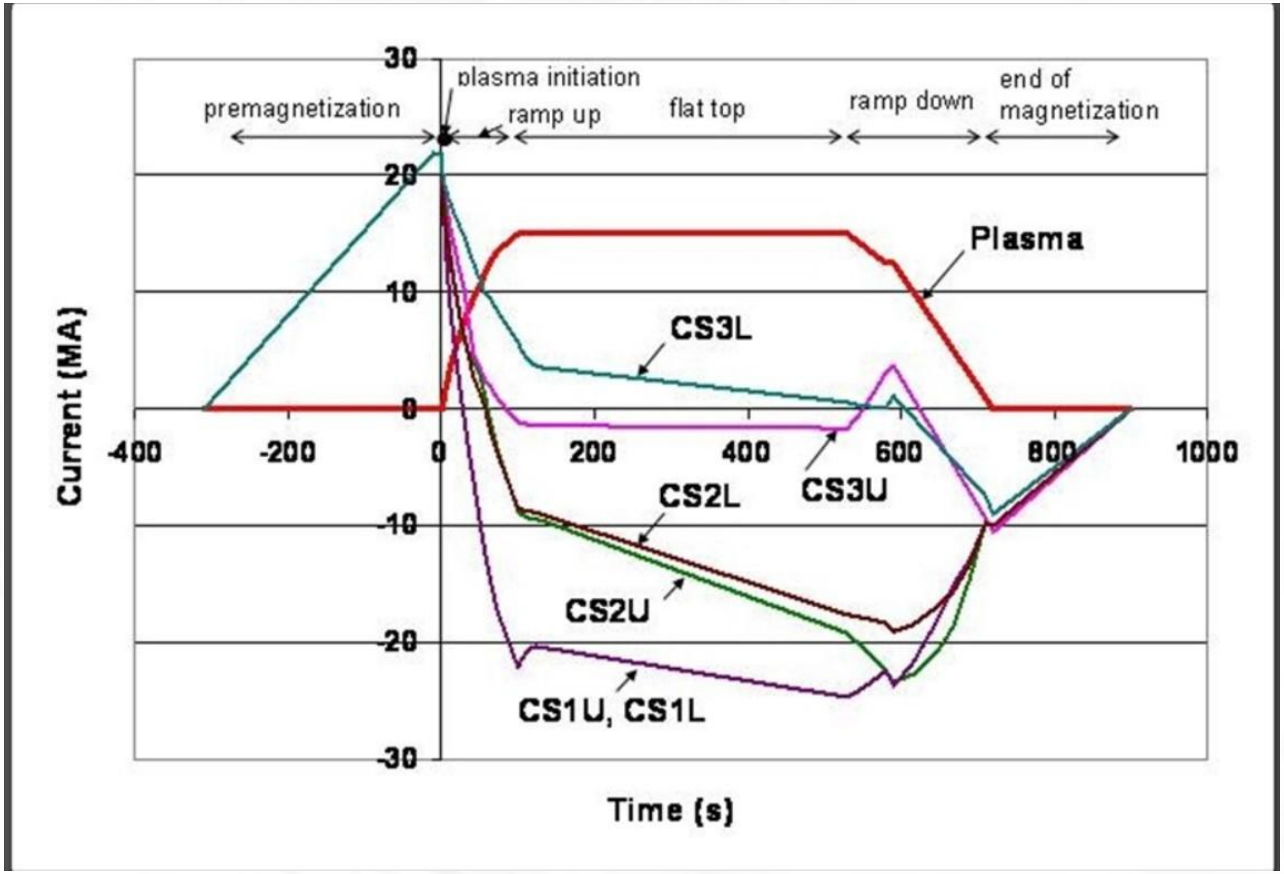


40 ft

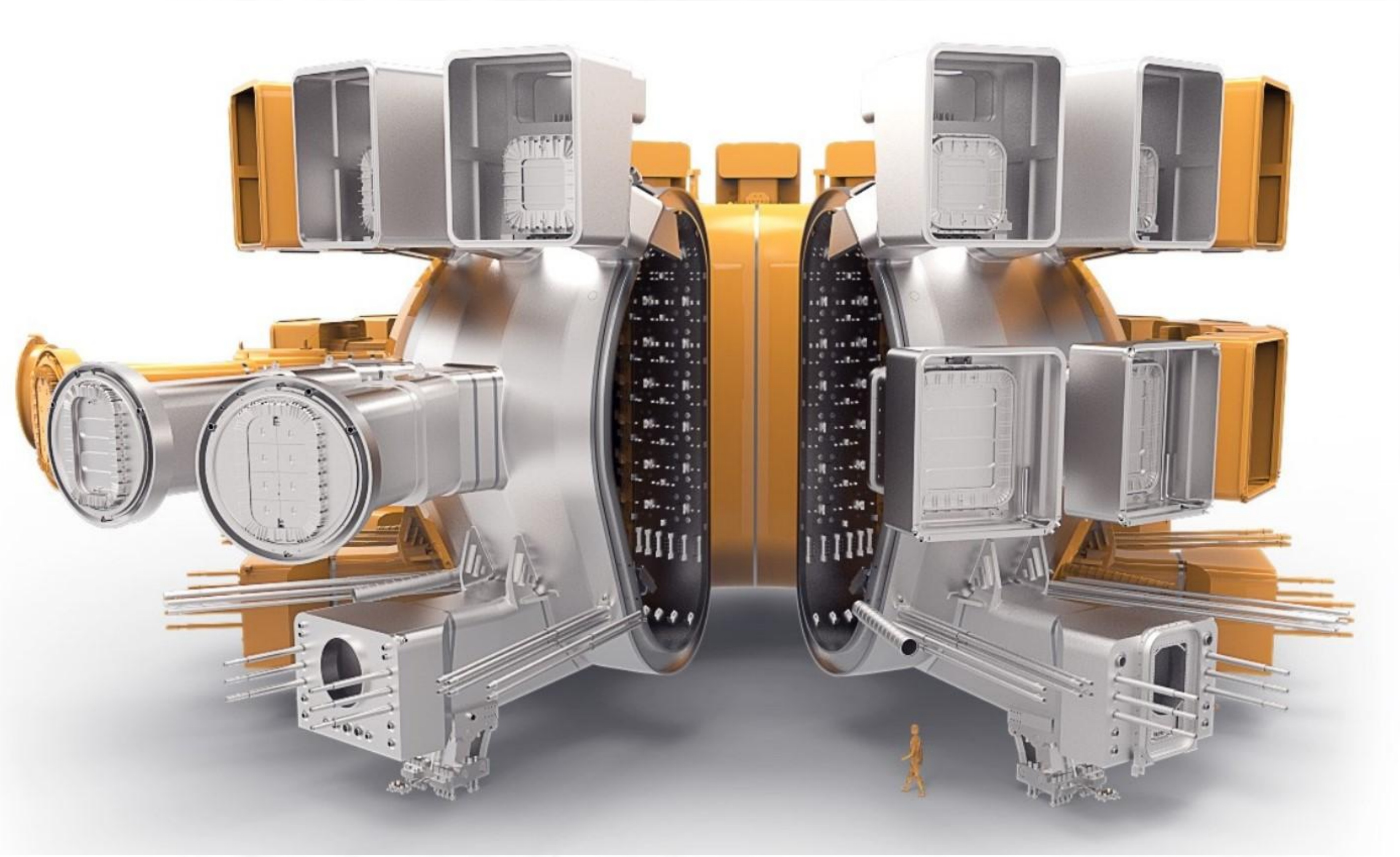
1000 tons



Central Solenoid Magnet,
USA supplied
Delivered
Ready for installation

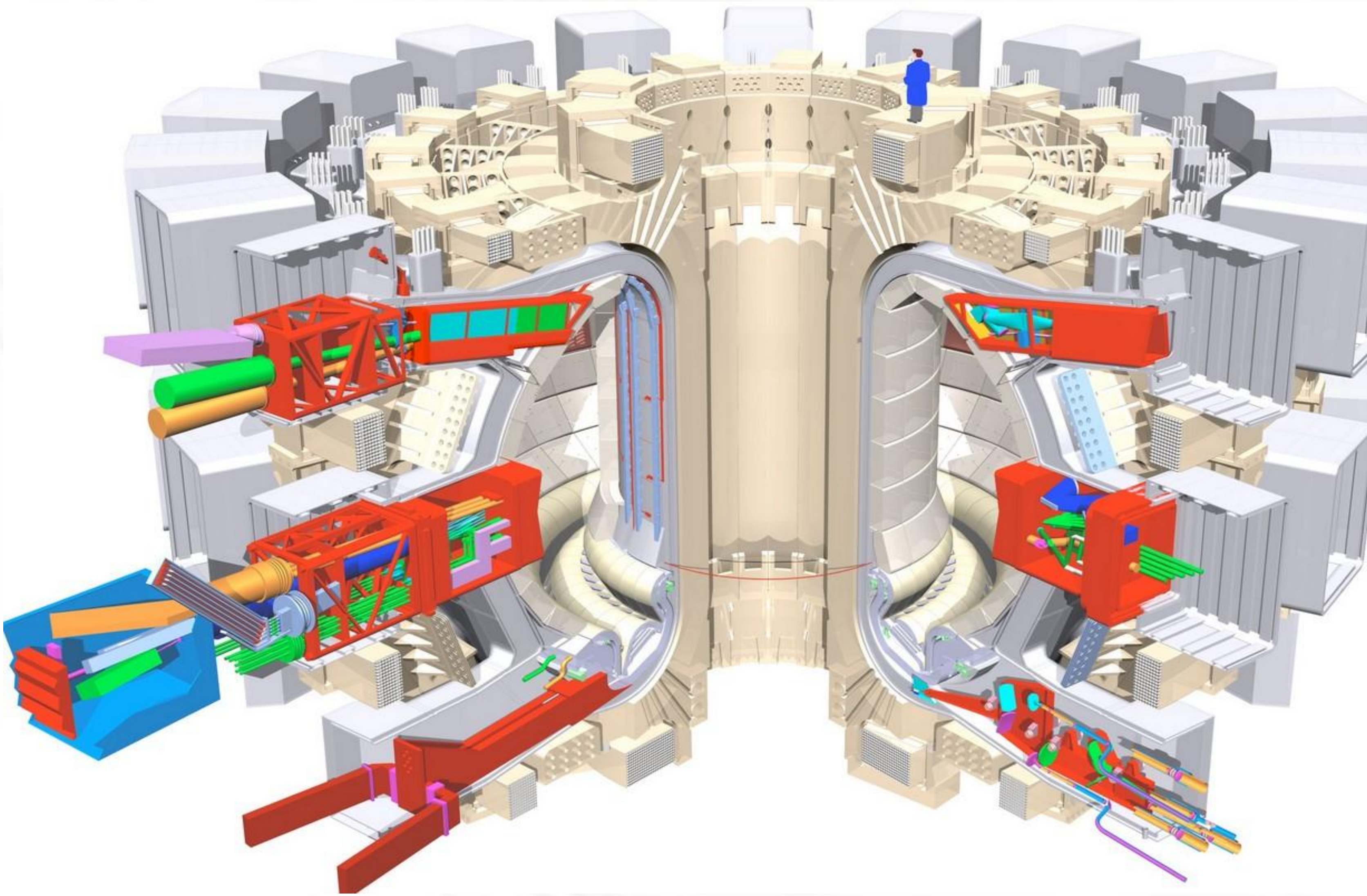


Central Magnet Control Current

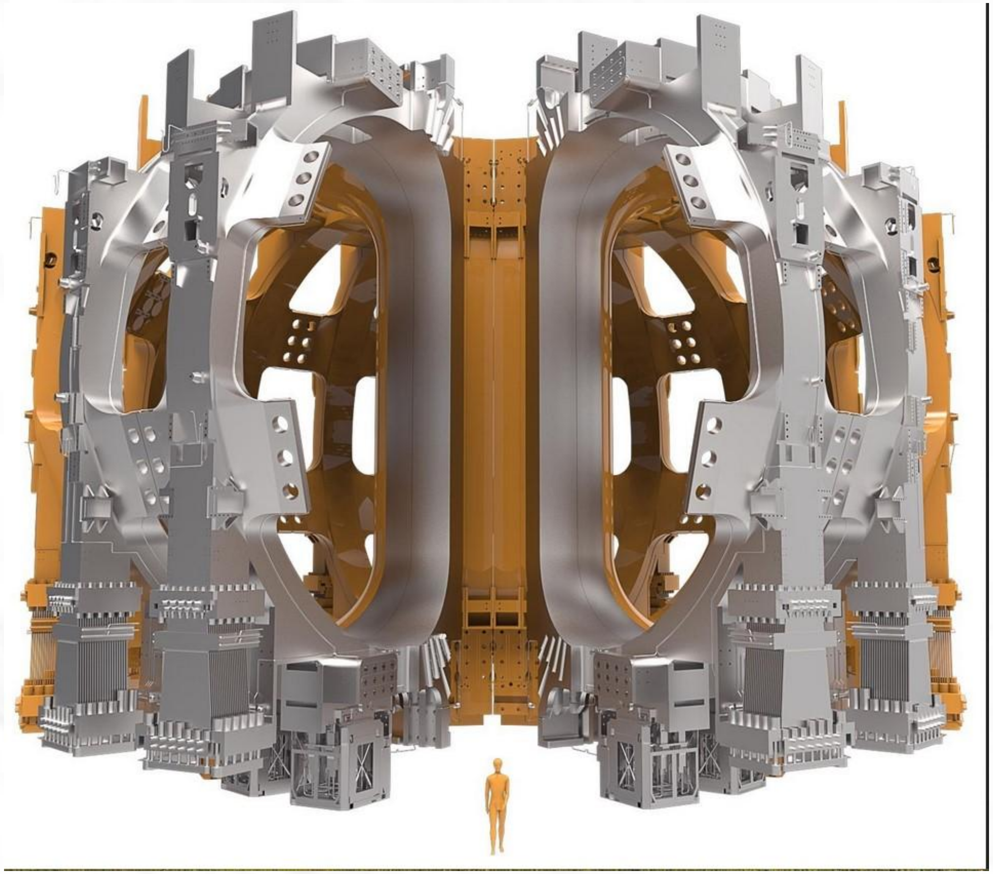


VACUUM VESSEL- 44 OPENINGS FOR PORTS, ETC

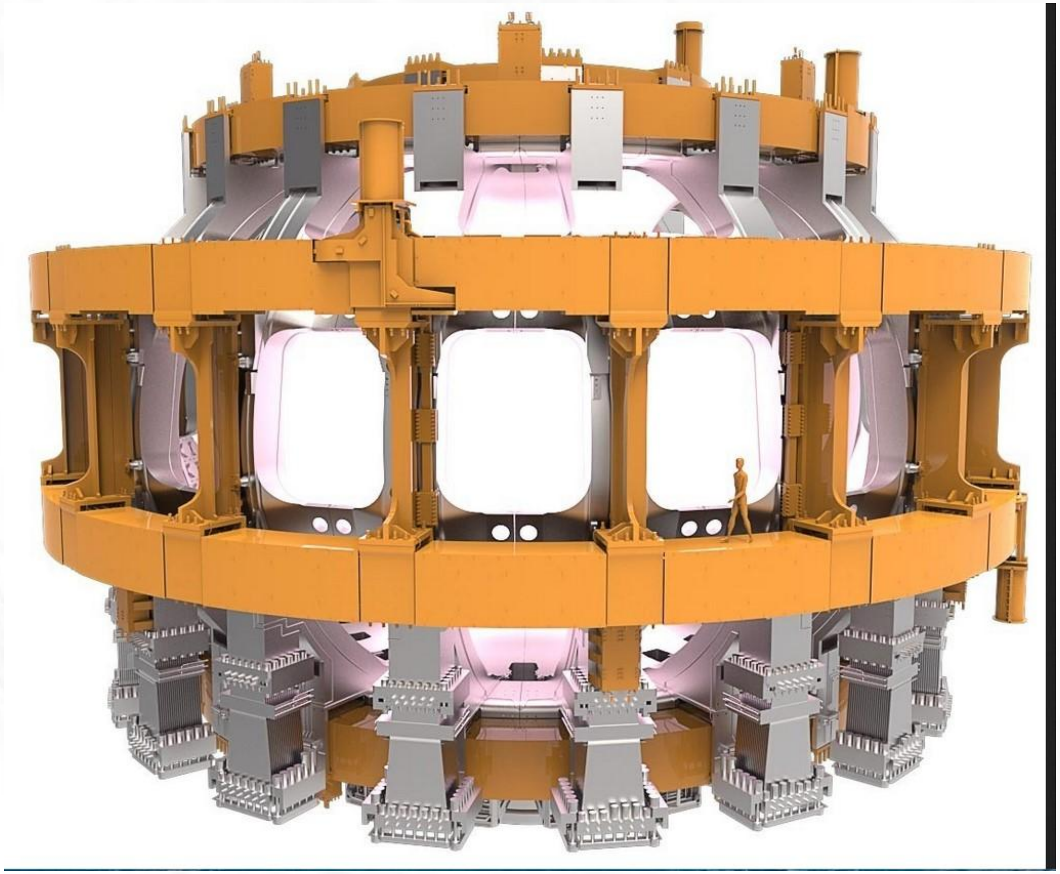
Instrumentation Ports to Vacuum vessel



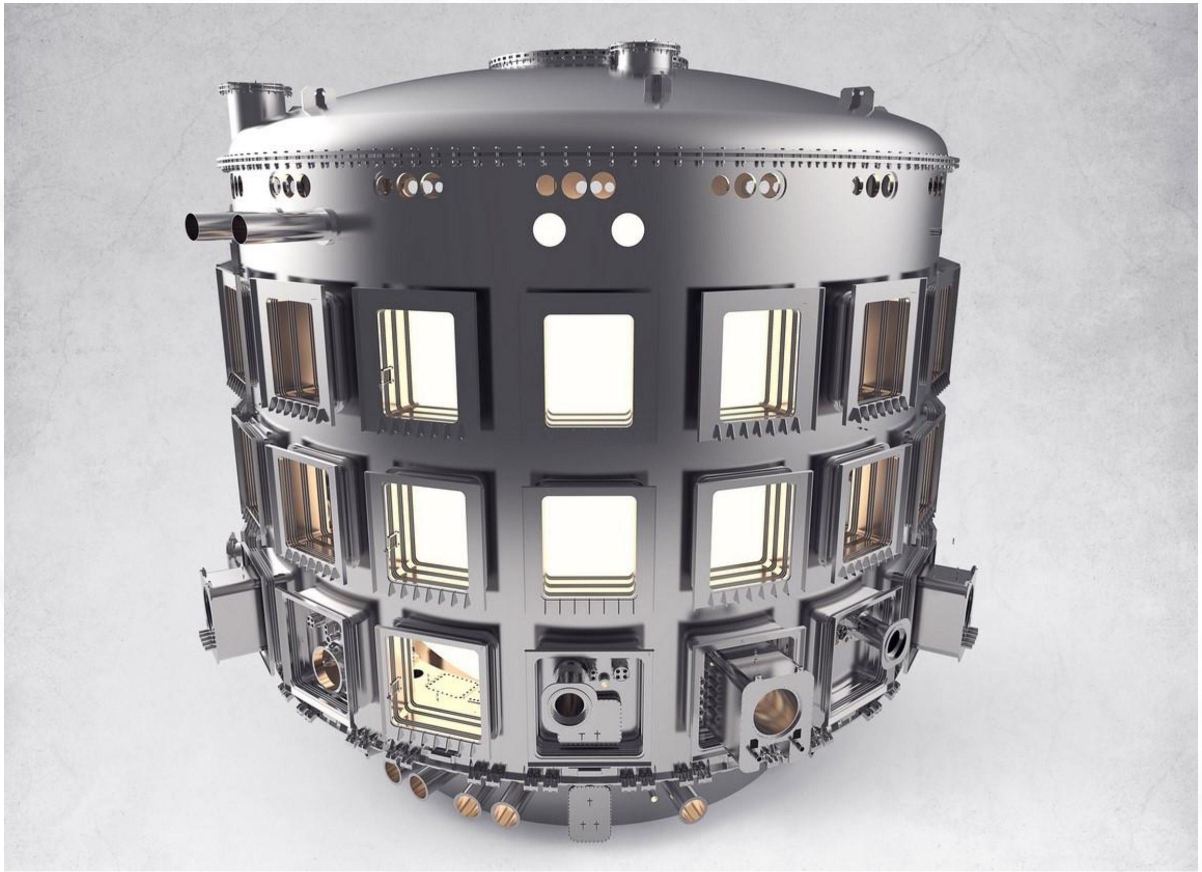
Toroid Magnets to provide spiral motion of ions
8 sections,16 magnets, each weigh 410 tons;



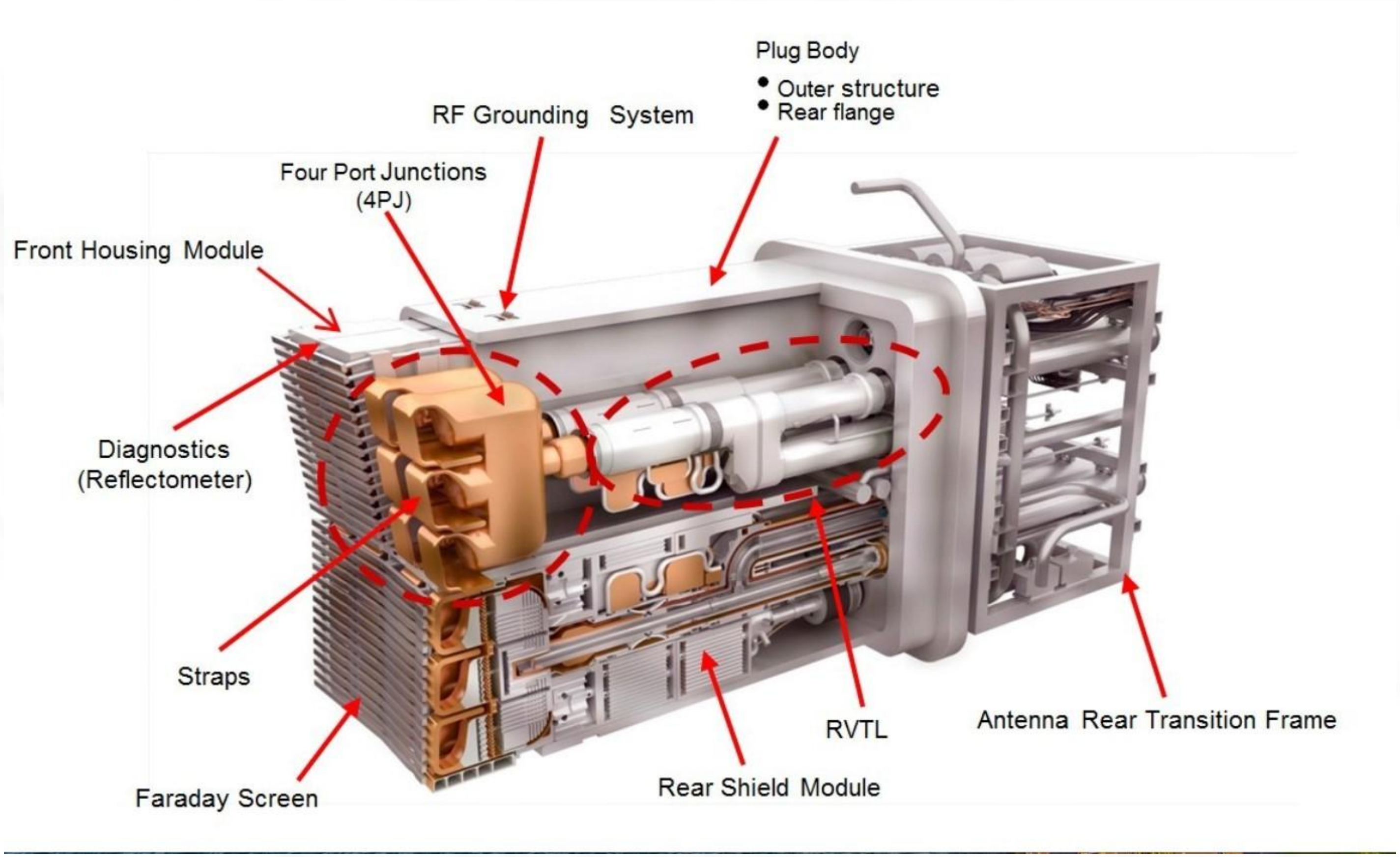
Poloidal Magnets to provide “pinch off” of ions at the walls



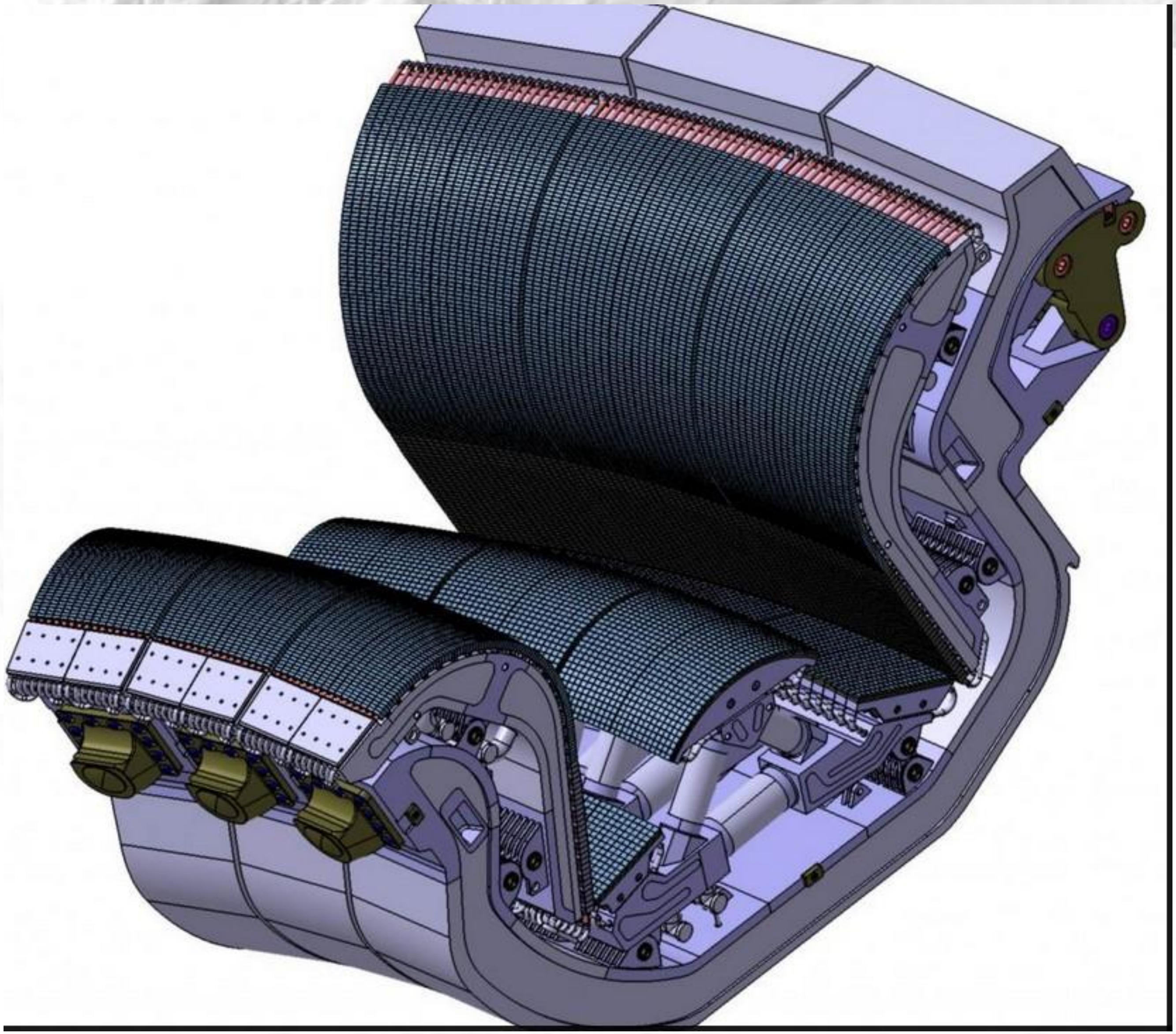
Vacuum Cryostat containing the Tokamak



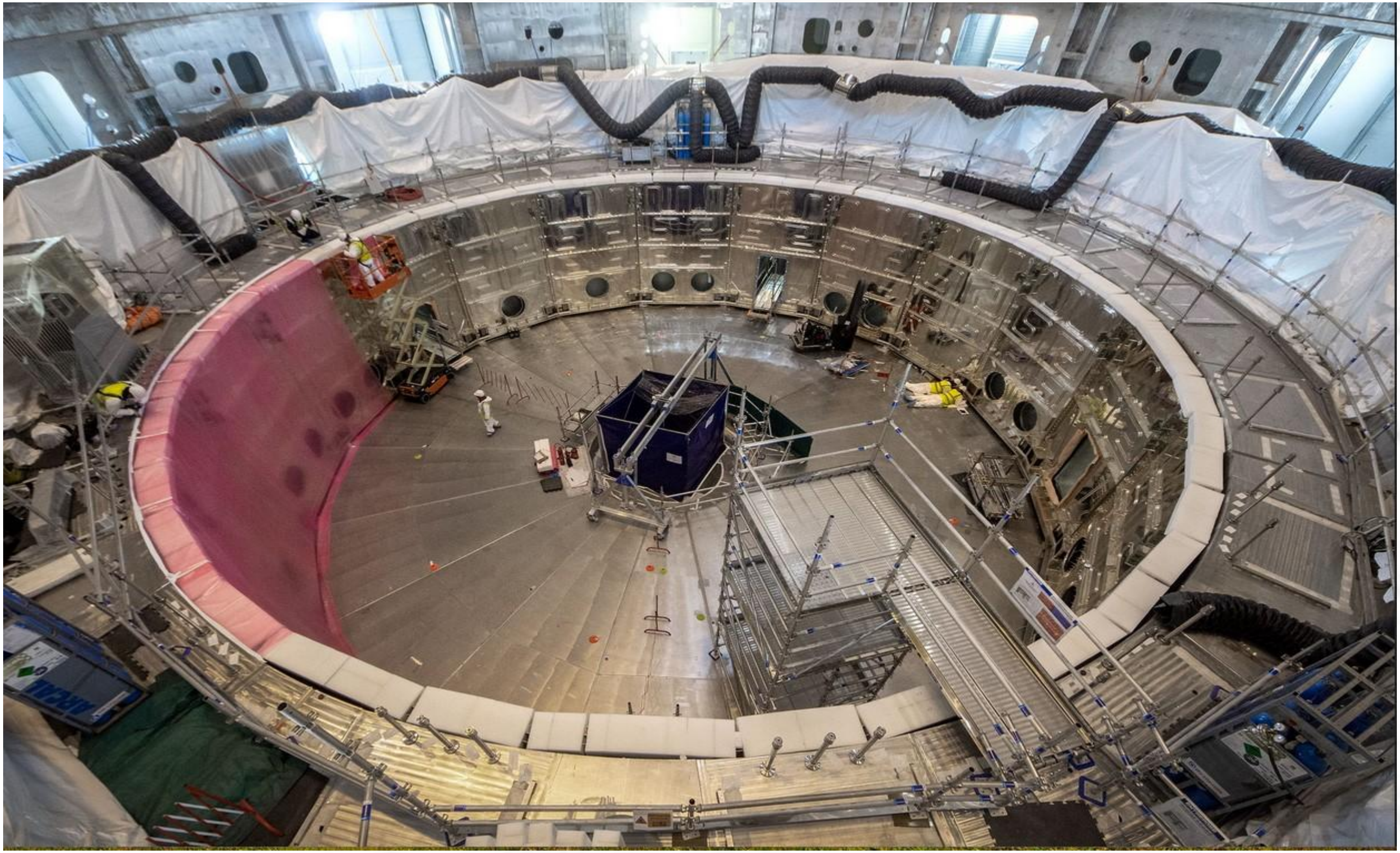
Supplies 20 MW



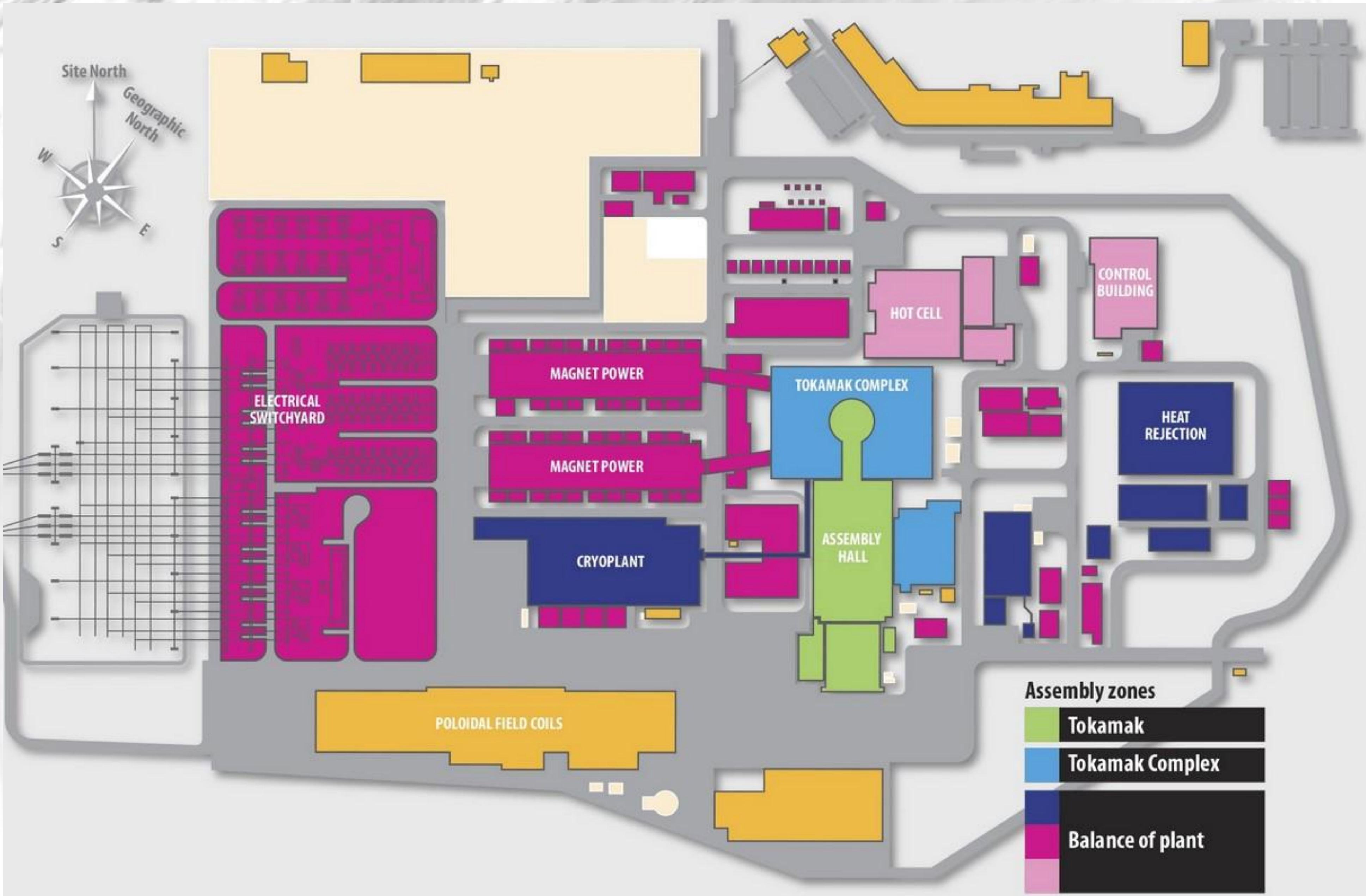
Cyclotron heater for supply to plasma stream; US supplied



Diverter Section at Bottom of Vacuum Chamber

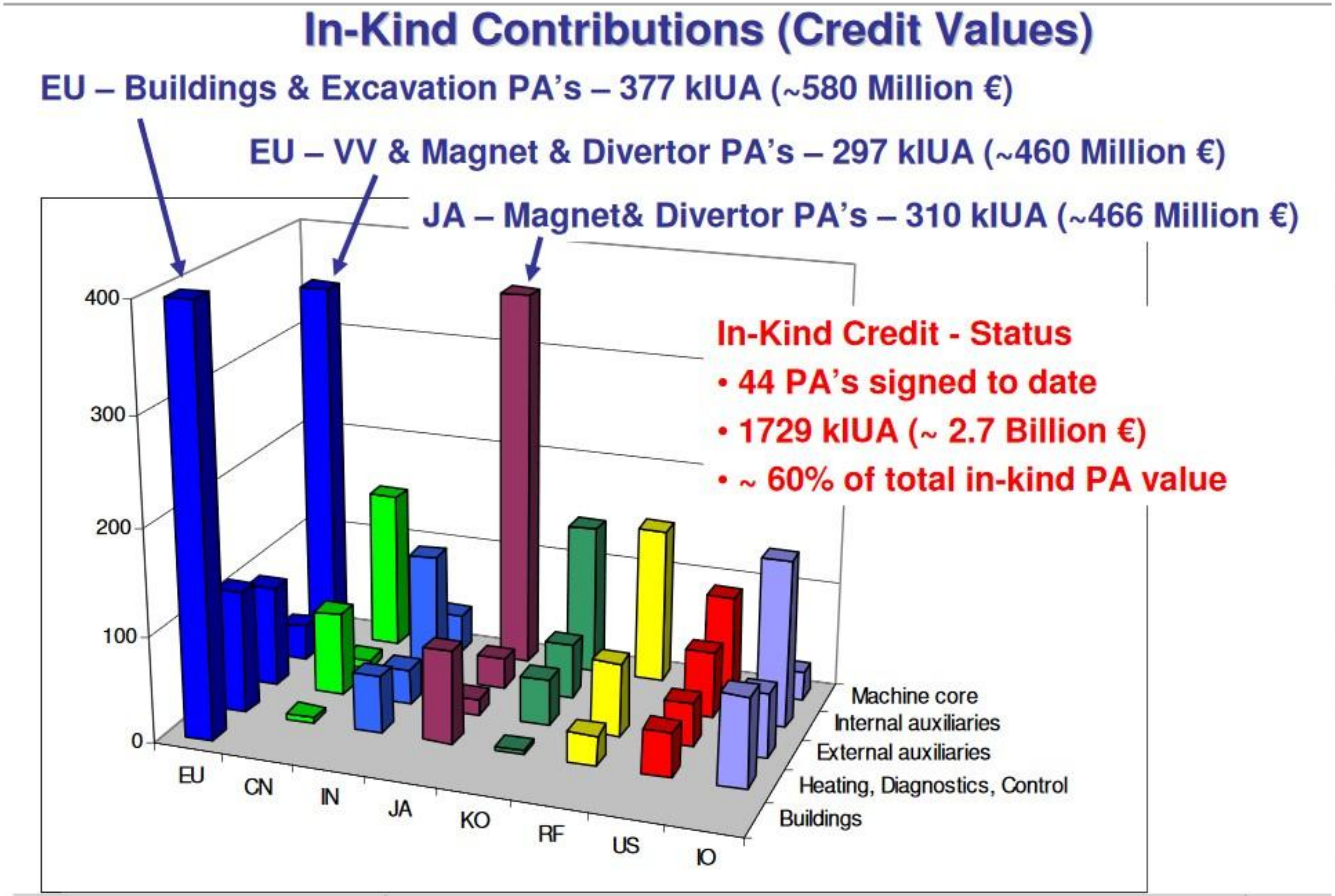


Heat Shield For Cryostat – Lower- Completed Jan 2021


Site North
Geographic North
W
E
S
ELECTRICAL SWITCHYARD
MAGNET POWER
MAGNET POWER
CRYOPLANT
TOKAMAK COMPLEX
ASSEMBLY HALL
HOT CELL
CONTROL BUILDING
HEAT REJECTION
POLOIDAL FIELD COILS
Assembly zones
Tokamak
Tokamak Complex
Balance of plant

© Fusion For Energy

Funding of ITER Project; $ and Equipment



ITER School Topics – Annual Event

2019	The Physics and Technology of Power Flux Handling in Tokamaks
2017	Physics of Disruptions and Control
2015	Transport and Pedestal Physics in Tokamaks
2014	High-Performance Computing in Fusion Science
2012	Radio-Frequency Heating
2011	Energetic Particles
2010	Magneto-Hydro Dynamics and Plasma Control
2009	Plasma-Surface Interactions
2008	Magnetic Confinement
2007	Turbulent Transport in Fusion Plasmas