MERCI A TOUS DE VOTRE PARTICIPATION A CETTE PRESENTATION DU PROJET ITER

VOUS TROUVEREZ CI-APRÈS LES SLIDES DE LA PRESENTATION AINSI QUE DES LIENS VERS DES VIDEOS ET ARTICLES INTERESSANTS SUR LE PROJET

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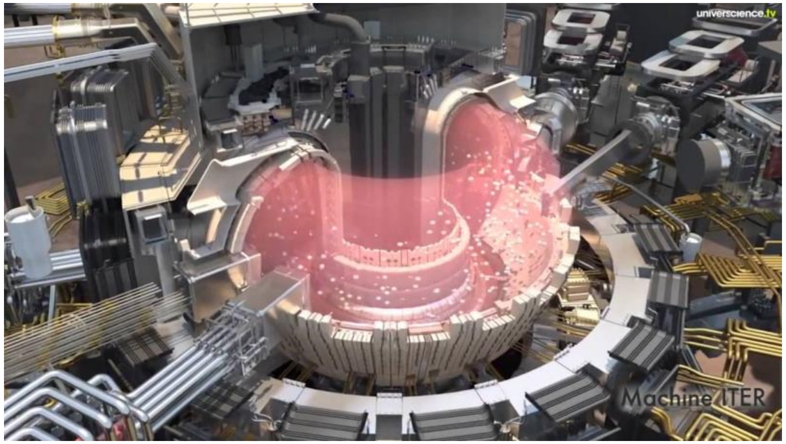
Fusion Reactors -
The ITER project and beyond

Emmanuel POTIÉ
Assystem

12/10/2021

iter



SOMMAIRE

FUSION NUCLEAR POWER

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The fusion what for ?

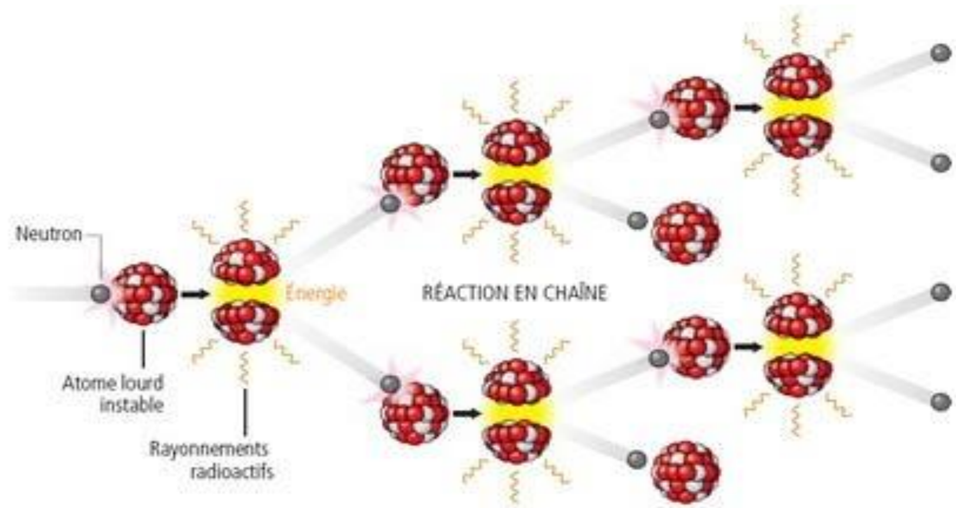
Unlimited Energy
Oblivione

To Explore the
galaxy

Discover the
future

QUELLE EST LA DIFFÉRENCE ENTRE FUSION ET FISSION ? (1/2)

La **fission** consiste à projeter un neutron sur un atome lourd instable (uranium 235 ou plutonium 239).
Ce dernier éclate alors en 2 atomes plus légers. Cela produit de l'énergie, des rayonnements radioactifs et 2 ou 3 neutrons capables à leur tour de provoquer une fission. Et ainsi de suite.
C'est le mécanisme de la réaction en chaîne.

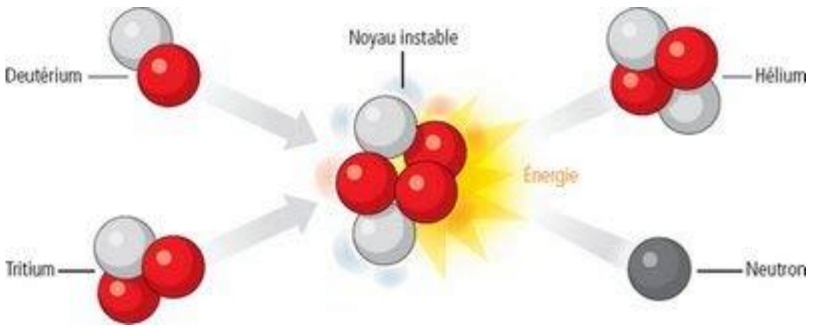


Aujourd'hui, c'est la fission qui est utilisée dans les centrales nucléaires de production d'électricité.

QUELLE EST LA DIFFÉRENCE ENTRE FUSION ET FISSION ? (2/2)

De son côté, la **fusion** consiste à rapprocher deux atomes d'hydrogène (deutérium et tritium) à des **températures de plusieurs millions de degrés**, comme au cœur des étoiles. Lorsque ces **noyaux légers fusionnent**, le noyau créé se retrouve dans un état instable. Il tente de retrouver un état stable en éjectant un atome d'hélium et un neutron et crée alors de l'énergie

Les différences de la Fusion / Fission:



Une quantité d'énergie plus importante

Pérennité

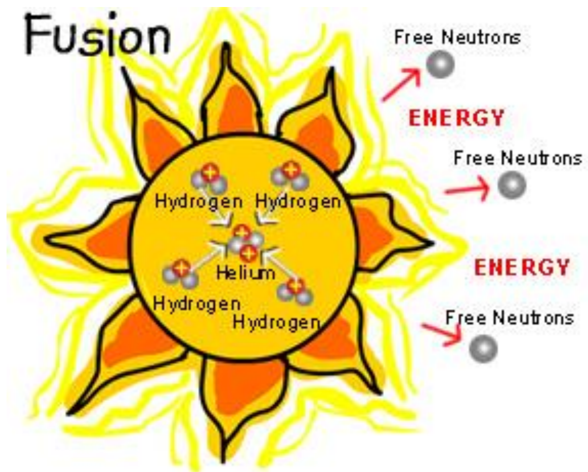
Aucune émission de CO_2

Aucun déchet radioactif de haute activité à vie longue

Aucune prolifération

Aucun risque de fusion du cœur

FUSION NUCLEAR POWER

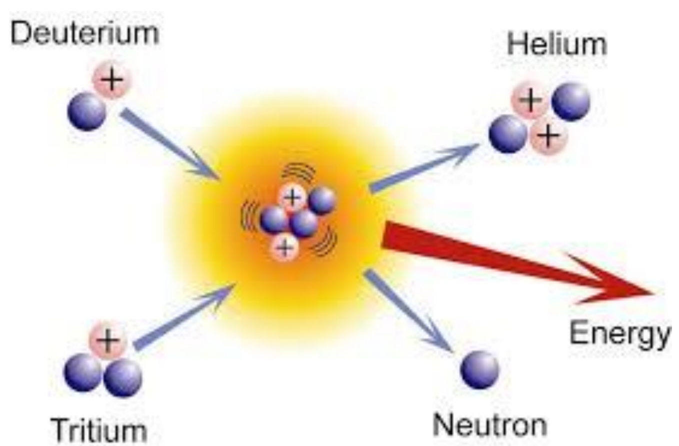


What is fusion ? Vs fission

- Fusion: reproducing the sun's energy
- Sun and stars fusion reaction: with hydrogen nuclei
- Most efficient fusion reaction is: Deuterium and Tritium into Helium and a neutron (release over 4 times more energy than uranium fission)

Why is it challenging ?

- Repulsive electrostatic forces between positively charged nuclei prevent them to collide – nuclei need to be confined
- Extreme temperature required
- Need a device to produce more energy through fusion reactions than is used to get the heat and confine the fuel
- Cost and complexity require international cooperation



FUSION NUCLEAR POWER

Why fusion?

- Environmental impact of fossil fuels
- Reduction of CO2 emission driving future energy policy
- Growing need for electricity
- Never been done before. Leads to innovation and creates new technologies

Advantages of fusion:

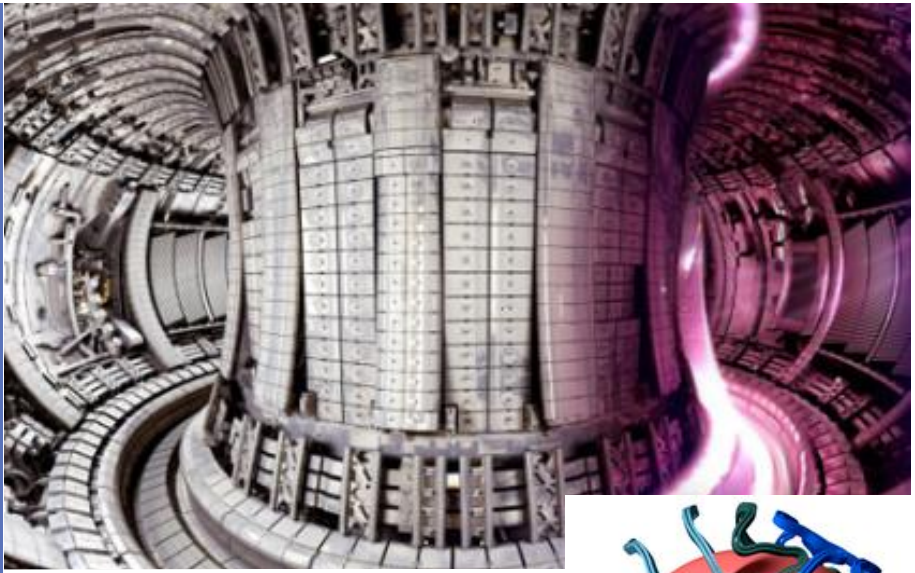
- Fuels are widely available (Deuterium can be found in seawater)
- Does not generate greenhouse gases
- Safer than fission as no chain-reaction
- Environmentally responsible (radiation decays ~10 years)

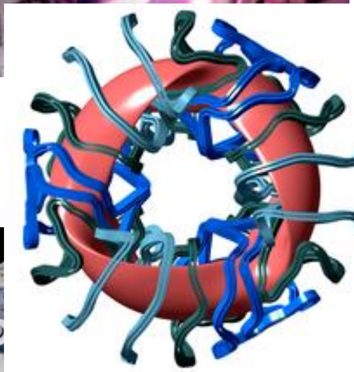
FUSION NUCLEAR POWER

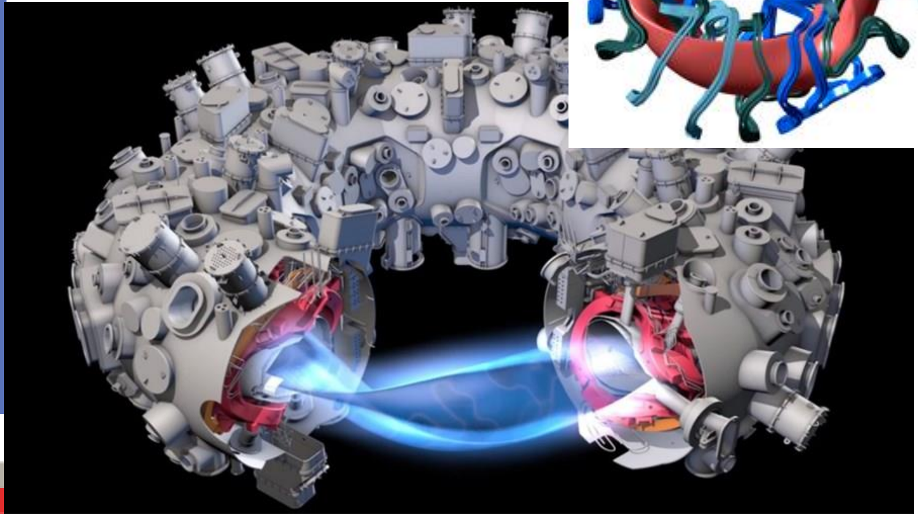
How to make fusion ? (1/2)

- => Confine and heat the fuel to produce conditions in which the atoms will collide with each other

- Magnetic Confinement Fusion (MCF): confine plasma with magnets
  - Tokamak:
    - Joint European Torus (JET)
    - Tokamak Fusion Test Reactor (TFTR)
    - Japan Torus-60 (JT-60)
    - Mega Amp Spherical Tokamak (MAST)
    - National Spherical Torus eXperiment Updgrade (NSTX-U)
    - WEST (new name for Tore Supra)
    - Korean Superconducting Tokamak Reactor (KSTAR)
    - ITER
  - Stellarators:
    - Large Helical Device
    - Wendelstein 7-X Germany
    - TJII Spain
    - NCSX (abandoned)







FUSION NUCLEAR POWER

How to make fusion ? (2/2)

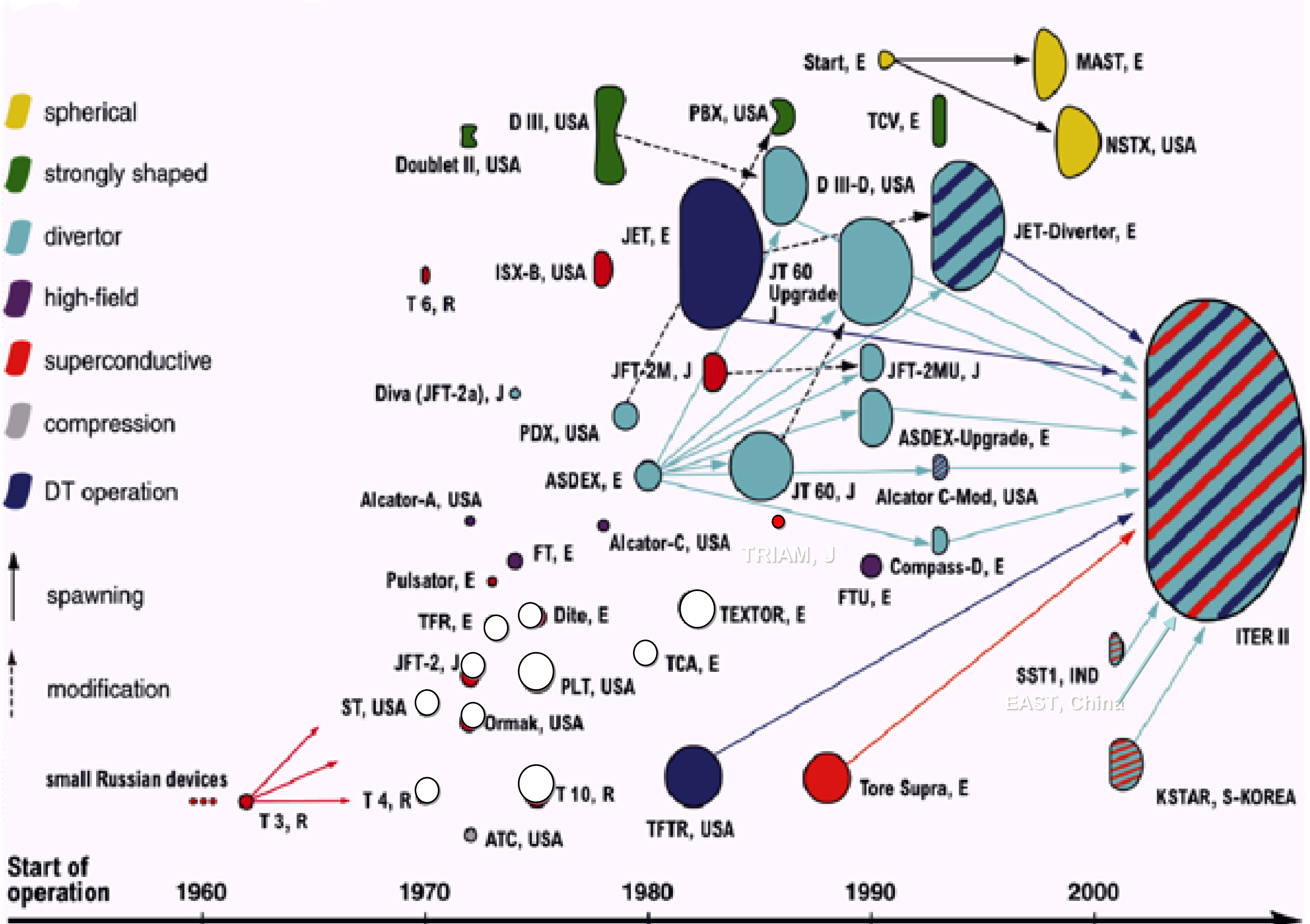
- Inertial Confinement Fusion (ICF): use of laser to implode fuel
  - National Ignition Facility (NIF)
  - Laser Megajoule (LMJ)
- Magnetized Target Fusion (MTF): combination of magnetic confinement fusion and inertial confinement fusion
  - FRX-L
- Hybrid Fusion: combination of fusion and fission reactor

EUROPE FUSION ROADMAP:

- Risk mitigation for ITER
- Pre-Conceptual design of DEMO
- The stellarator as back-up strategy

EUROfusion

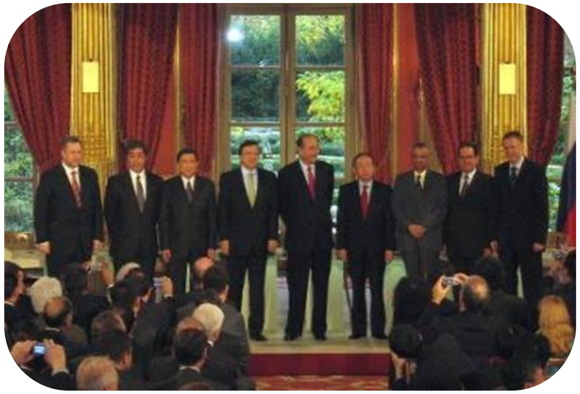
History of Tokamaks



KEY STEPS & THE CONCEPT

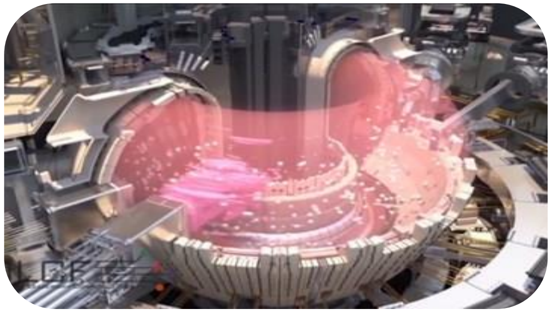
KEY STEPS

2006=> SIGNATURE OF ITER'S CONTRACT=>



=> 2010 => START OF INFRASTRUCTURE & BUILDING ERECTION

2020 => START OF EQUIPMENT INSTALLATION =>



2025 => 1st PLASMA

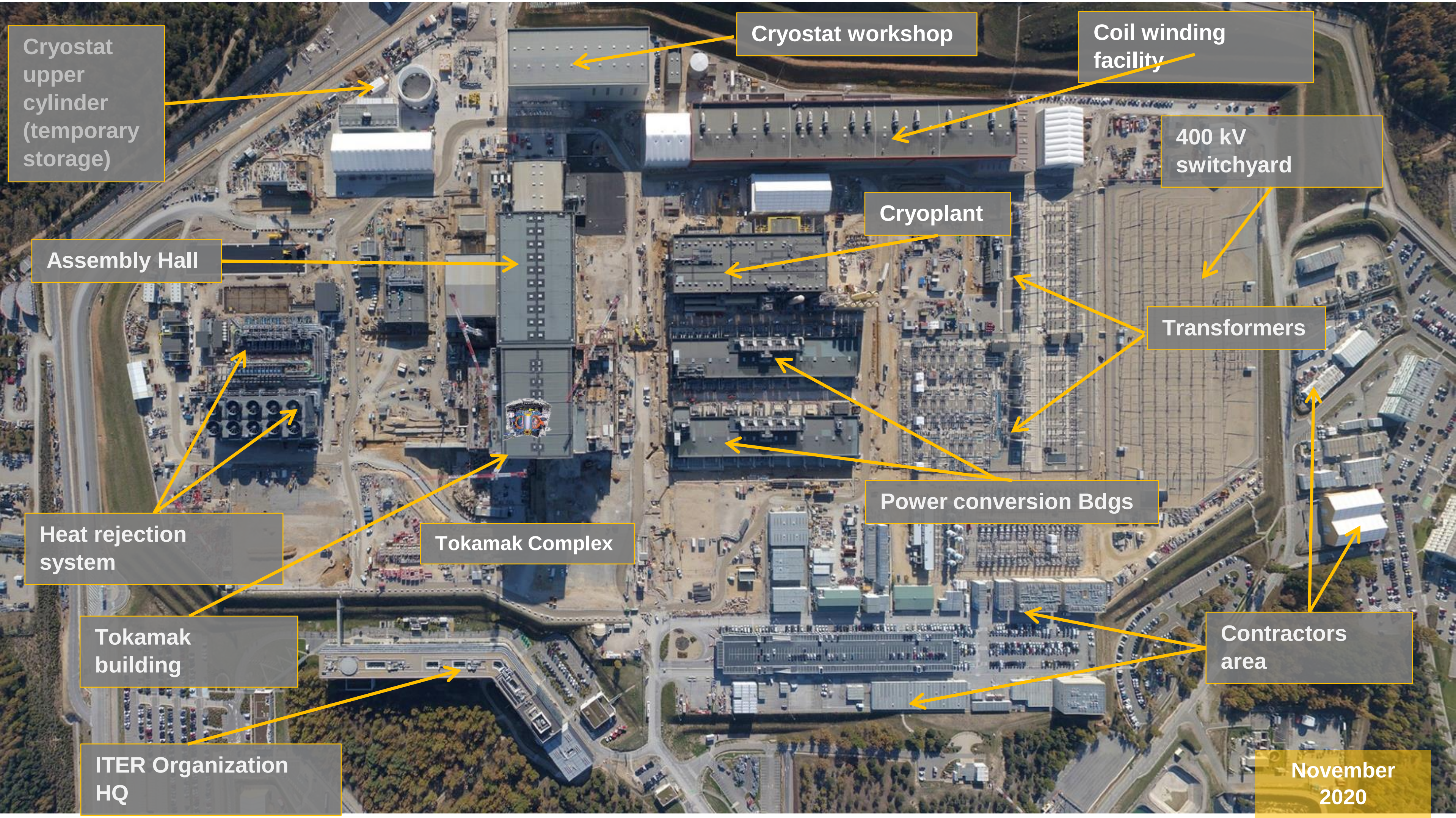
2035 => 1st NUCLEAR FUSION

ITER PROJECT

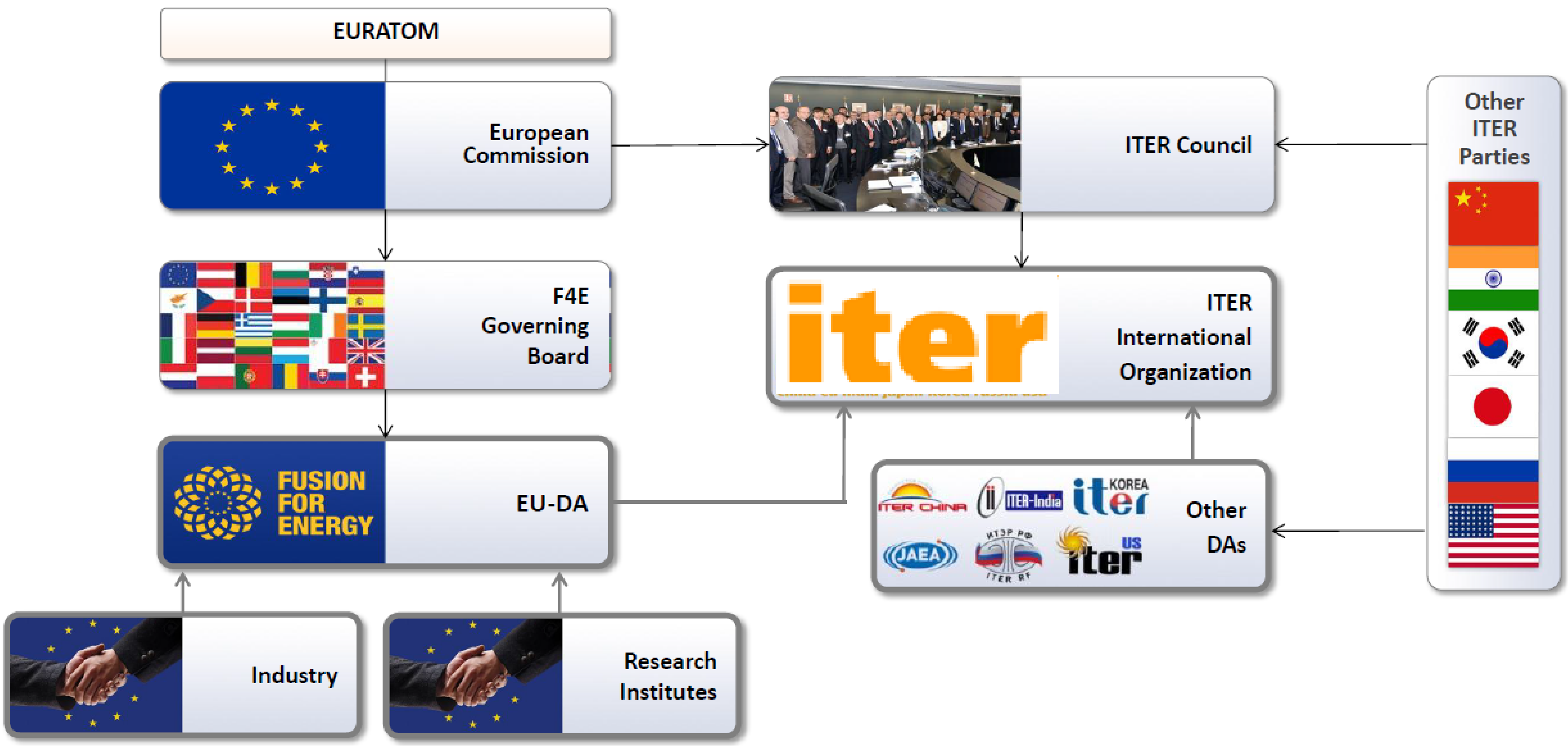
What is ITER ?

- The largest fusion nuclear reactor in the world using the Tokamak technology
- Currently being built in South of France
- Started in 1985 between the Soviet Union and USA at the Geneva Superpower Summit
- ITER's primary mission: sustain a DT plasma producing ~500MW of fusion power for durations of 300-500s with a ratio Q=10
- Provide an integrated demonstration of the physics and technology required for a fusion power plant based on magnetic confinement

ITER PROJECT: The Worksite



ITER PROJECT : A COMPLEX STRUCTURE
2 PILLARS F4E & IO



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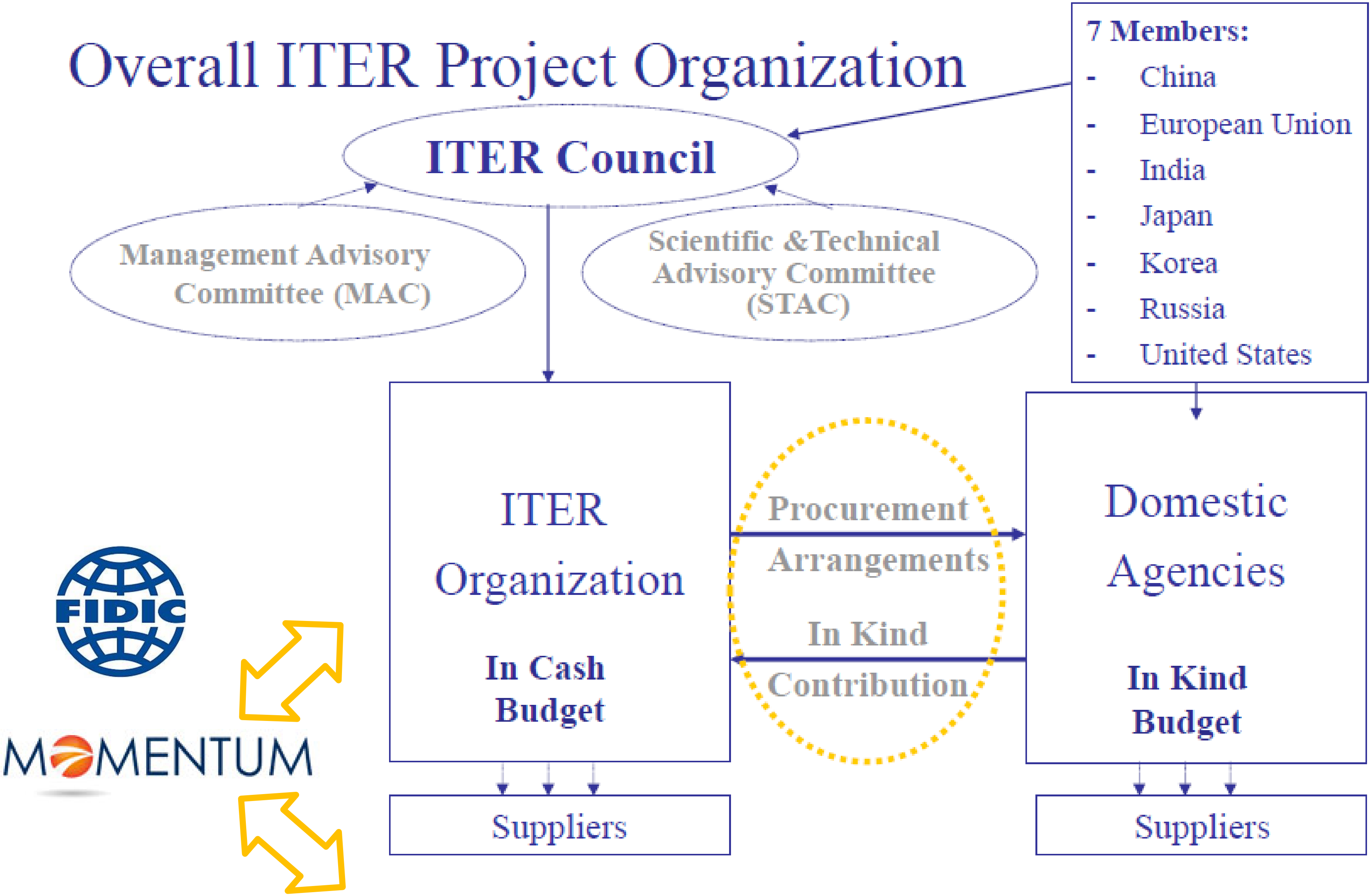
ITER PROJECT

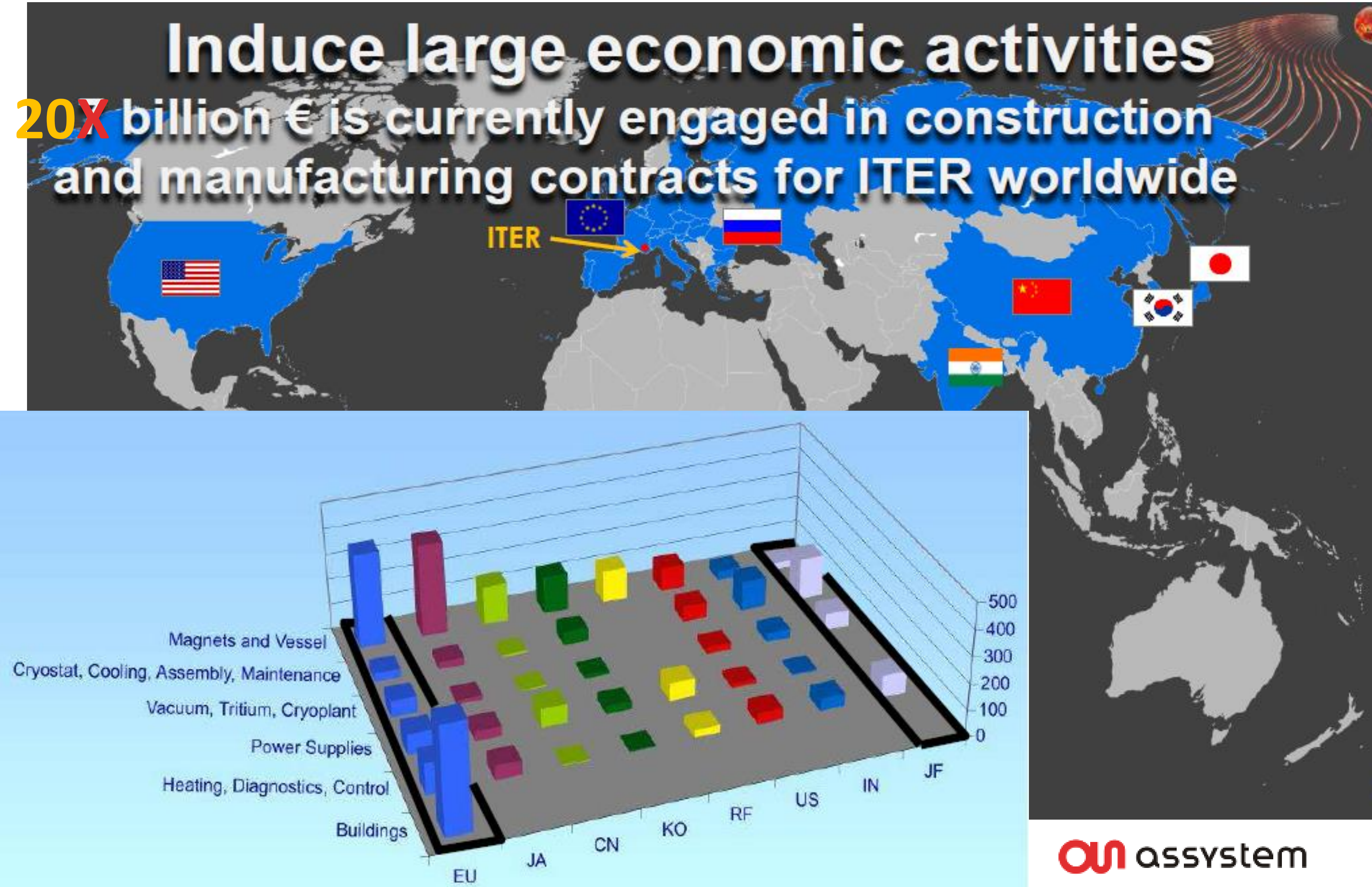
ITER Structure

- ITER Project led by ITER Organization
- 7 Members of the project called Domestic Agencies
- Each DA is responsible for handling procurement of member contributions (in-kind contributions to ITER)
- EU provides about 45% funding (F4E)
- Gather together different international company to achieve common goal

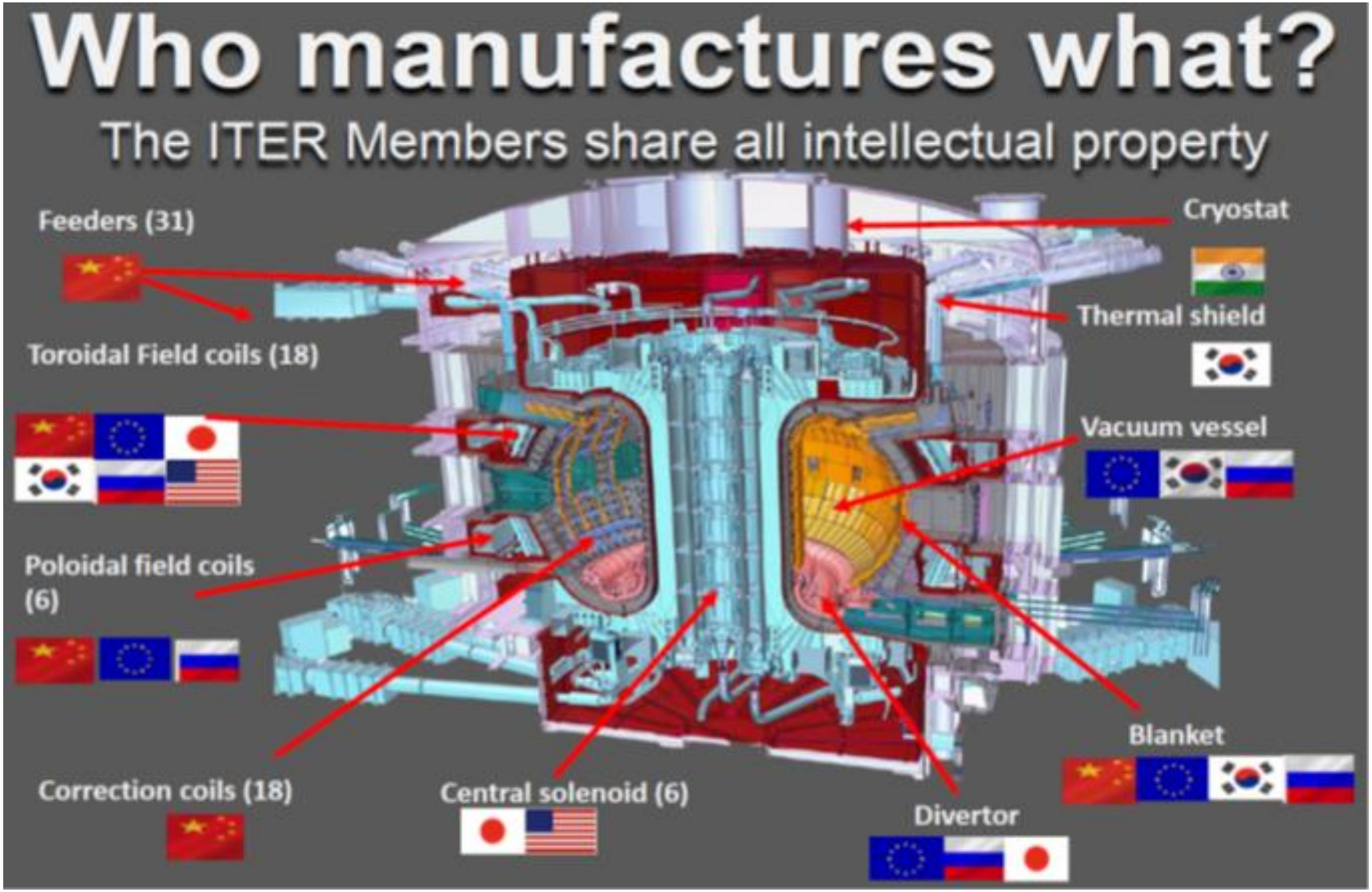
ITER PROJECT RULES



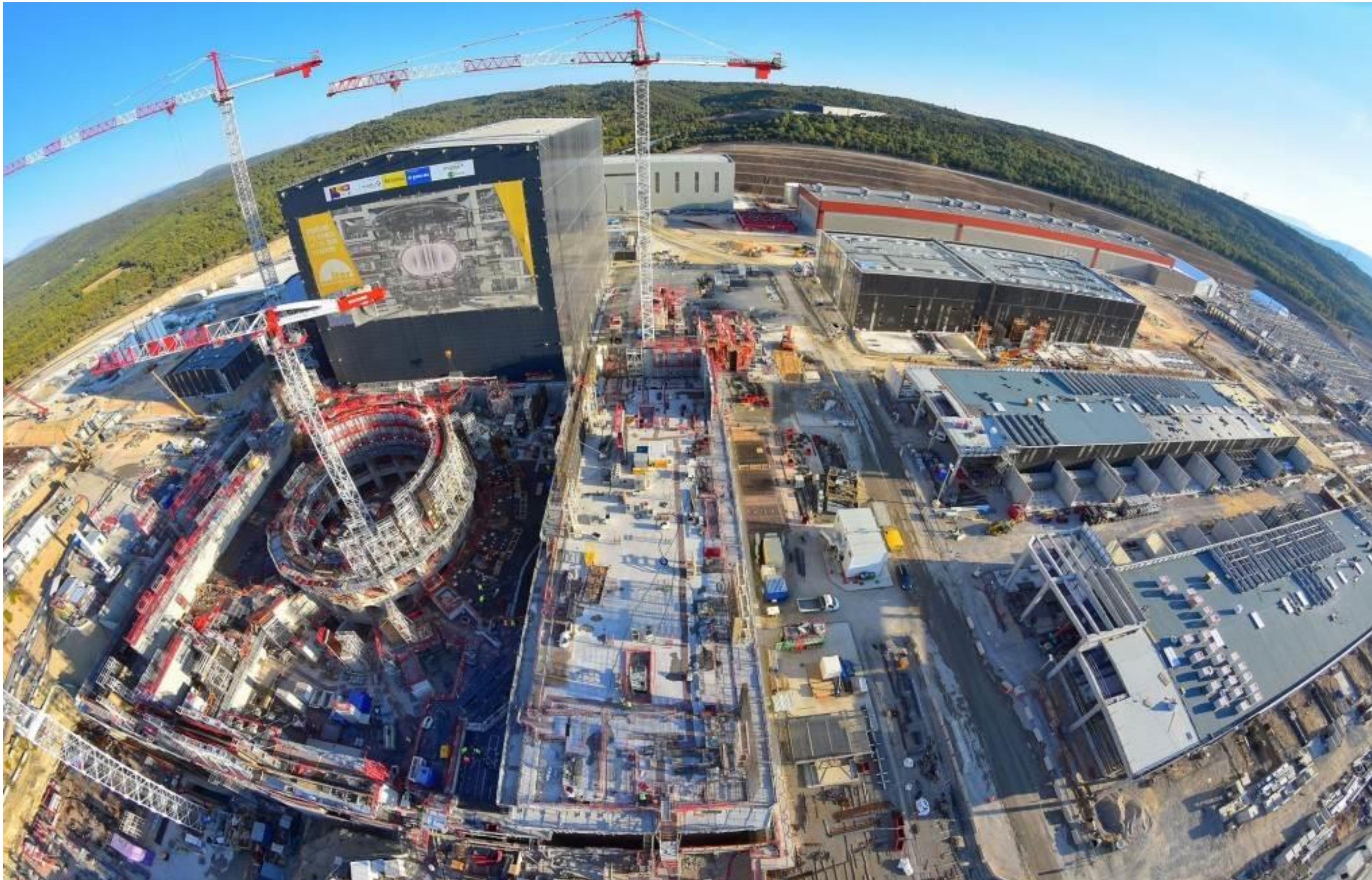
ITER PROJECT



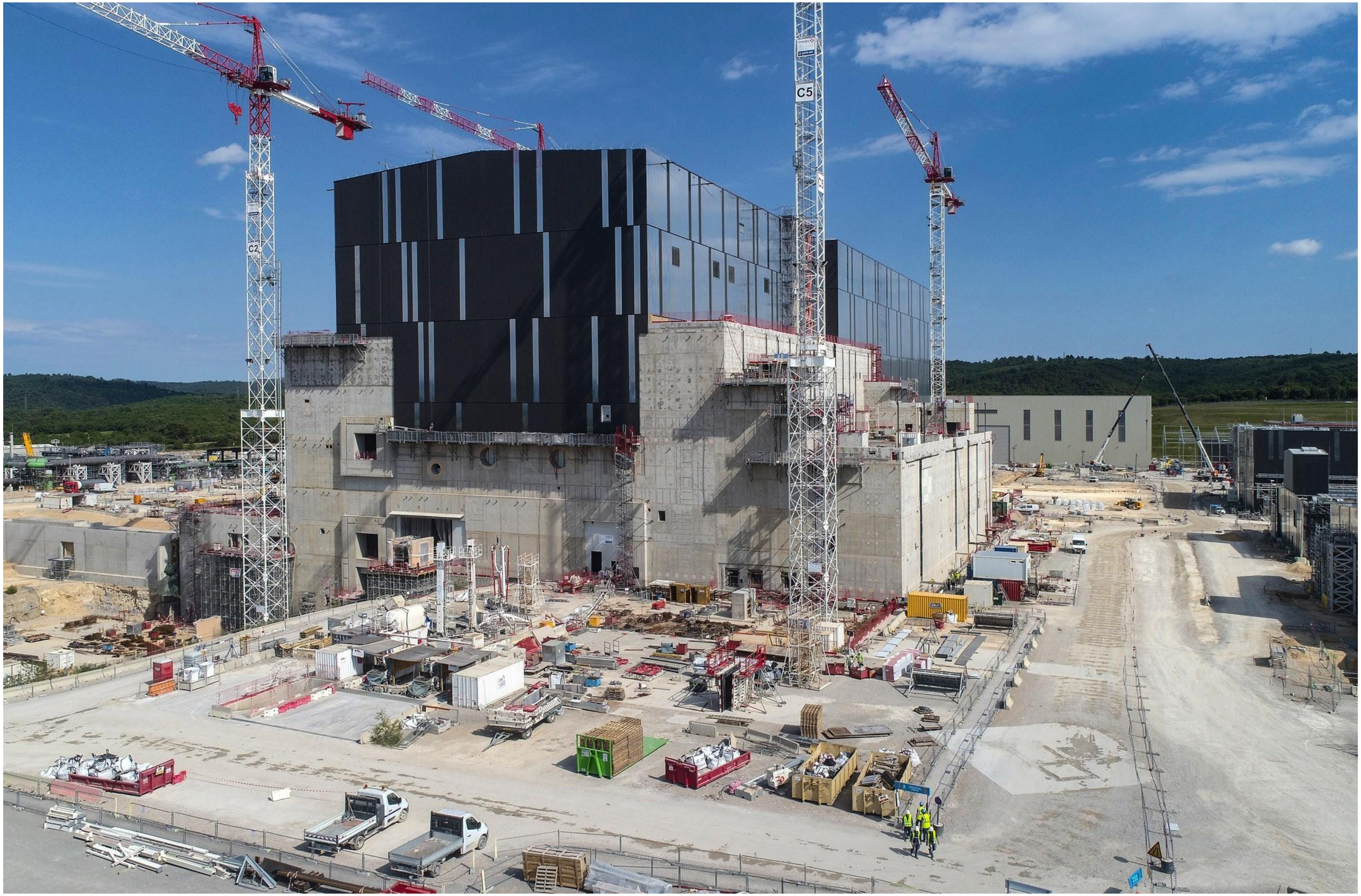
ITER UNIQUE SUPPLY CHAIN ORGANIZATION



ITER PROJECT : THE WORKSITE 2017

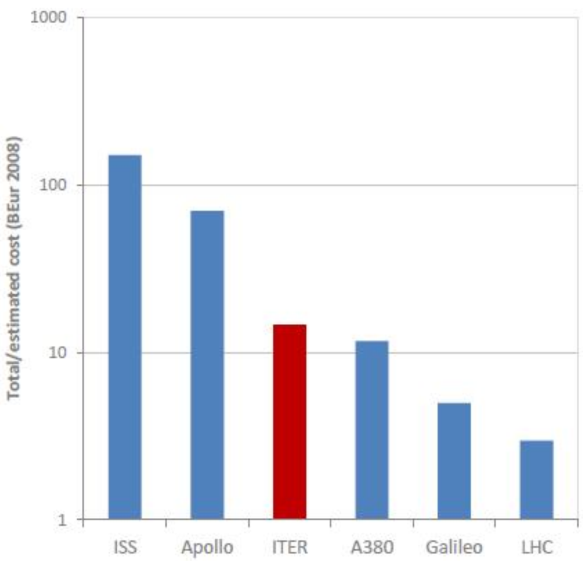


ITER PROJECT : THE WORKSITE MAY 2020



ITER PROJECT : Large & Complex

ITER is one of the largest and most complex science and technology projects we have attempted in modern history



23.000 tons

The ITER Machine will be **3 times** the weight of **the Eiffel Tower**

10 million components

ITER has **10 times more** components than the A 380
ITER: 10^7
Airbus 380: 10^6

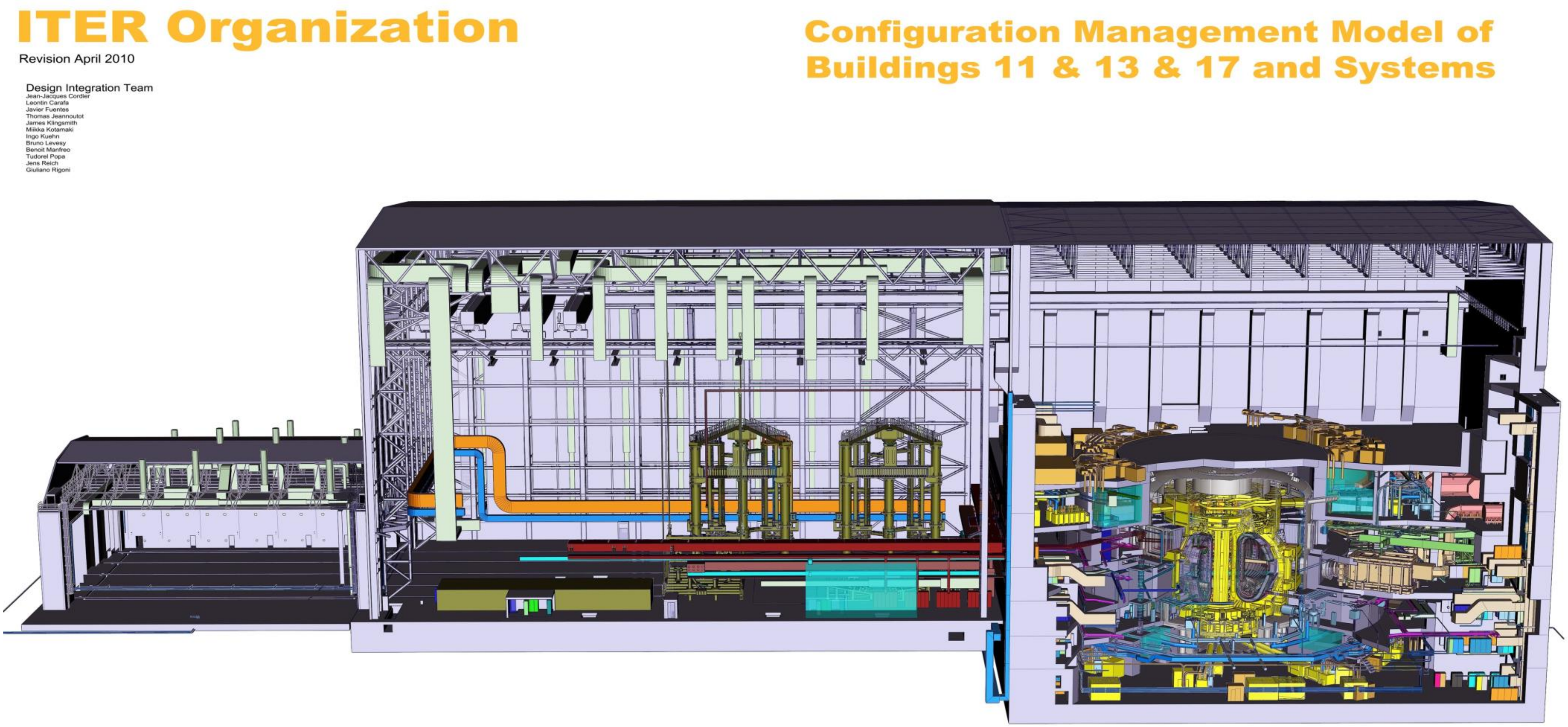
400.000 tons

Tokamak Complex will support the same weight as the **Empire State Building**

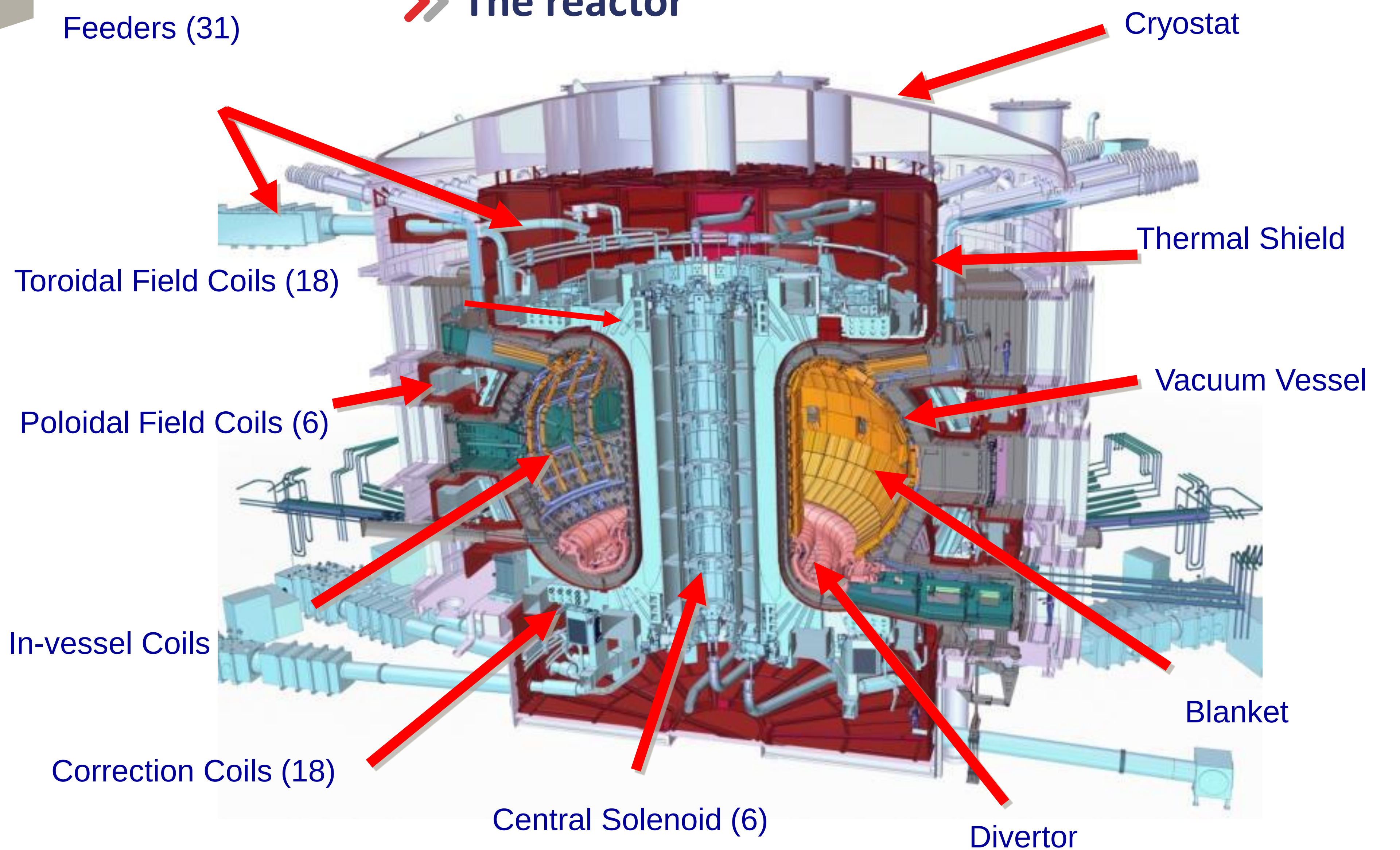
ITER PROJECT

The reactor

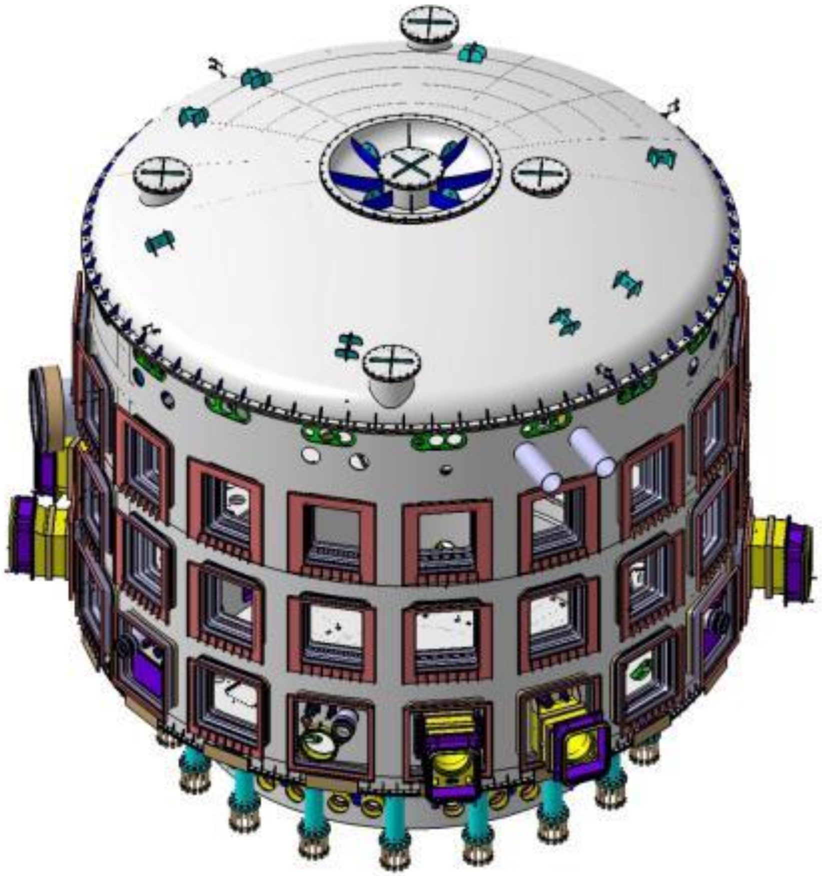
ITER PROJECT

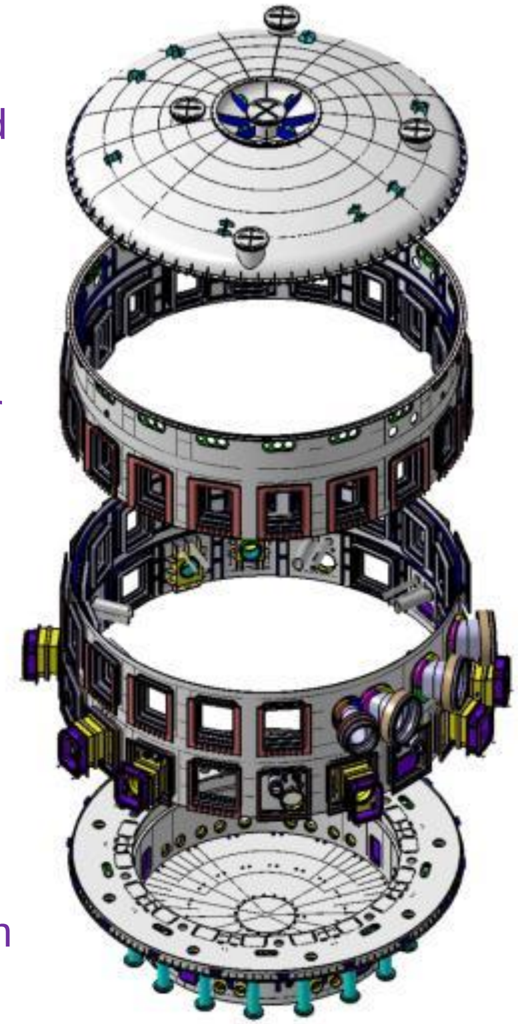


The reactor


Feeders (31)
Cryostat
Thermal Shield
Toroidal Field Coils (18)
Vacuum Vessel
Poloidal Field Coils (6)
In-vessel Coils
Blanket
Correction Coils (18)
Central Solenoid (6)
Divertor

The Cryostat

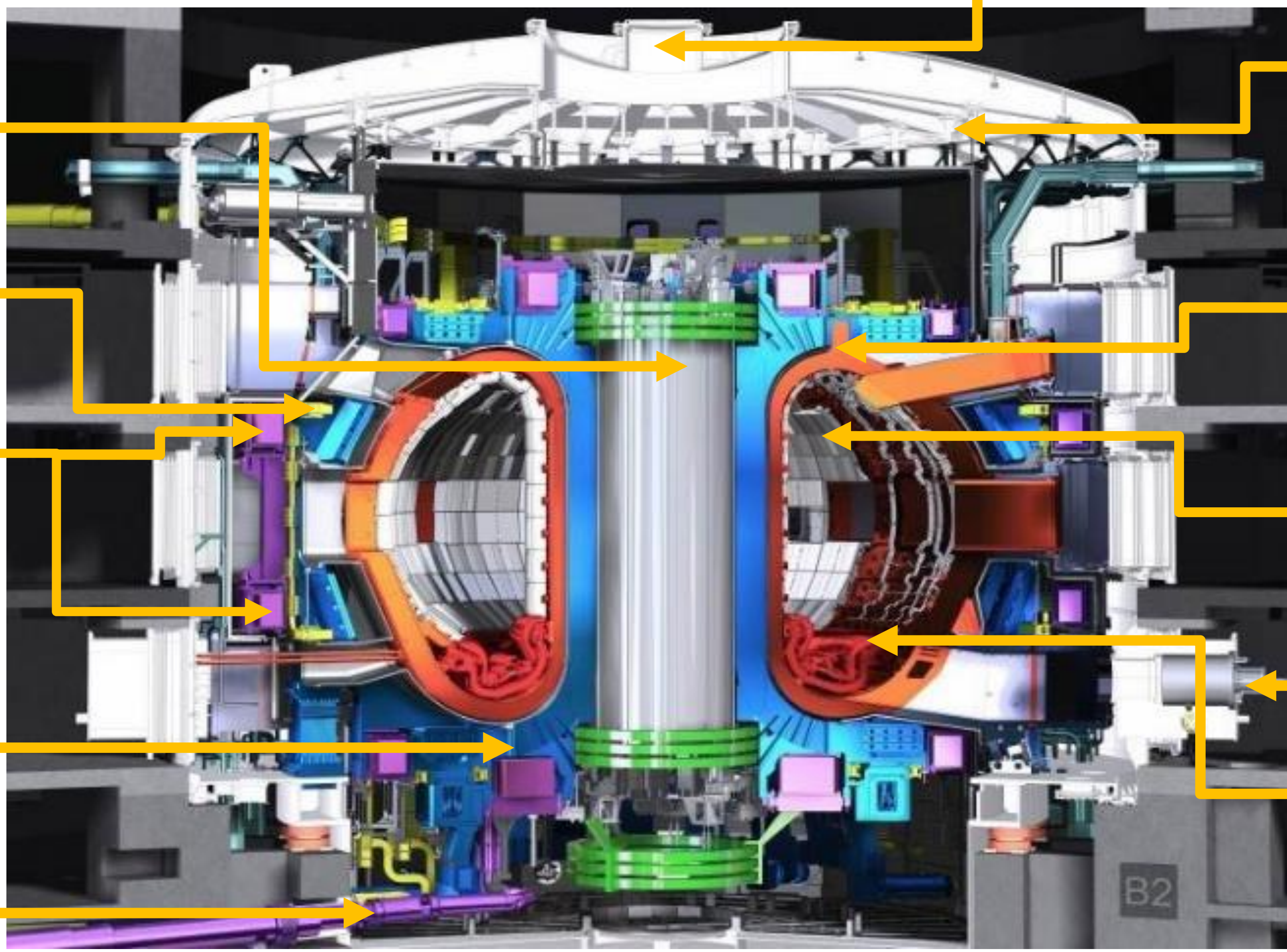




- Provides the vacuum insulation for operating the superconducting magnets and thermal shield system
- 304L stainless steel 40 – 180 mm thick
- Weight ~3500 tonnes

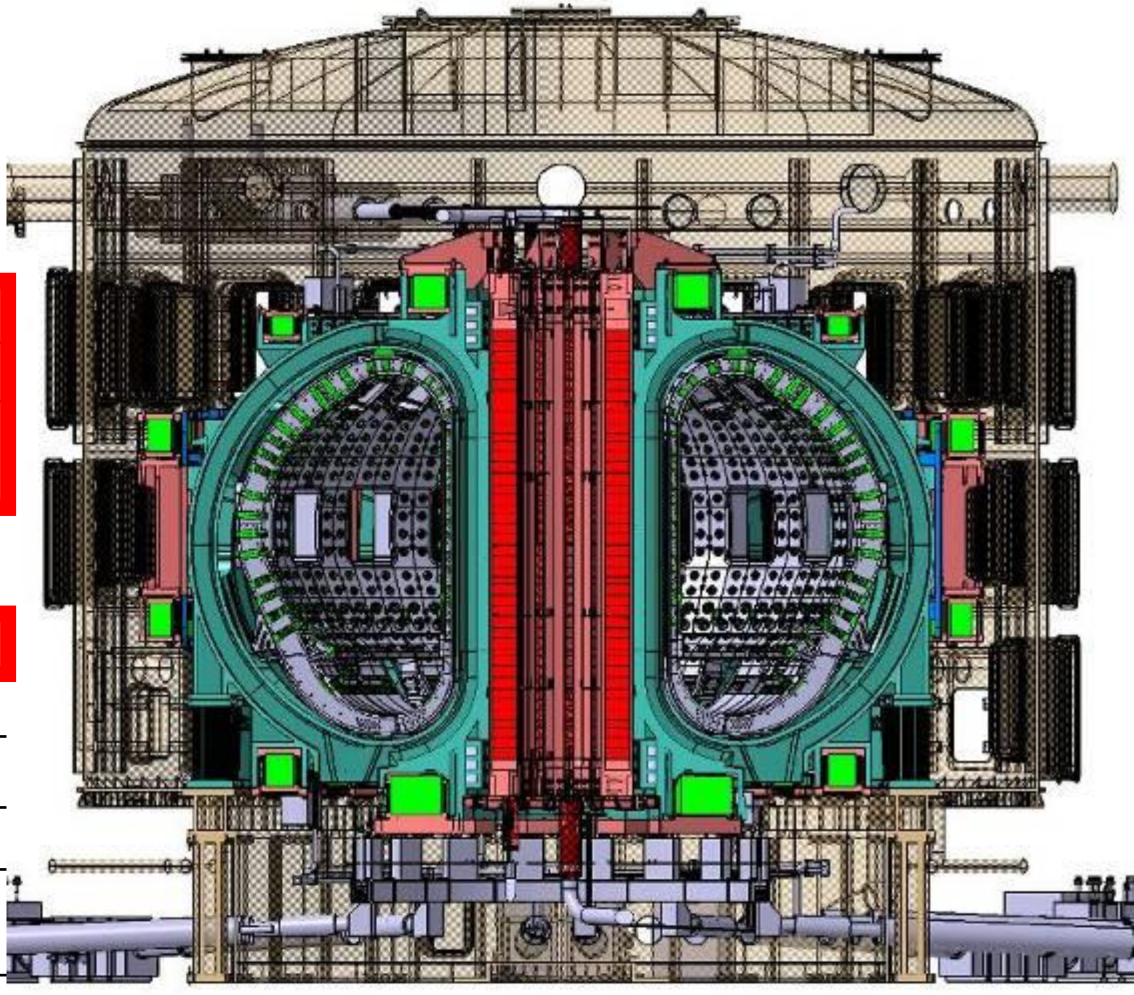
ITER PROJECT : THE MACHINE

The reactor



The Core of ITER

Total fusion power	500 MW
Additional heating power	50 MW
Q - fusion power/ additional heating power	≥ 10
Average 14MeV neutron wall loading	≥ 0.5 MW/m^2
Plasma inductive burn time	300-500 s *
Plasma major radius (R)	6.2 m
Plasma minor radius (a)	2.0 m
Plasma current (I_p)	15 MA
Toroidal field at 6.2 m radius (B_T)	5.3 T



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

ITER PROJECT

CONSTRUCTION ON GOING

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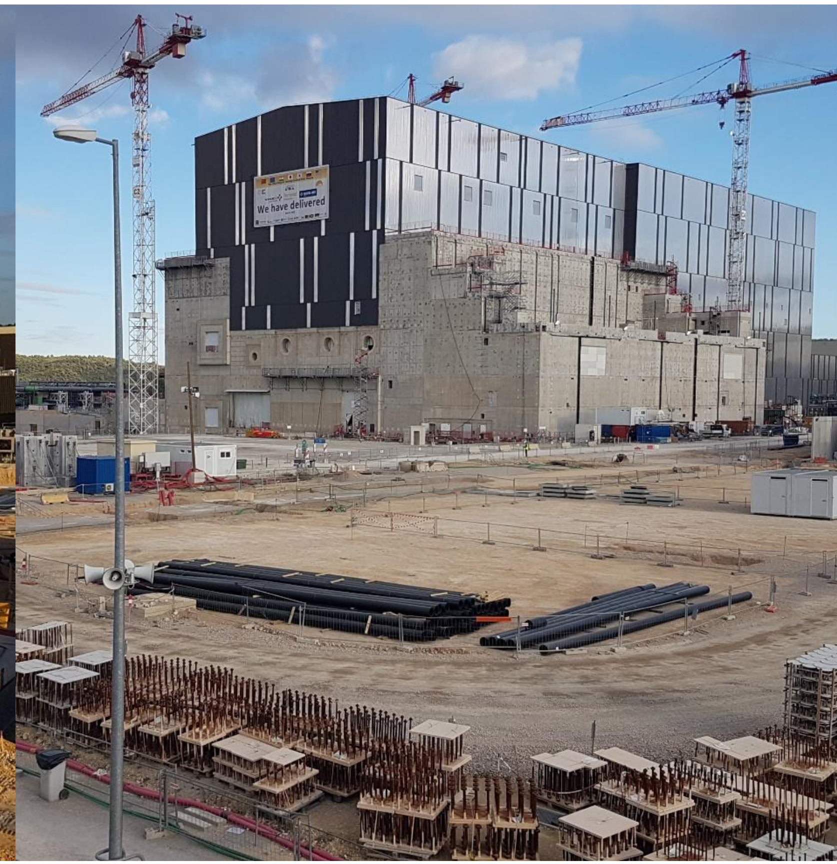
IN MAY 2020 ACHIEVEMENT OF FIRST MILESTONES ON THE PATH FORWARD TOWARDS FIRST PLASMA IN 2025

END OF BUILDING B11 ERECTION (march 2019 & Oct. 2020)



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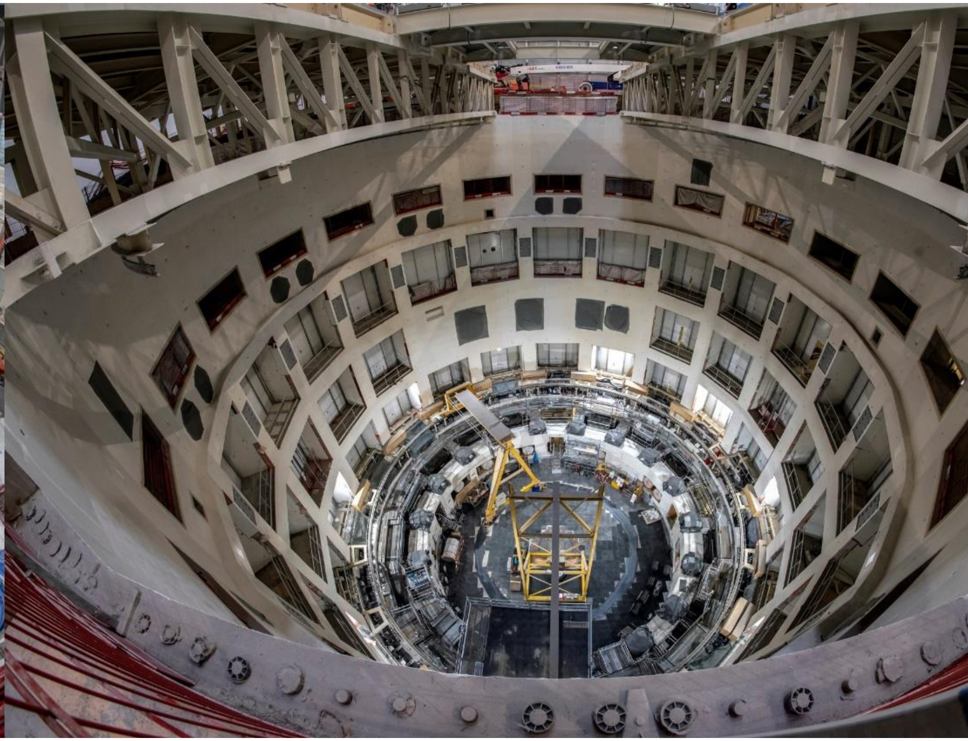
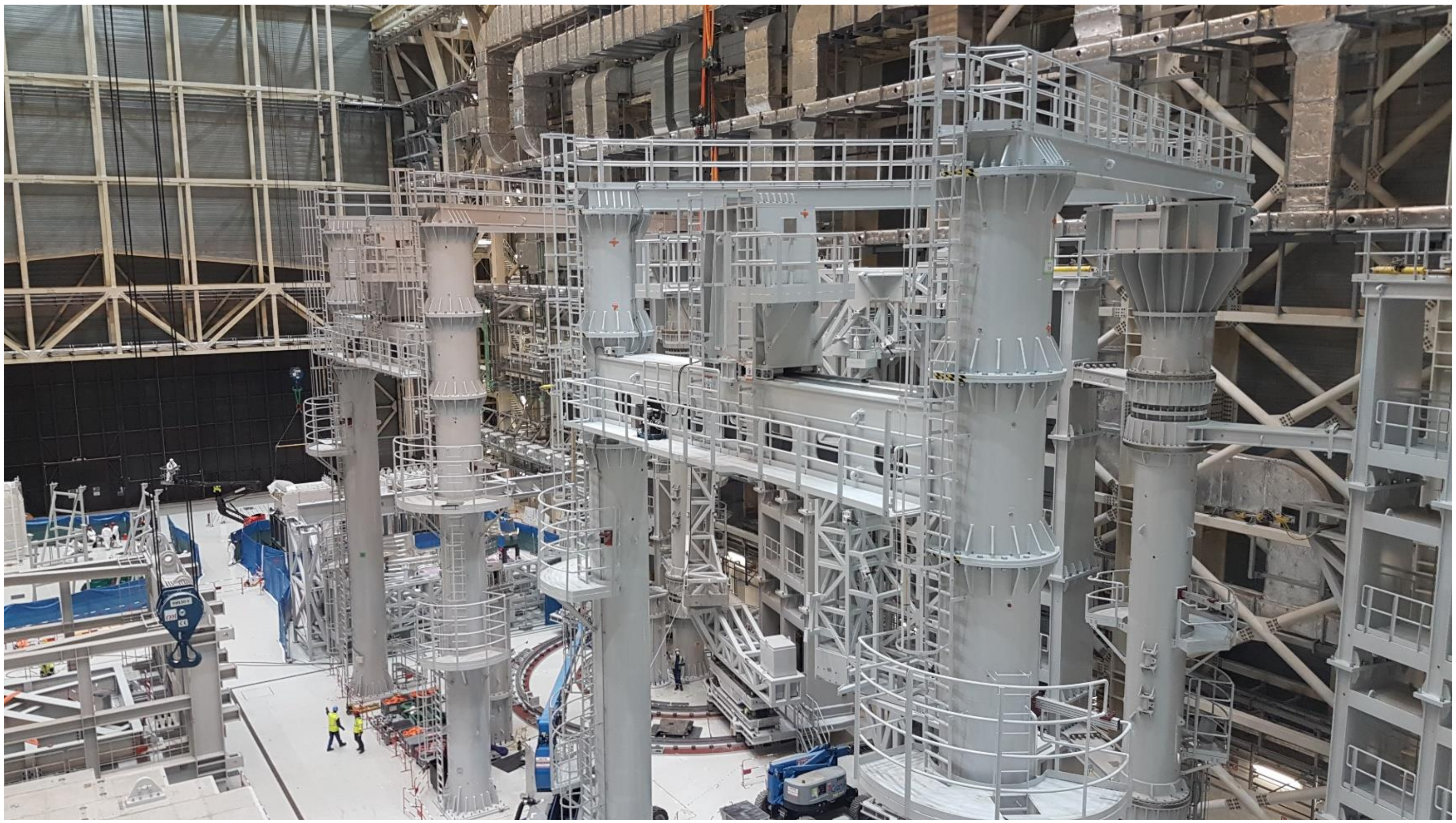
IN MAY 2020 ACHIEVEMENT OF FIRST MILESTONES ON THE PATH FORWARD TOWARDS FIRST PLASMA IN 2025

TOP LID REMOVAL



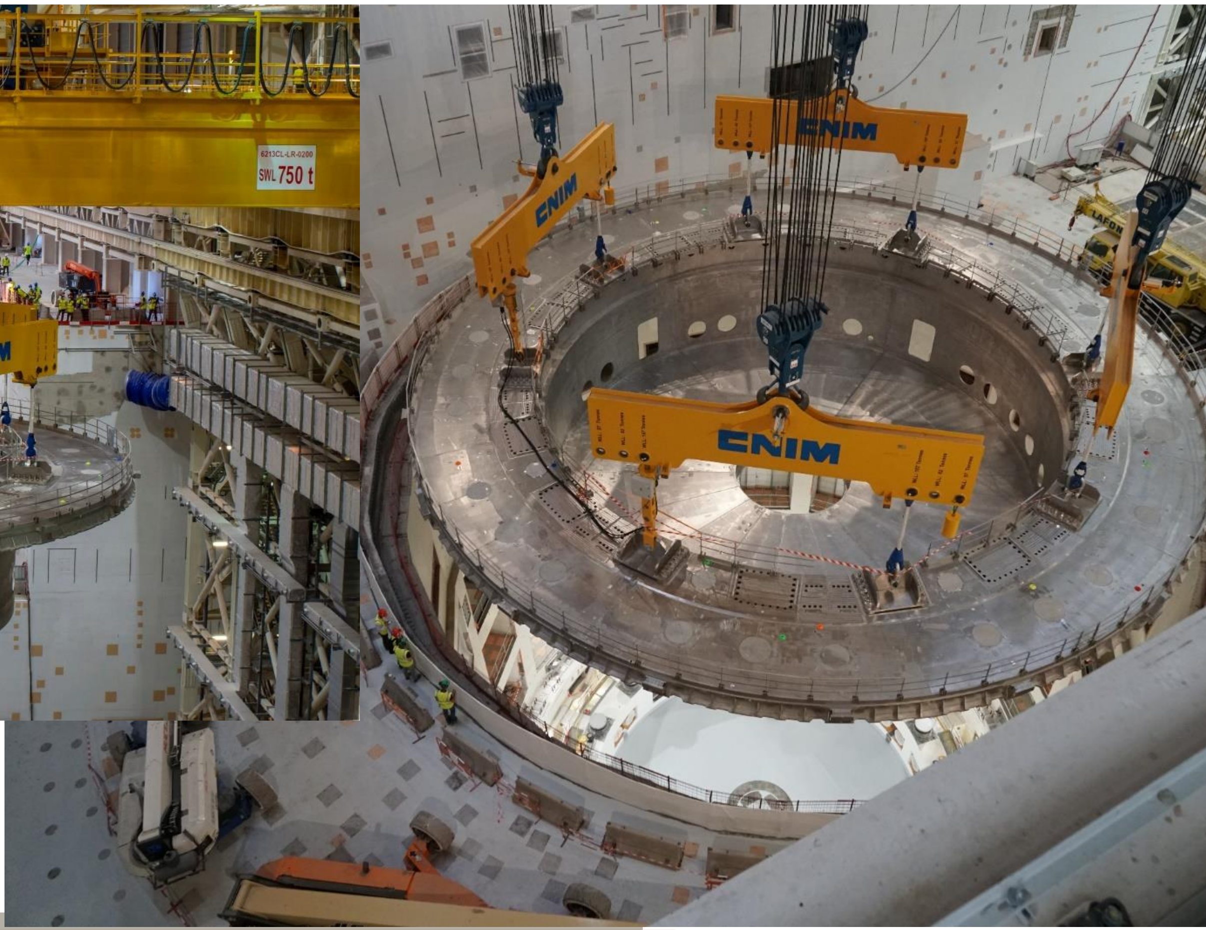
IN MAY 2020 ACHIEVEMENT OF FIRST MILESTONES ON THE PATH FORWARD TOWARDS FIRST PLASMA IN 2025

TOP LID EXITED THROUGH ASSEMBLY HALL



IN MAY 2020 ACHIEVEMENT OF FIRST MILESTONES ON THE PATH FORWARD TOWARDS FIRST PLASMA IN 2025

PIT RECEIVING CRYOSTAT BASE



ITER PROJECT

IN MAY 2020 ACHIEVEMENT OF FIRST MILESTONES ON THE PATH FORWARD TOWARDS FIRST PLASMA IN 2025

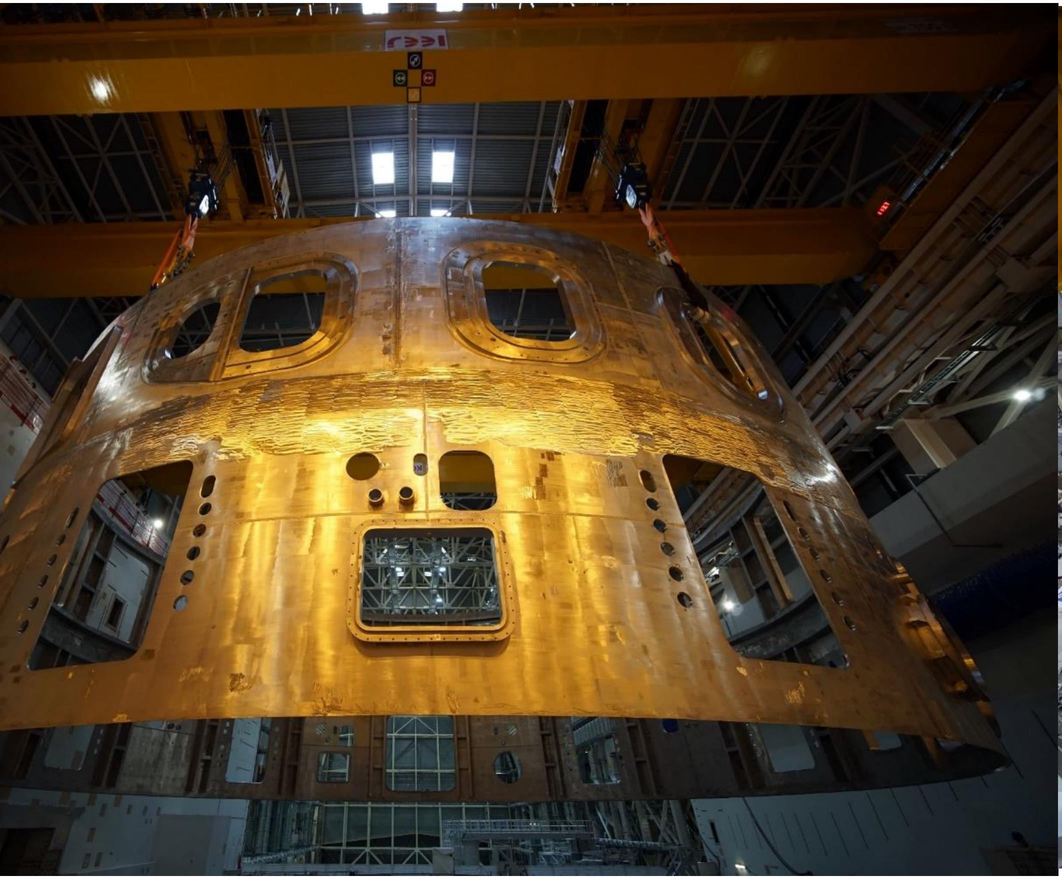
PIT RECEIVING CRYOSTAT BASE

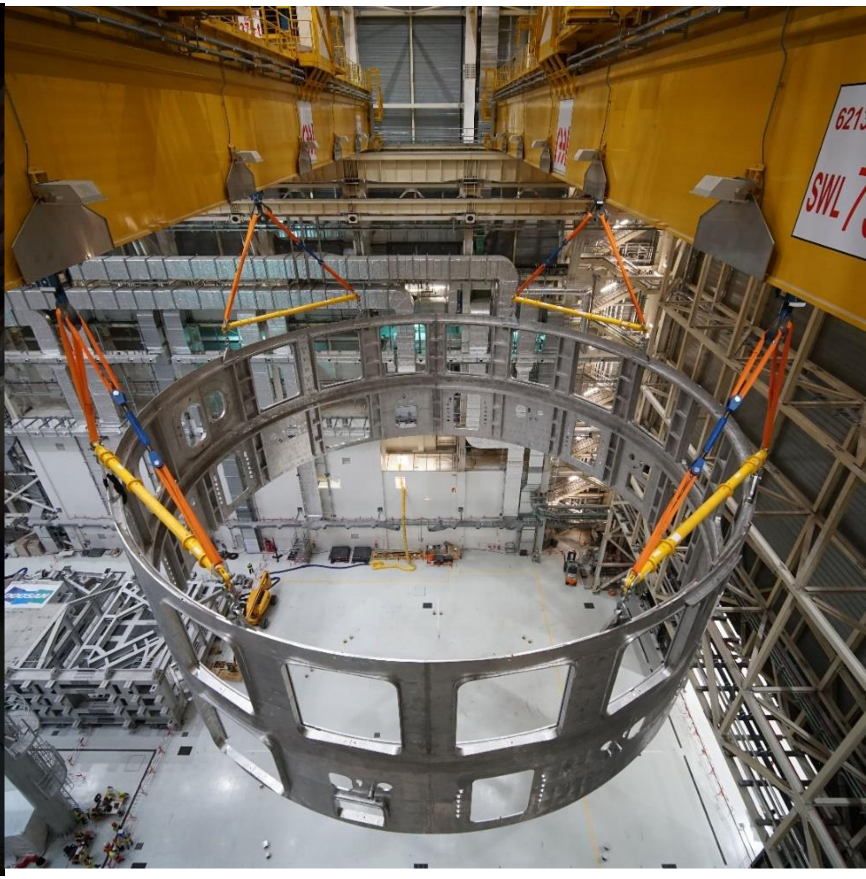
IN MAY 2020 ACHIEVEMENT OF FIRST MILESTONES ON THE PATH FORWARD TOWARDS FIRST PLASMA IN 2025

PIT RECEIVING CRYOSTAT BASE

IN 2020 ACHIEVEMENT OF FIRST MILESTONES ON THE PATH FORWARD TOWARDS FIRST PLASMA IN 2025

LOWERING CRYOSTAT LOWER CYLINDER IN PIT ON AUGUST 2020



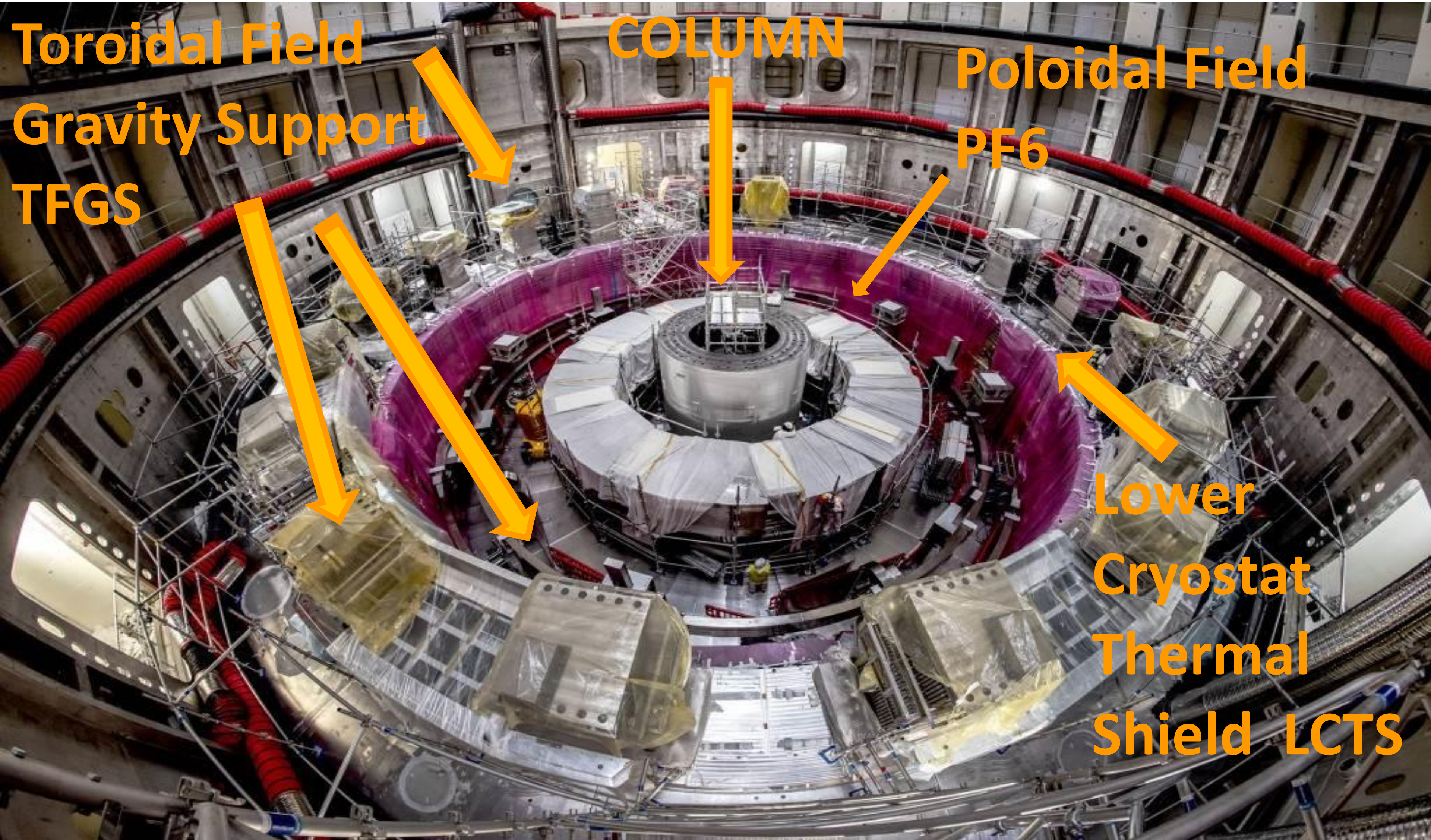


IN MAY 2020 ACHIEVEMENT OF FIRST MILESTONES ON THE PATH FORWARD TOWARDS FIRST PLASMA IN 2025

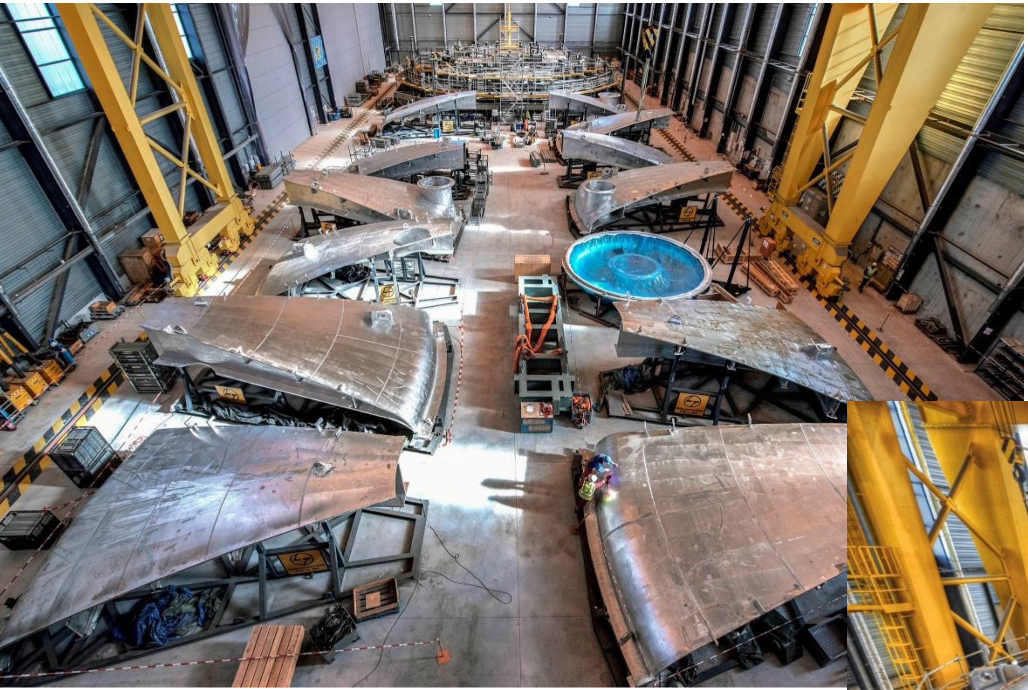
WORKS RESTARTED AS SOON AS CRYOSTAT BASE IN POSITION

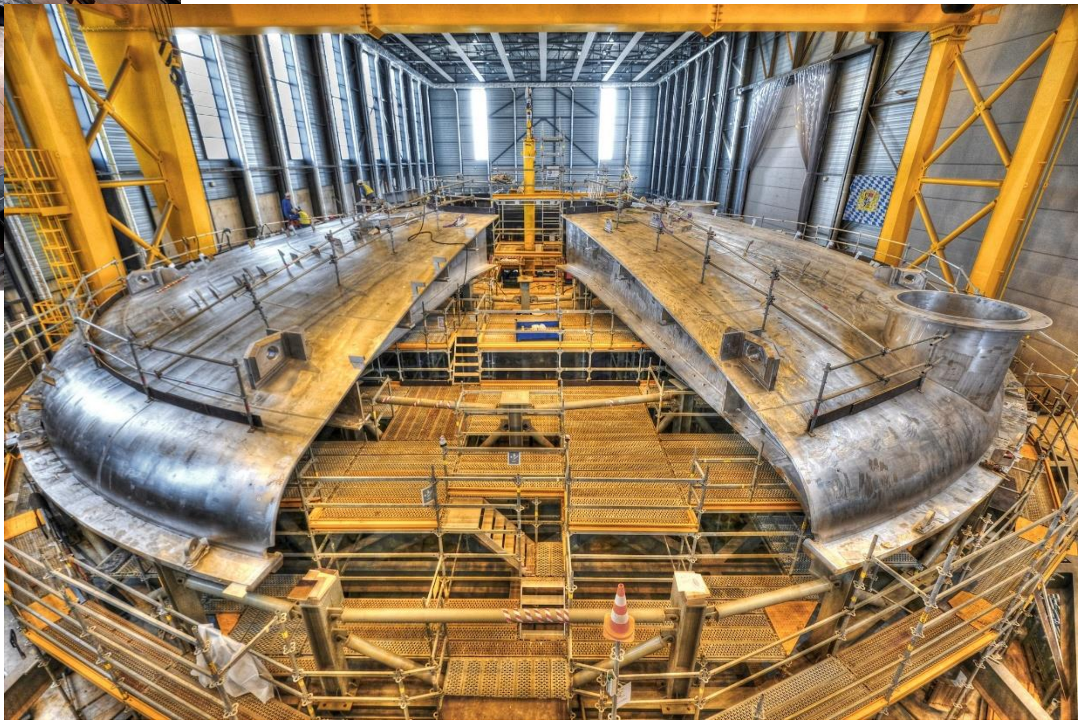
WORKS CONTINUE at B2M and below CRYOSTAT BASE

WORKS CONTINUE , MAJORS COMPONENTS INSTALLATION



WORKS CONTINUE , MAJORS COMPONENTS ASSEMBLY





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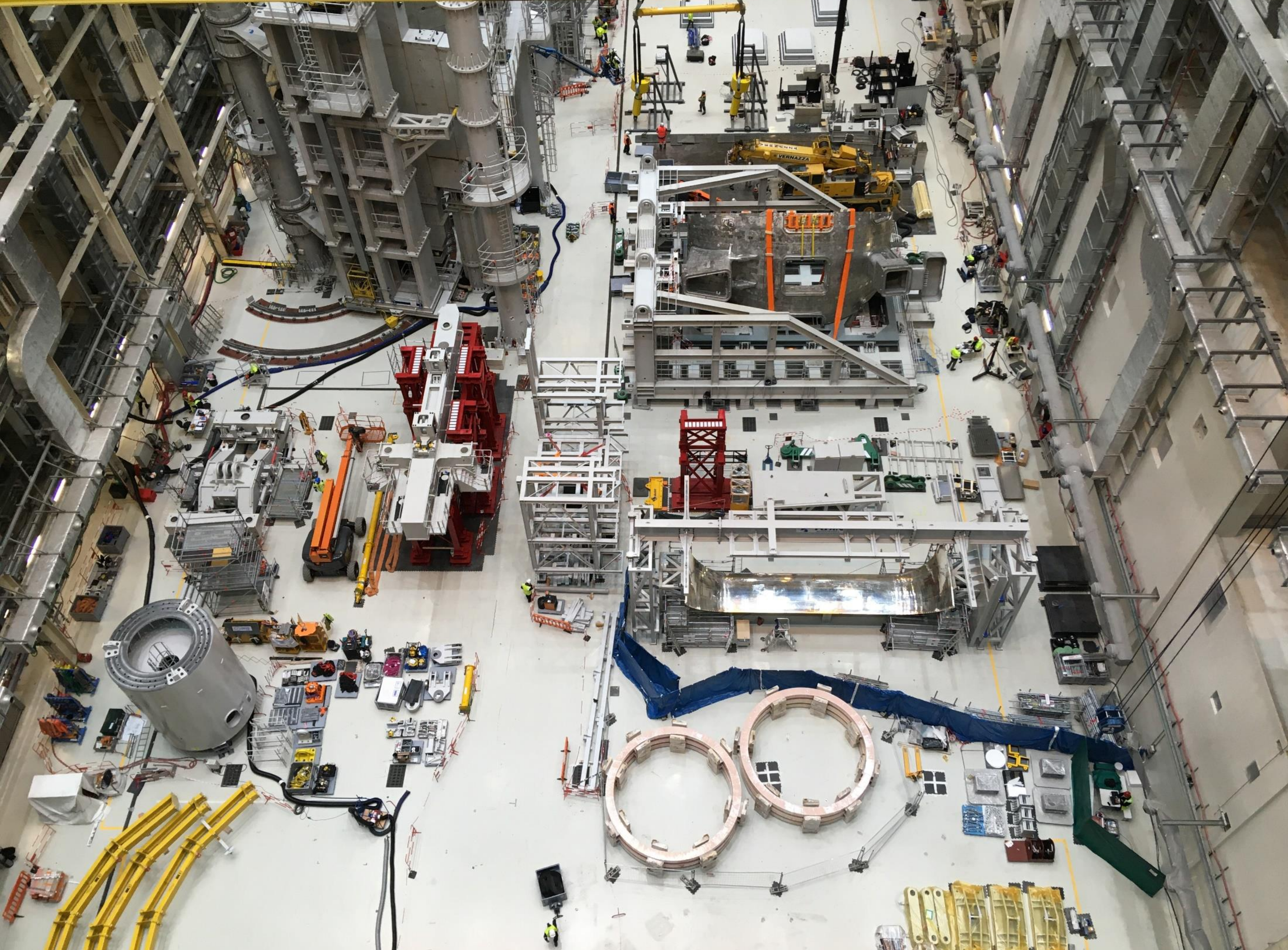
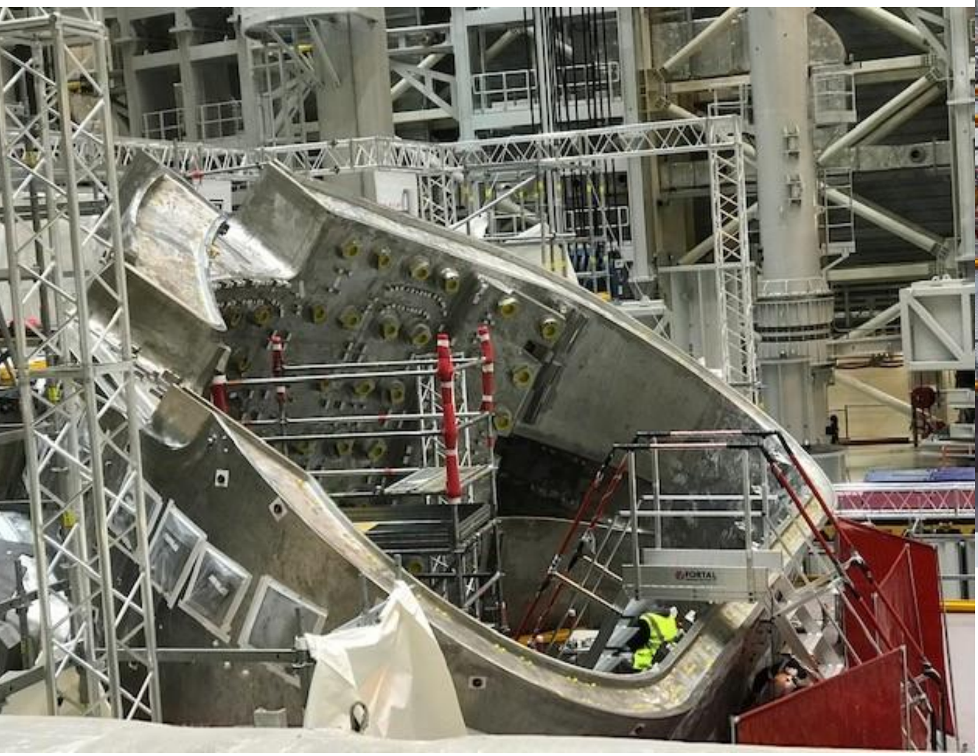
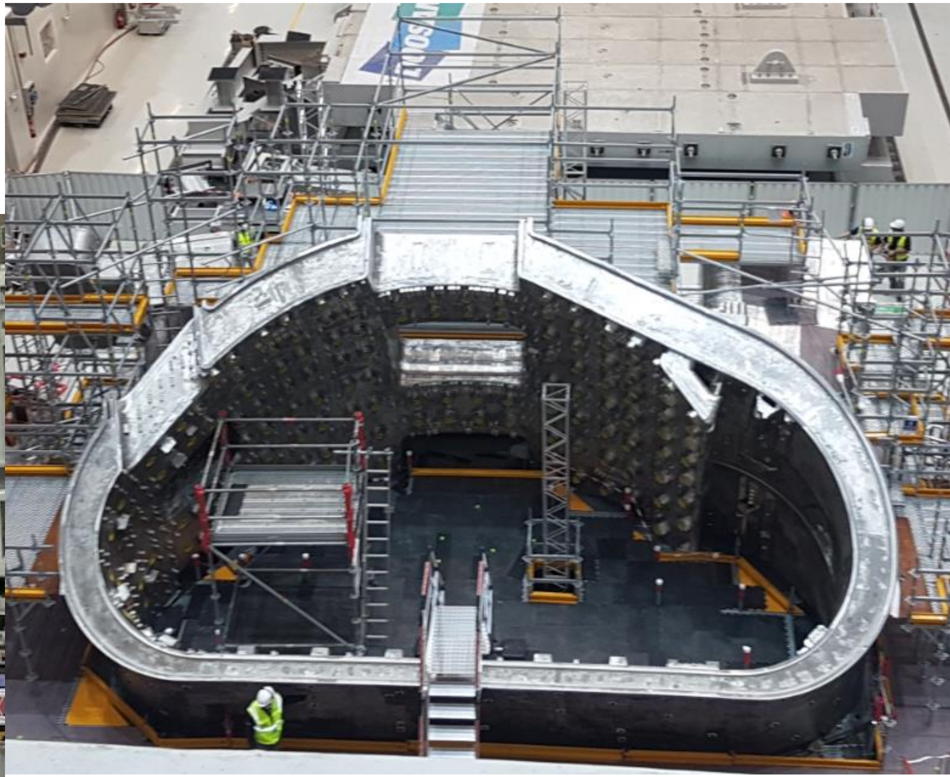

VERNAZZA

NEXT STEP IS INTEGRATION OF 1st VACCUM VESSEL SECTOR NEXT AUTUMN 2021





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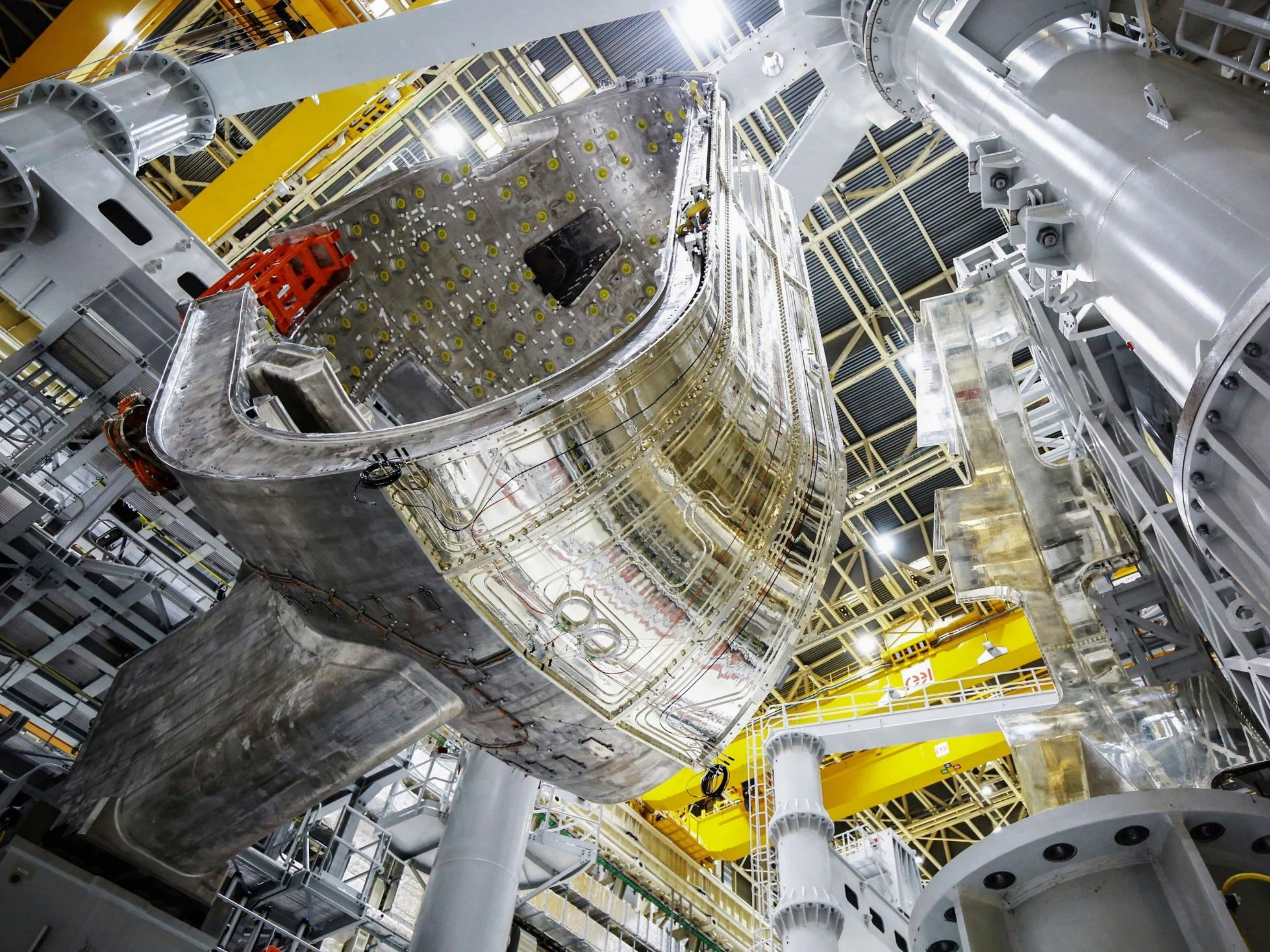
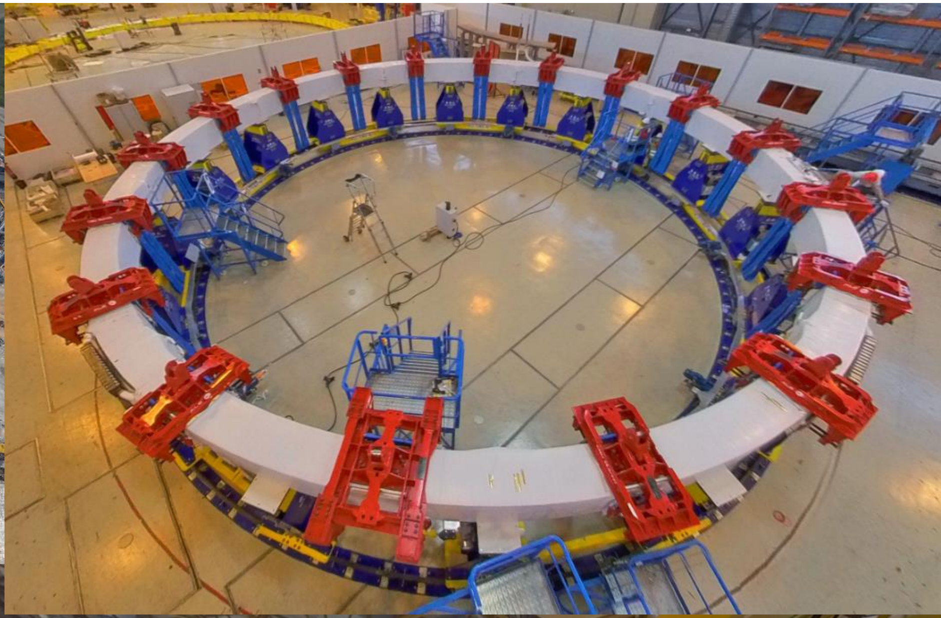
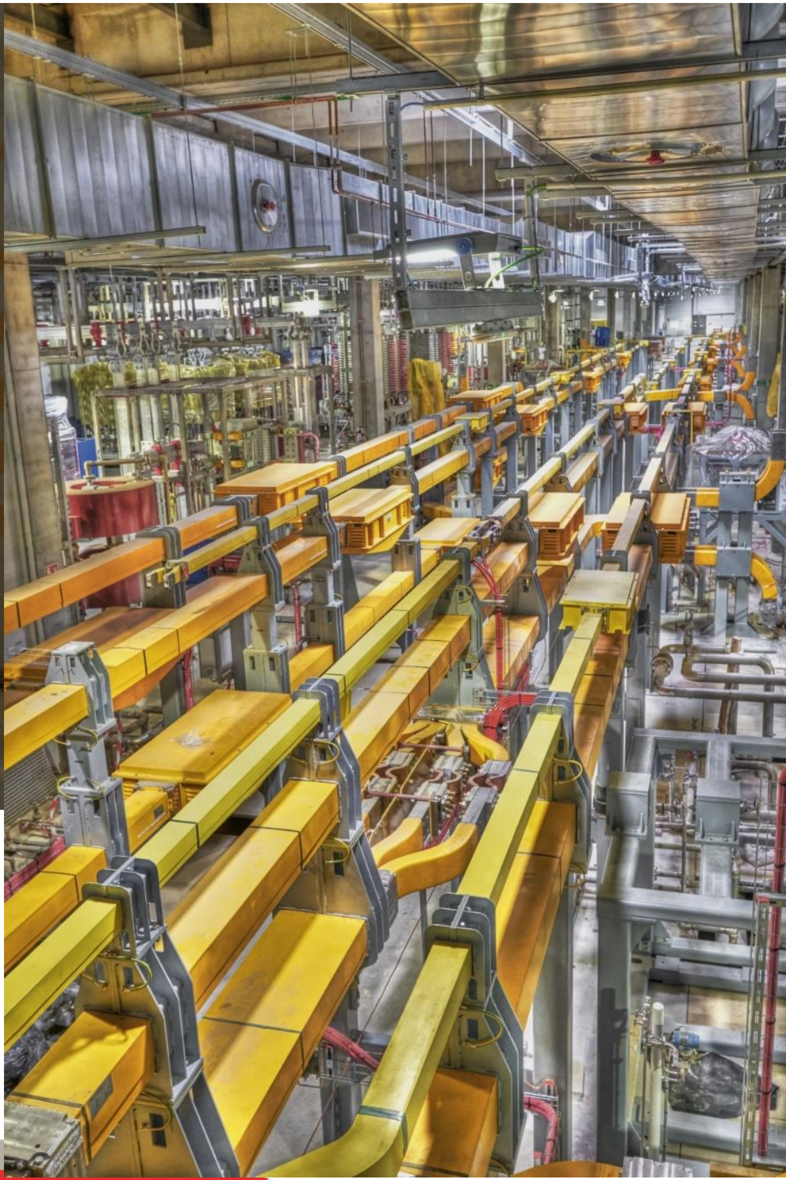


INTEGRATION OF EQUIPEMENT CONTINUES
BALANCE OF PLANT BEEING COMMISSIONED



WORKS OUTSIDE THE TOKAMAK BUILDING



ASSYSTEM SUPPORTING ITER

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15 YEARS SUPPORTING ITER

2006
Nuclear Safety Engineering

2008
On Site Design Office

2009
Remote Handling Framework

2010
Architect Engineer Building Design and Construction

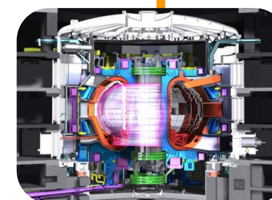
2011
Machine Assembly and Installation

2014
Divertor Remote Handling Framework

2016
Construction Manager As-Agent

2020
First Milestone

2025
First Plasma



2035

engage

MOMENTUM

FUSION FOR ENERGY

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ON THE WAY FORWARD TO FULL POWER

Fusion

TODAY 2021

..2017.. Construction

Assembly

Installation

Commissioning

..2025.. First Plasma

Start of Operation 1

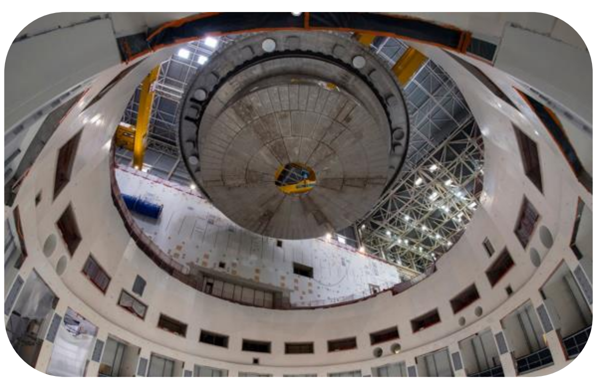
2^{nd} Phase Assembly & Test

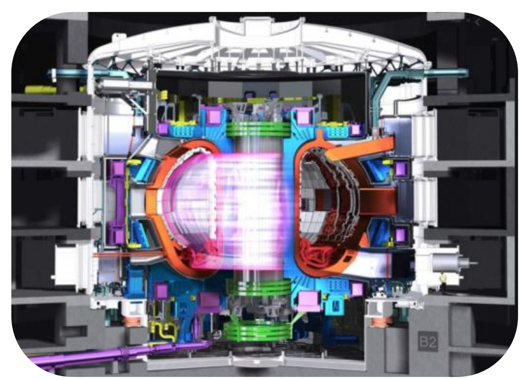
..2035.. D.T. Phase

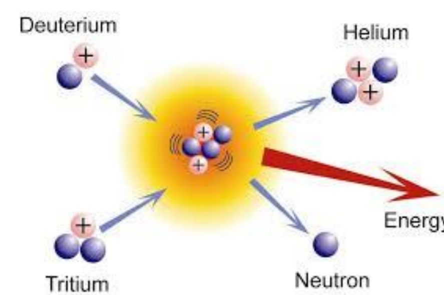
Start of Operation 2

Operation & Maintenance

..2050 Deactivation Decomissioning

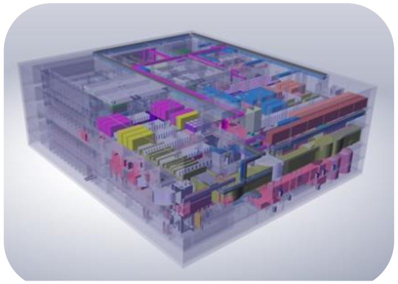




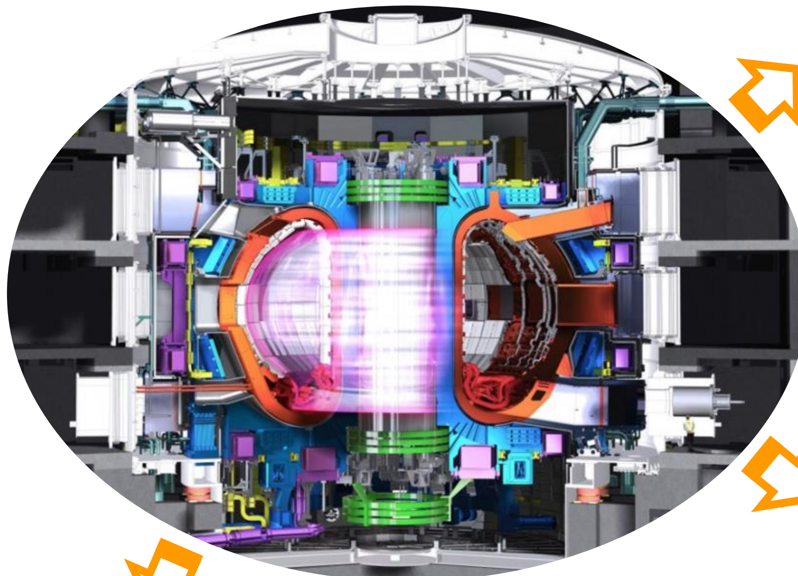


ON THE WAY FORWARD TO FULL POWER

HOT CELL COMPLEX

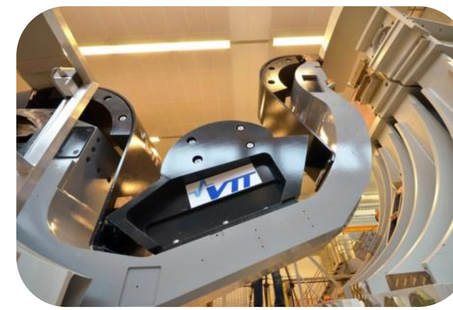


Front end Design & Dev.
Construction & Comm.
Operation & Maintenance
Waste Management



REMOTE HANDLING

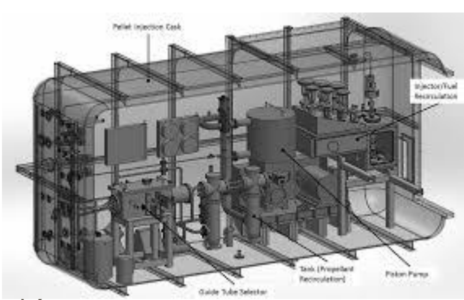
In Vessel Maintenance
Port-Plugs, Diagnostics Maintenance.
TBM Post-Irradiation Handling
Toolings, Multi-purpose Deployer



CONTROL & INSTRUMENTATION

Plant Systems
Supervisory Control Syst.

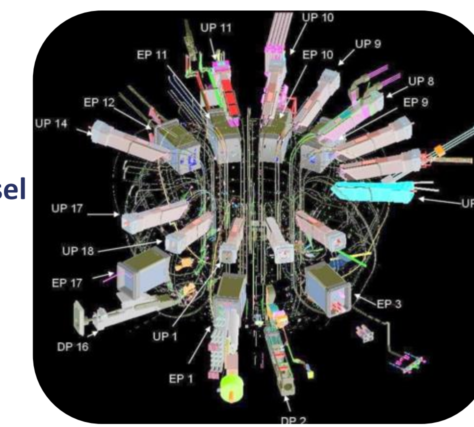
TRITIUM PLANT



De-Triation Systems
Development & Construction
Processing & Recycling

DIAGNOSTICS

PP Integration
RH Compatibility
In Vessel, Ex Vessel



NEXT STEP

&

DEMO PROJECT

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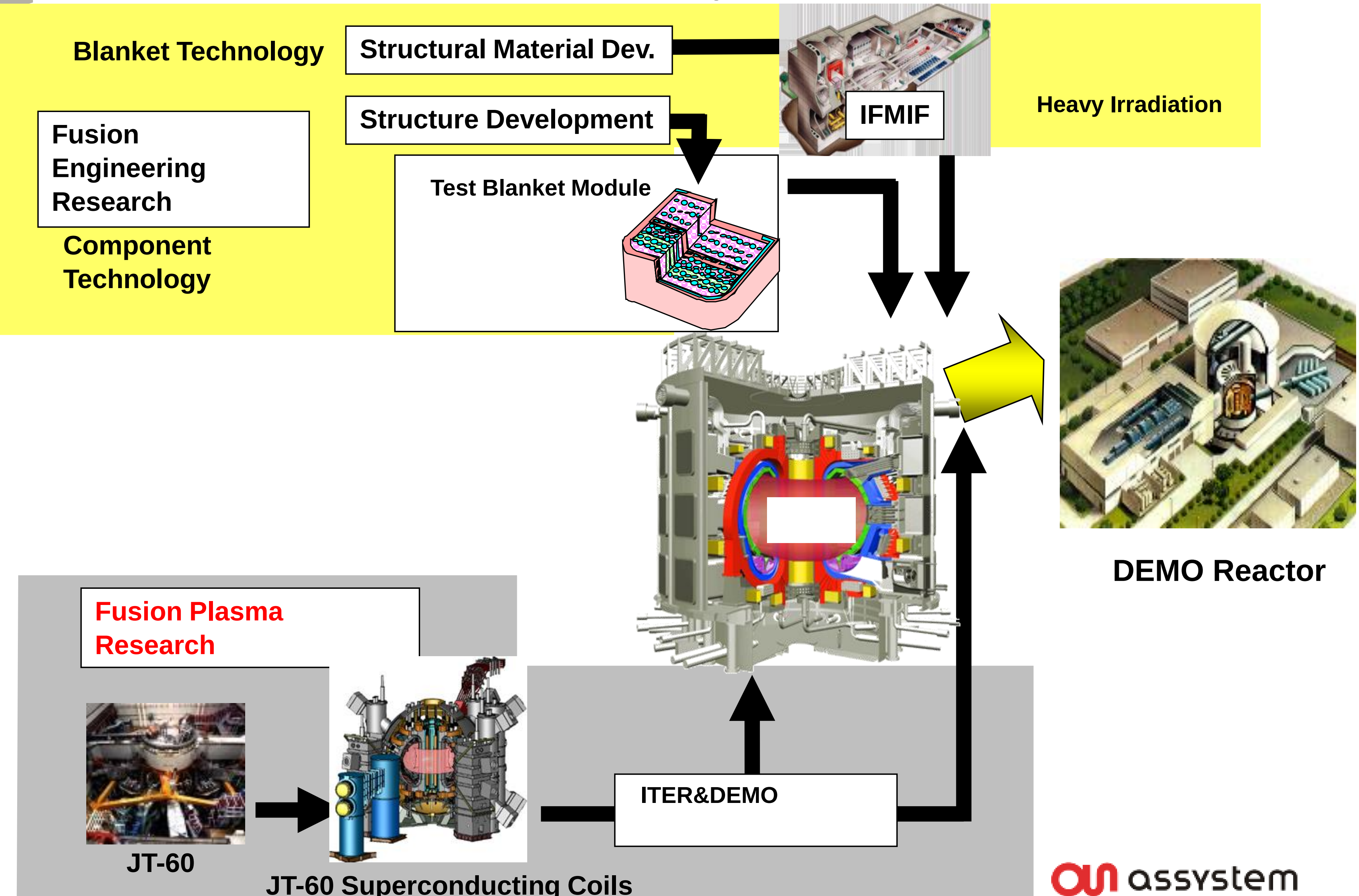
The Present and the Future Road Map to Fusion: The DEMO Reactor

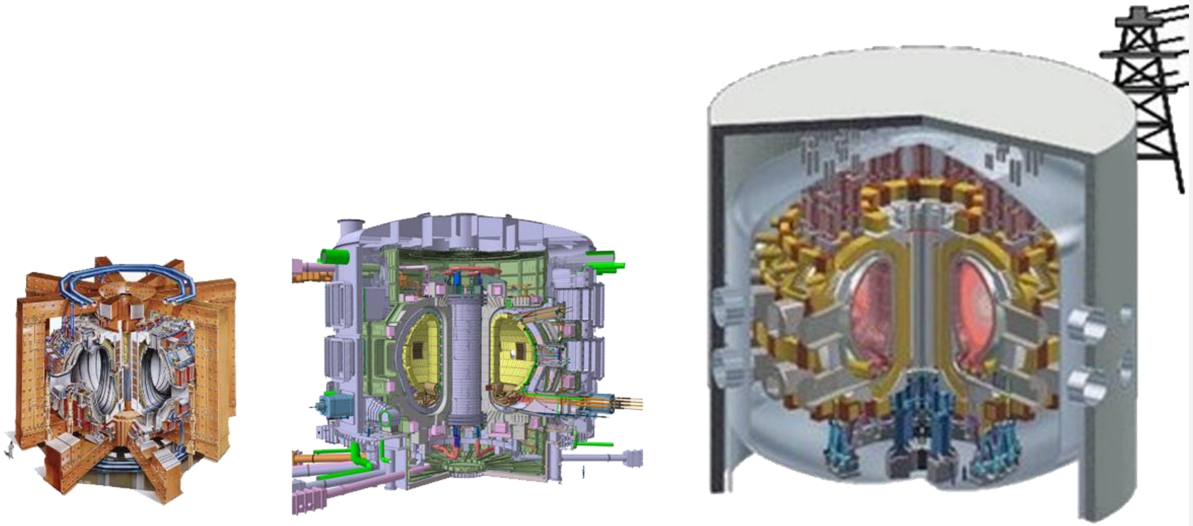


DEMO PROJECT

What is DEMO ?

- DEMOnstration Power Station: "upgrade" of ITER → produces electricity: 2 gigawatts on a continual basis with a closed fuel-cycle
- 15% bigger and 30% increase in the plasma density compare to ITER
- EUROfusion programme is leading the research and developing concept for the plant in Europe
- Last step before commercial fusion plant capable to:
  - Resolve all remaining physics and technical issues foreseen
  - Demonstrating production of several 100 MW electricity
  - Achieve tritium self-sufficiency
  - Operate with adequate availability/reliability over a reasonable time span

DEMO PROJECT



JET	ITER	DEMO
$80\ m^3$	$800\ m^3$	$\sim 1000 - 3500\ m^3$
$\sim 16\ MW_{th}$	$\sim 500\ MW_{th}$	$\sim 2000 - 4000\ MW_{th}$

DEMO key challenges

- Breeding Blankets concept (~10m tall, 80t)
- Divertor concept and layout configuration
- First wall design
- Heating and current drive mix
- Remote maintenance scheme
- Compatible plasma scenario

ITER & DEMO

ITER

ITER, the world's largest and most advanced fusion experiment, will be the first magnetic confinement device to produce a net surplus of fusion energy. It is designed to generate 500 MW fusion power which is equivalent to the thermal output of a medium size power plant. For a planned injected power of 50 MW, this corresponds to a fusion gain Q=10 in the plasma. ITER will also demonstrate some key technologies for a DEMO fusion power plant. ITER is not intended to generate any electricity to the grid from fusion.

The realisation of fusion energy depends completely on ITER's success. Therefore, the vast majority of EU fusion resources over the next decade are dedicated to the construction of ITER and the preparation of its exploitation. ITER is being built in southern France in the framework of a collaboration between China, Europe, India, Japan, Korea, Russia and the USA.

DEMO: The step between ITER and a commercial power plant

DEMO will mark the very first step of fusion power into the European energy market by supplying electricity to the grid. DEMO will largely build on the ITER experience. Beyond that:

- DEMO will breed its own tritium, which is part of the fusion fuel;
- DEMO will demonstrate materials suitable for handling the fluence of neutrons produced during the fusion reactions;
- DEMO will demonstrate safety and environmental sustainability, and sufficient technology to allow a first commercial power plant to be constructed.

To achieve fusion electricity early in the second half of the century, a European DEMO construction has to start in the early 2040s, shortly after ITER achieves the milestone of Q_{DT} = 10 operation. DEMO engineering design will become a major activity after 2030.

M1. Plasma regimes of operation:

Demonstrate plasma scenarios (based on the tokamak configuration) that increase the success margin of ITER and satisfy the requirements of DEMO.

M2. Heat-exhaust systems:

Demonstrate an integrated approach that can handle the large power leaving ITER and DEMO plasmas.

M3. Neutron tolerant materials:

Develop materials that withstand the large 14MeV neutron flux for long periods while retaining adequate physical properties.

M4. Tritium self-sufficiency:

Find an effective technological solution for the breeding blanket which also drives the generators.

M5. Implementation of the intrinsic safety features of fusion:

Ensure safety is integral to the design of DEMO using the experience gained with ITER.

M6. Integrated DEMO design and system development:

Bring together the plasma and all the systems coherently, resolving issues by targeted R&D activities

M7. Competitive cost of electricity:

Ensure the economic potential of fusion by minimising the DEMO capital and lifetime costs and developing long-term technologies to further reduce power plant costs.

M8. Stellarator:

Bring the stellarator line to maturity to determine the feasibility of a stellarator power plant.

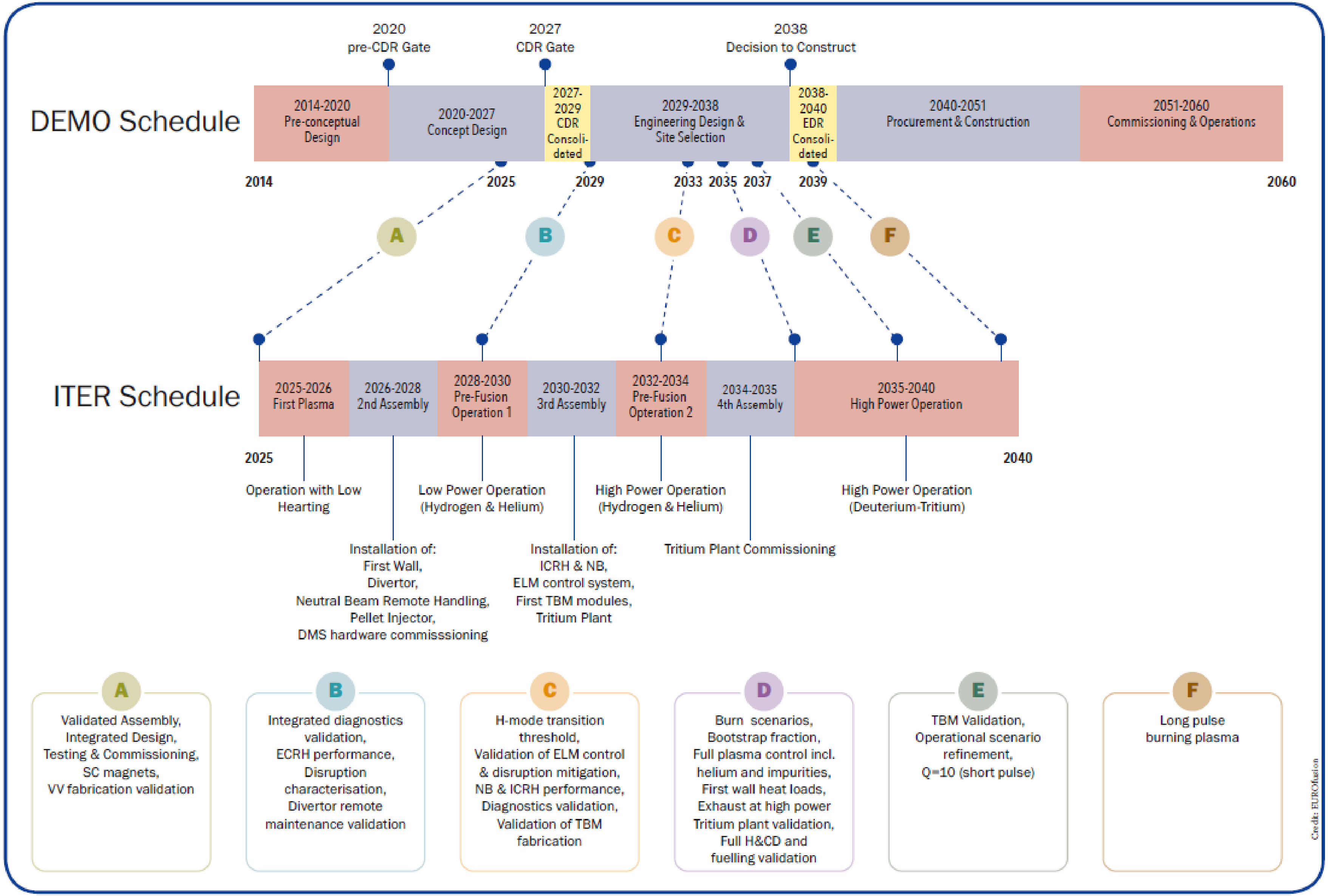


Figure 4: Diagram depicting how information from ITER, during its four-phase assembly/operation phase, flows into the DEMO Conceptual and Engineering Design Activities. CDR=Concept Design Review. The dates are indicative.

REFERENCES

- Video of ITER May 2021 :
- https://www.youtube.com/watch?v=WIRdKDMhGUQ&t=1s
- Video of ITER by Drone June 2020
- Photothèque ITER : https://www.iter.org/album/Construction
- www.iter.org
- www.euro-fusion.org
- http://www.world-nuclear-news.org/NN-First-plasma-for-WEST-fusion-reactor-1912161.html
- “Challenges on the road toward fusion electricity” by Tony Donné - DOI: http://dx.doi.org/10.1051/epn/2016502
- “The first fusion reactor: ITER” by D.J Campbell - DOI: http://dx.doi.org/10.1051/epn/2016504
- Remote Handling of DEMO breeder blanket segments: Blanket transport conceptual studies by J. Keeo, S. Wood, N. Gupta, M Coleman and A. Loving – DOI: https://doi.org/10.1016/j.fusengdes.2017.02.016
- Overview of the design approach and prioritization of R&D activities towards an EU DEMO by G. Federici et al - DOI: https://doi.org/10.1016/j.fusengdes.2015.11.050
- https://www.linkedin.com/company/iter-organization/posts/?feedView=all
- https://www.iter.org/news/videos
- https://www.futura-sciences.com/sciences/actualites/fusion-fusion-controlee-cle-futur-humanite-93321/
- For more information please feel free to contact :   emmanuel.potie@iter.org

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