The new Divertor Tokamak Test facility

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and DTT Team

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Outline

1. EU Roadmap toward fusion electricity
2. Introduction to the DTT Project
3. DTT design status
4. Planning and conclusions

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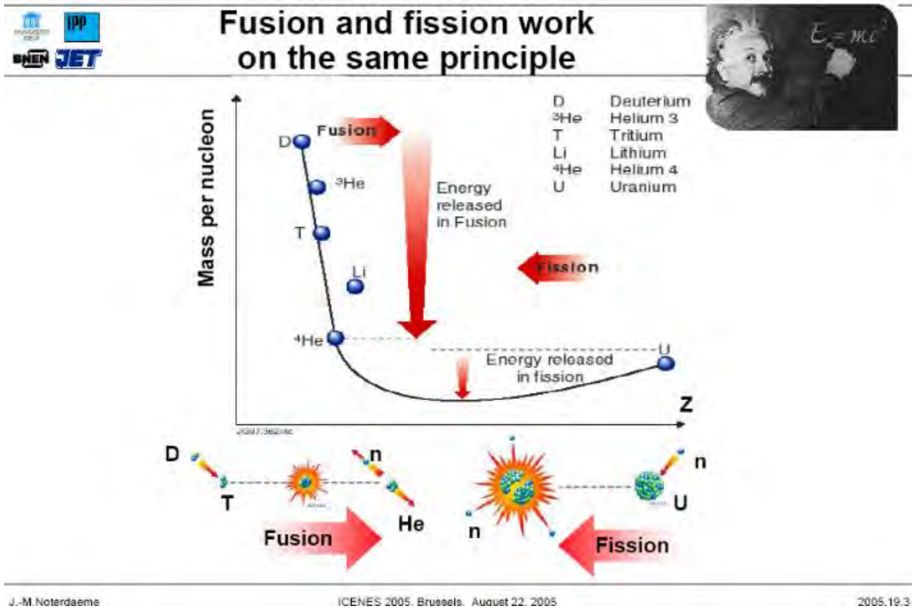
FUSION: What



Fusion and fission work on the same principle

D	Deuterium
^3He	Helium 3
T	Tritium
Li	Lithium
^4He	Helium 4
U	Uranium

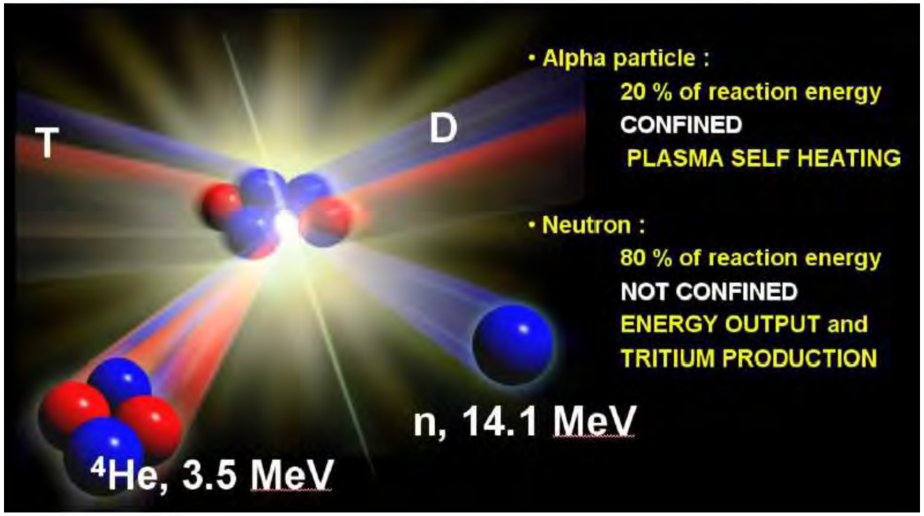
J.-M.Noterdaeme ICENES 2005. Brussels. August 22. 2005 2005.19.3

Advantages of fusion:

- **Abundance of fuel**
- **Small amount of fuel needed for reactor conditions**
- **No pollution**
- **No greenhouse effect**
- **No direct nuclear waste**
- **No risk of severe accidents**

$$\Delta E = \Delta m\, c^2$$

D-T Fusion Reaction: $D + T \rightarrow {}^4He + n$

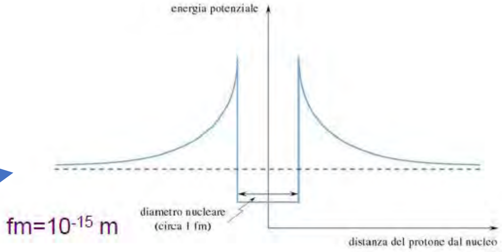


- **Alpha particle :**
  20 % of reaction energy
  CONFINED
  PLASMA SELF HEATING
- **Neutron :**
  80 % of reaction energy
  NOT CONFINED
  ENERGY OUTPUT and TRITIUM PRODUCTION

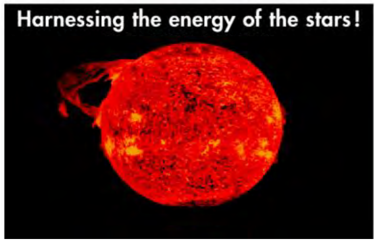
FUSION: What

Conditions needed for fusion reactions

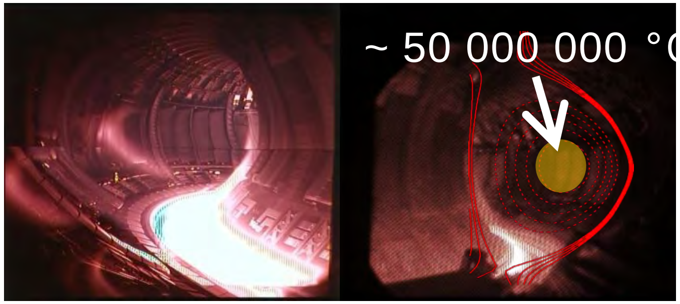
- EM & nuclear forces. Potential barrier.
- At the very high temperatures needed for fusion the gas is fully ionized and is a very good conductor: plasma (4th state of the matter).
- Magnetic confinement



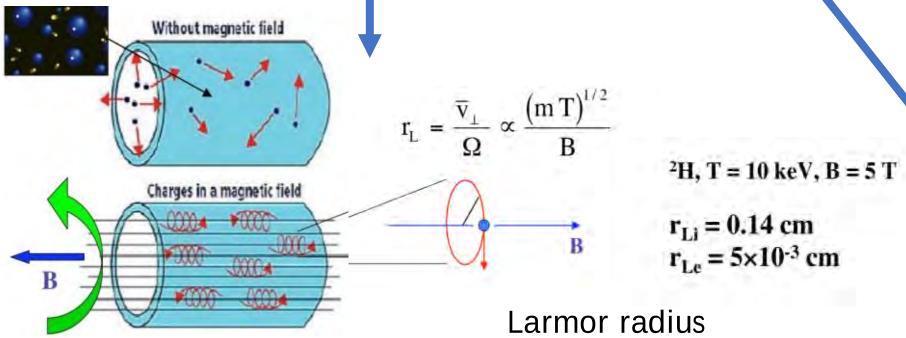
Courtesy of CERM.UniFI



Courtesy of CCFE, JET



EAST (Hefei,China) 100 M °C Nov 2018



$$r_L = \frac{v_\perp}{\Omega} \propto \frac{(m\,T)^{1/2}}{B}$$

^2H, $T = 10$ keV, $B = 5$ T

$r_{Li} = 0.14$ cm

$r_{Le} = 5\times10^{-3}$ cm

Larmor radius

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FUSION: How

Ignition condition: *Lawson criterion*

$n \cdot T \cdot \tau \geq 5 \times 10^{21}\ m^{-3}\ s\ KeV$

In the 90s the JET Tokamak achieved:

$n \cdot T \cdot \tau = 0.9 \times 10^{21}\ m^{-3}\ s\ KeV$

$Q = P_{fus}/P_{in} = (16MW/25MW) = 0.6$

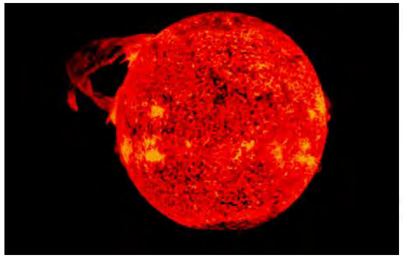
Good confinement needed

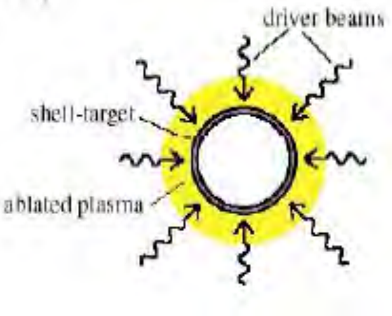
How?

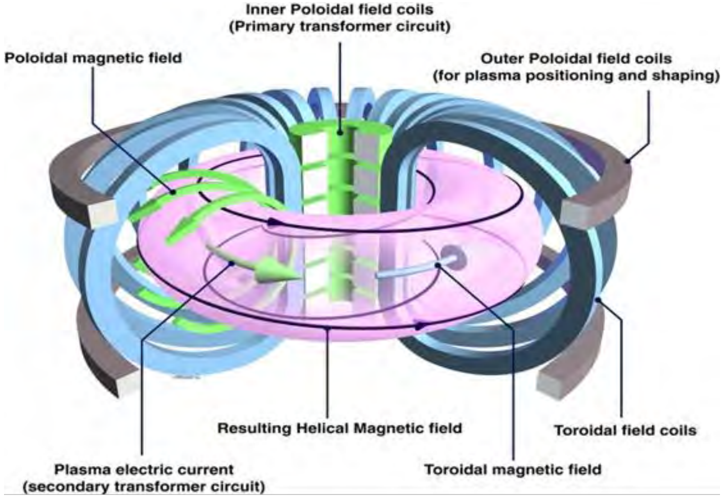
Gravitational

Inertial

Magnetic







Schematic view
(courtesy of EUROfusion)

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Fusion electricity: when

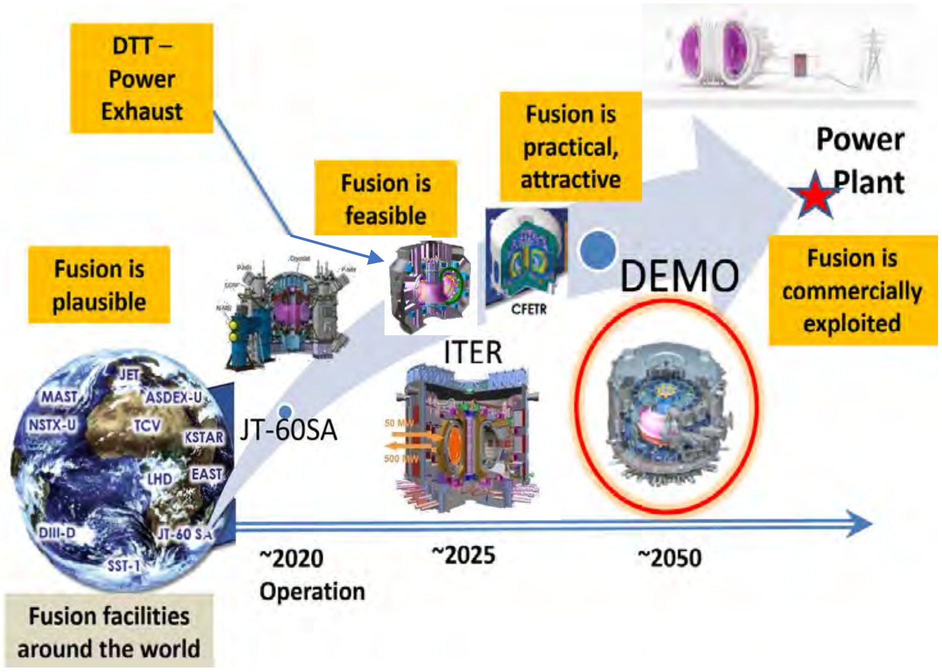
	Military weapon	Commercial reactor
Fission	1945	1956-57
Fusion	1951-52	?

In the 90's the **JET** provided a fusion gain **$Q>0.6$**. **(16 MW of nuclear fusion power (**D-T reactions, with 25 MW of input heating power)

Next Step: **ITER (2015)**
Mission of ITER: to improve Q, by increasing magnetic field, plasma current and machine size.

- OUT: P_{fus}=500 MW from
- INPUT P_{in}=50 MW ($Q\approx10$).

Further Step: **DEMO, 2050**
(Demonstration Fusion Power Plant)



Which are the main challenges to face along the roadmap toward the fusion power plant?

EU Fusion Roadmap: Missions

EU Fusion Roadmap

The European fusion community identified eight important missions on the path towards fusion electricity:

1) Plasma regime of operation

2) Heat-exhaust system

3) Neutron resistant materials

4) Tritium self-sufficiency

5) Implementation of intrinsic safety features of fusion

6) Integrated DEMO design and system development

7) Competitive cost of electricity

8) Stellarator

SOFT 2018

European Research Roadmap to the Realisation of Fusion Energy

EUROfusion

"If alternate exhaust strategies were to be only explored in the event of ITER showing that the baseline exhaust strategy cannot be extrapolated to DEMO, the realisation of fusion would be delayed by at least 10 years…. for the alternative approaches the extrapolation from proof-of-principle devices to DEMO based on modelling alone is considered too large. If a promising alternative concept emerges, a divertor optimised for the concept will be implemented in the Italian Divertor Test Tokamak (I-DTT) facility as a joint European collaboration."

Tony Donné, William Morris, et al., "European Research Roadmap to the Realisation of Fusion Energy A road map to the realisation of fusion energy" www.euro-fusion.org/fileadmin/user_upload/EUROfusion/Documents/2018_TopLevel_Roadmap.pdf

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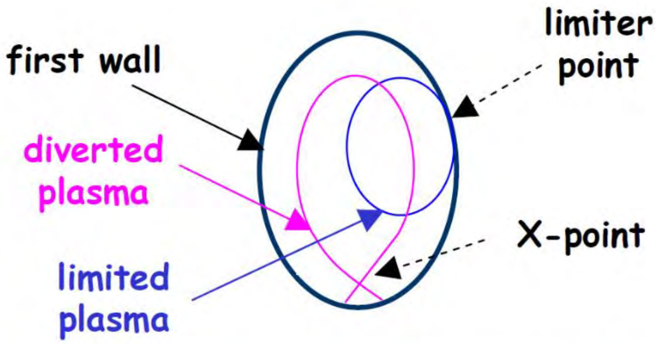
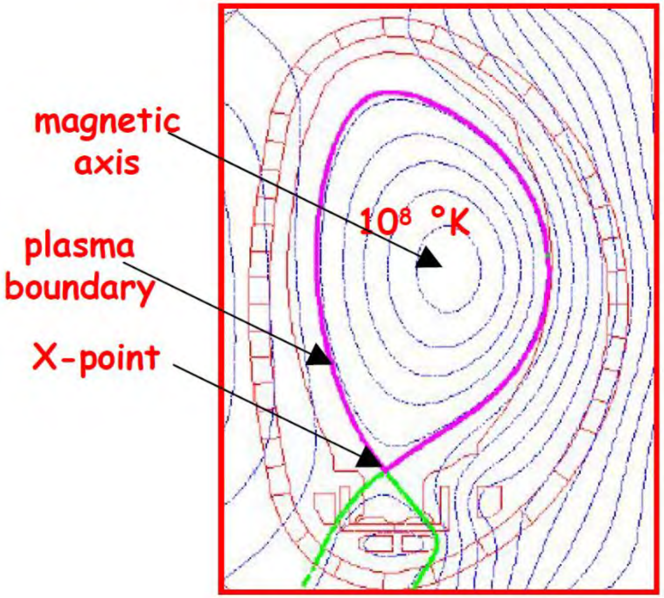
Fusion Roadmap: plasma edge

PLASMA BOUNDARY

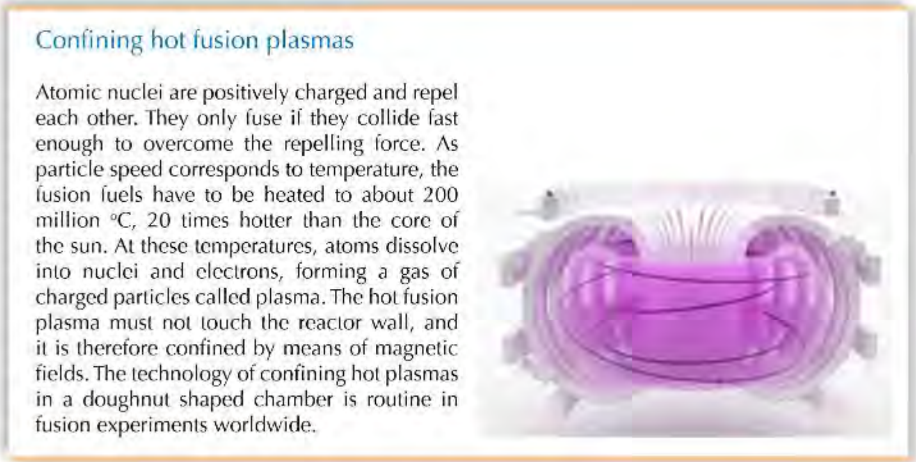
- The plasma boundary is defined as the **outermost closed magnetic surface that does not intersect solid walls**:
  - limited plasmas (the plasma core touches the wall at a *limiter point*)
  - diverted plasmas (the boundary flux is determined by the *X-point*, i.e., the magnetic null point)
- The plasma boundary is determined by both external currents and plasma current density: therefore, it is usually a result of the calculation (*free boundary problem*)





diverted configuration

Fusion Roadmap: the heat exhaust challenge



Confining hot fusion plasmas

Atomic nuclei are positively charged and repel each other. They only fuse if they collide fast enough to overcome the repelling force. As particle speed corresponds to temperature, the fusion fuels have to be heated to about 200 million °C, 20 times hotter than the core of the sun. At these temperatures, atoms dissolve into nuclei and electrons, forming a gas of charged particles called plasma. The hot fusion plasma must not touch the reactor wall, and it is therefore confined by means of magnetic fields. The technology of confining hot plasmas in a doughnut shaped chamber is routine in fusion experiments worldwide.

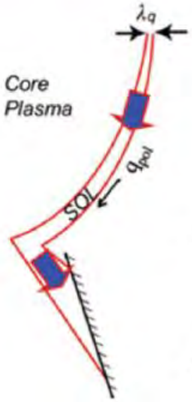
Extreme conditions:

- *in the plasma core: $T > 100$ M °K*
- *in the SOL: $q_{//} \approx 1$ GW/m^2*

The geometry reduces it by a factor of 30:

- *B toroidal >> B poloidal*
- *Expansion of the flux on divertor*
- *Plate inclination*

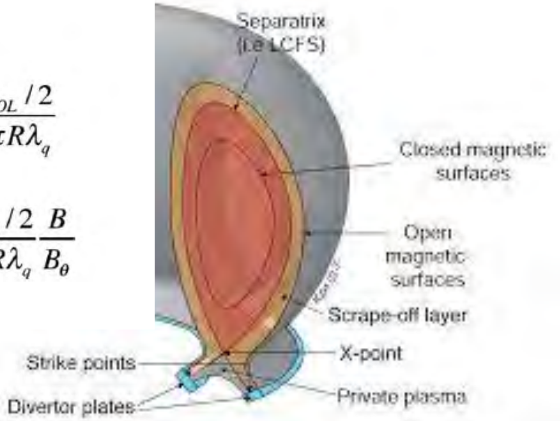
… … But the unmitigated heat flow on the plates is still higher than the current technological limits (5-10 MW/m^2)

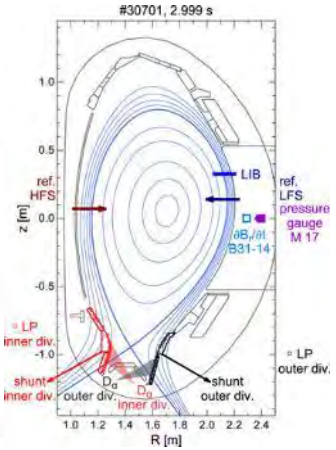


$$q_{pol} \sim \frac{P_{SOL}/2}{2\pi R\lambda_q}$$

$$q_{\|} \sim \frac{P_{SOL}/2}{2\pi R\lambda_q}\frac{B}{B_\theta}$$

Fig. 1. Power flux on the divertor.





Two-point Modeling of the Divertor SOL
P. Stangeby, Inst. for Aerosp. Studies, Toronto Univ., Ont., Canada

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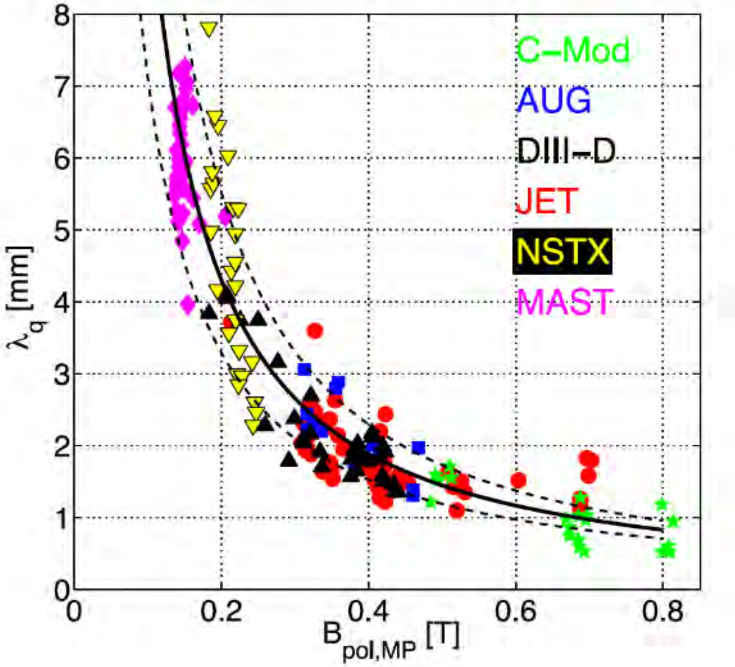
Fusion Roadmap: SOL (Scrape-Off Layer)

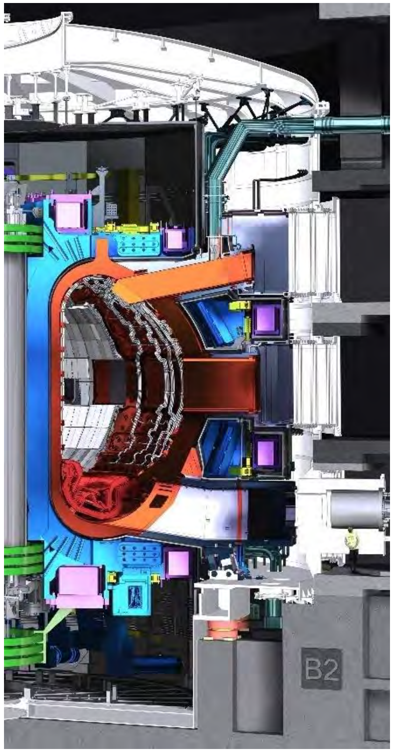
From a multimachine scaling of the upstream heat flux width the SOL power flow decay length scales as: $\lambda_q \propto B_{pol}^{-1}$ and does not depend on R

$$\text{Power flux } q_\vartheta = {}^{P}/_{2\pi R\lambda_q} \propto \frac{P}{R}$$

for ITER and DEMO:
$\lambda_q \approx \mathbf{1\,mm}$, P/R ≈ 15 MW/m



T.Eich. et al. NF 53 (2013) 093031

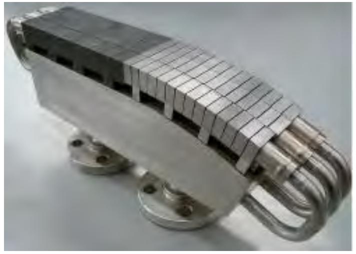


Effective surface 1-2 m^2

Power flux: tens of MW/ m^2

Fusion Roadmap: Possible solutions for heat exhaust

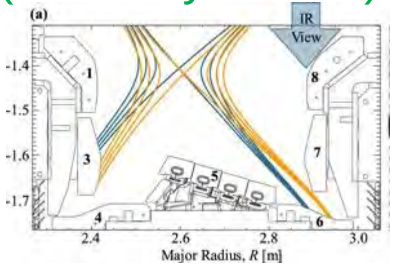
- Plasma facing components to cope with very large power fluxes
  - 10-20 MWm^{-2} achieved



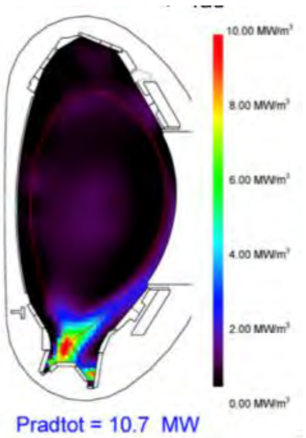
Innovative materials (Liquid Metal PFCs)

- Geometry + plasma physics

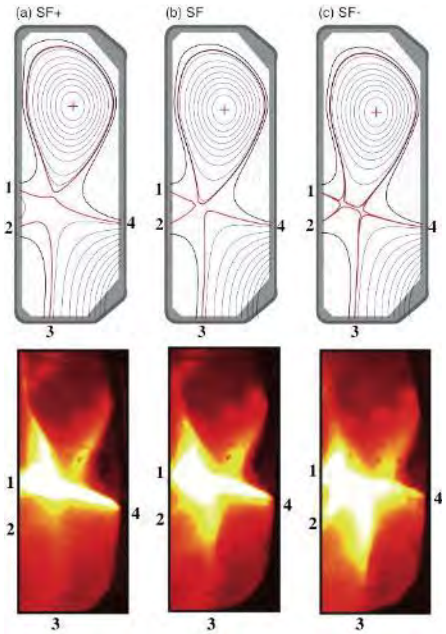
Strike point sweeping (courtesy of JET)



Remove plasma energy before it reaches PFCs → radiation



Alternative configurations (courtesy of EPFL)



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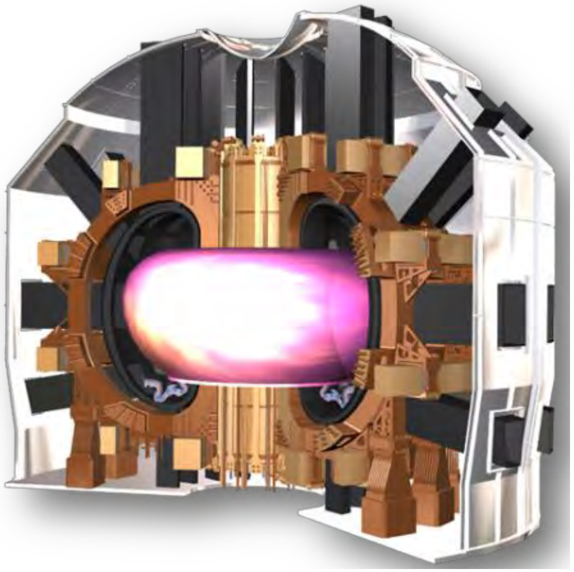
What is DTT?

DTT = Divertor Tokamak Test facility is:

- An Italian 6 T, 5.5 MA superconducting tokamak
- Under final design
- To be built in ENEA Frascati Research Centre
- Within the European roadmap to the realization of fusion energy
- To study the power exhaust problem in:
  - o An integrated environment
  - o DEMO relevant conditions



Great national and international interest:

- \>150 **M€ from national funds**
- 60 **M€ from** EUROfusion
- **250 M€ EIB loan for this research infrastructure**
- **EU and int'l** cooperations activated

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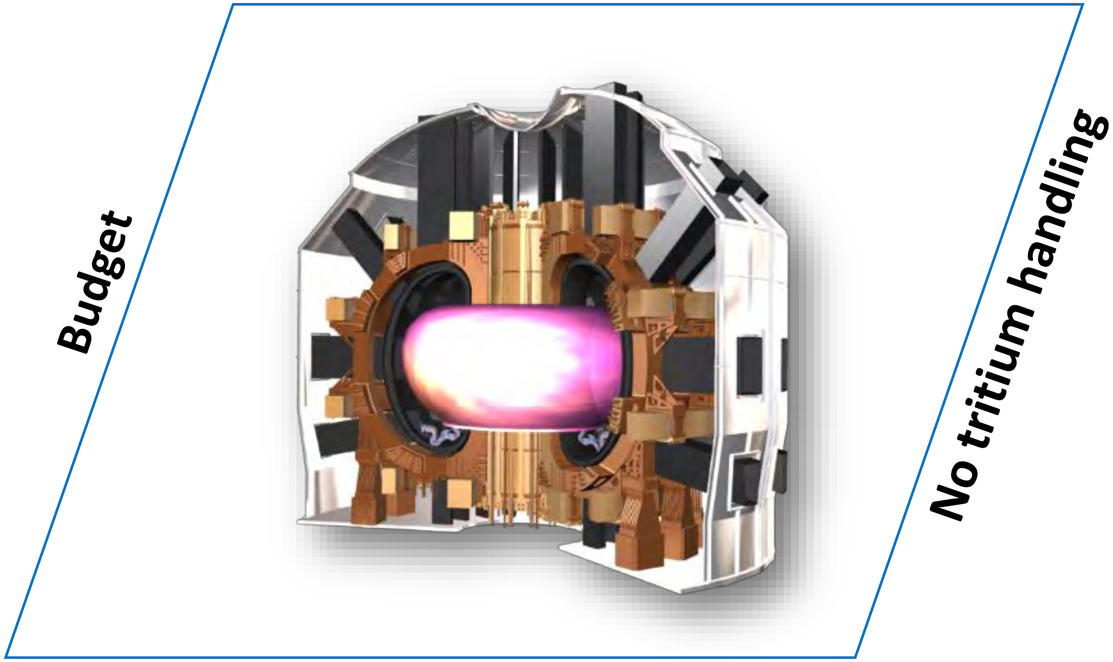
DTT: Boundary conditions in the design



Physics parameters relevant for ITER/DEMO and core – edge integration

Budget

No tritium handling

Technology choices relevant for DEMO

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How? The recipe: parameters + technology

	DTT	ITER	EU DEMO
R (m)	2.14	6.2	9.1
a (m)	0.65	2	2.93
A	3.3	3.1	3.1
I_p (MA)	5.5	15	19.6
B (T)	6	5.3	5.7
Heating P_{tot} (MW)	45	120	460
P_{sep} /R (MW/m)	15	14	17
Pulse length (s)	95	400	7600

+

Flexibility and DEMO relevant technologies

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Why DTT?

Power exhaust problem solved by:

1. Plasma facing components technology -> max heat flux presently limited to 10-20 MW/m^2
2. Geometry + Plasma shape
3. Impurity seeding to increase radiation
4. Liquid metals

DTT aims at providing a key integrated environment, relevant to DEMO, where all the previous approaches can be tested.

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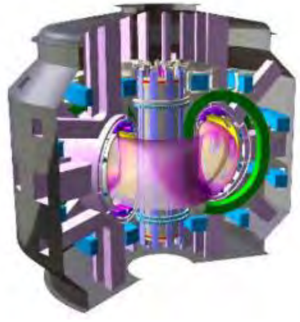
How? Some history…


DTT
Divertor Tokamak Test facility
Project Proposal

2015

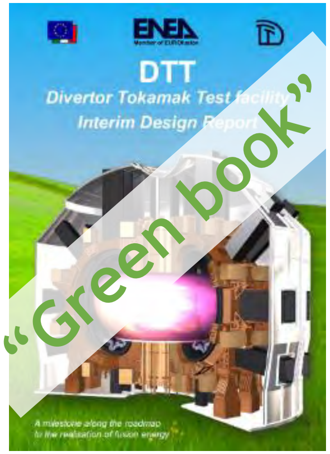

Fusion Engineering and Design

2017



30th SOFT

2018


DTT
Divertor Tokamak Test facility
Interim Design Report
A milestone along the roadmap to the realization of fusion energy

2019

- **July 2015: DTT Project proposal**
- **Apr 2018: Frascati selected as DTT site**
- **July 2018: 1st Design Review Meeting of major components**
- **End 2018: Launched first call for tender procedure (for SC strands)**
- **End 2018: Recruitment of ENEA personnel started**
- **Mar 2019: 2nd Design Review Meeting**
- **Apr 2019: DTT Interim Design Report**
- **June 2019: 3rd Design Review Meeting**
- **June 2019: Availability of EFSI portfolio guarantee for 250 M€ EIB loan**
- **Aug 2019: Partial award of SC strand contract**
- **Sept 2019: Establishment of DTT Consortium**

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DTT project management

1. Project integration organization
    a. Project team
    b. Work Breakdown Structure

2. Project meetings
    a. Technical Coordination Meeting (TCM)
    b. System Level Engineering meetings (SLE)
    c. Design Review Meeting (DRM)
    d. Project Review Meetings (PRM)

3. Project management tools
    a. Action list
    b. Plant Integration Document
    c. Project requirements documentation
    d. Document Management System
    e. Planning

DTT Project team today

BOARD

Aldo Pizzuto

Raffaele Albanese

Flavio Crisanti

Piero Martin

Full time equivalent

Board	4
Project integration	16
Components/Systems	110
Procurement office	5
Adminstrative staff	15

TASK COORDINATORS

Gian Mario Polli	Management implementation
Giuseppe Ramogida	Management implementation
Sandro Sandri	Radio-protection and licensing
Luigi Di Pace	Quality assurance
Raffaele Martone	Interim design report
Angelo A. Tuccillo	Physics tasks
Paolo Innocente	Power exhaust
Roberto Ambrosino	Plasma scenarios
Rosaria Villari	Neutronics
Aldo Di Zenobio	Magnet system
Giuseppe Di Gironimo	Mechanical components
Selanna Roccella	Thermohydraulic design
Paolo Rossi	In-vessel components
Gustavo Granucci	Heating and current drive
Alessandro Lampasi	Power supply system
Claudia Lanchi	Building
Antonio Cucchiaro	Layout
Giuseppe Mazzitelli	Auxiliary systems
Antonio Frattolillo	Cryogenic system
Alex Rydzy	Water cooling system
Marco Valisa	Diagnostics
Vincenzo Vitale	Instrumentation and control

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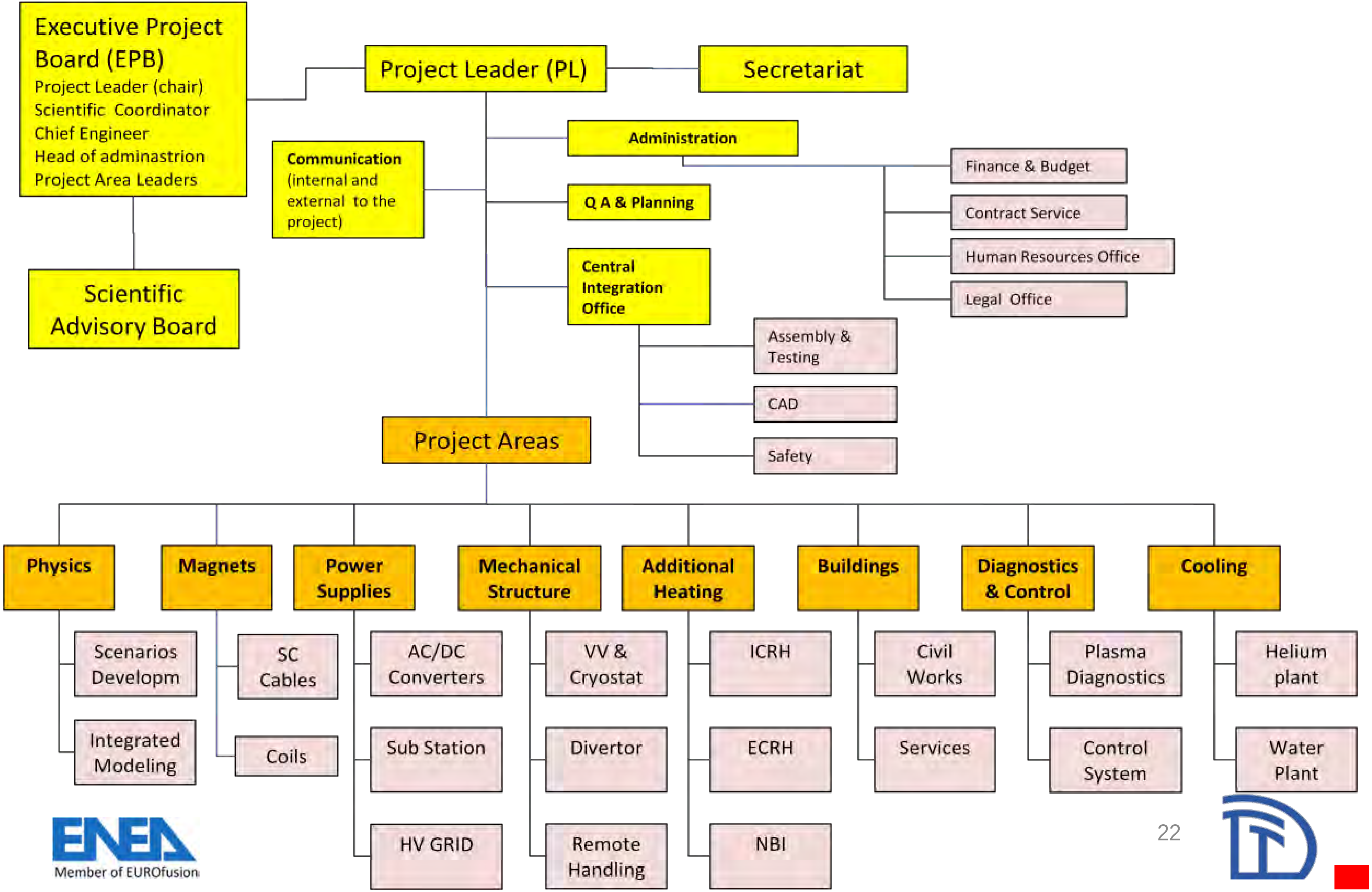
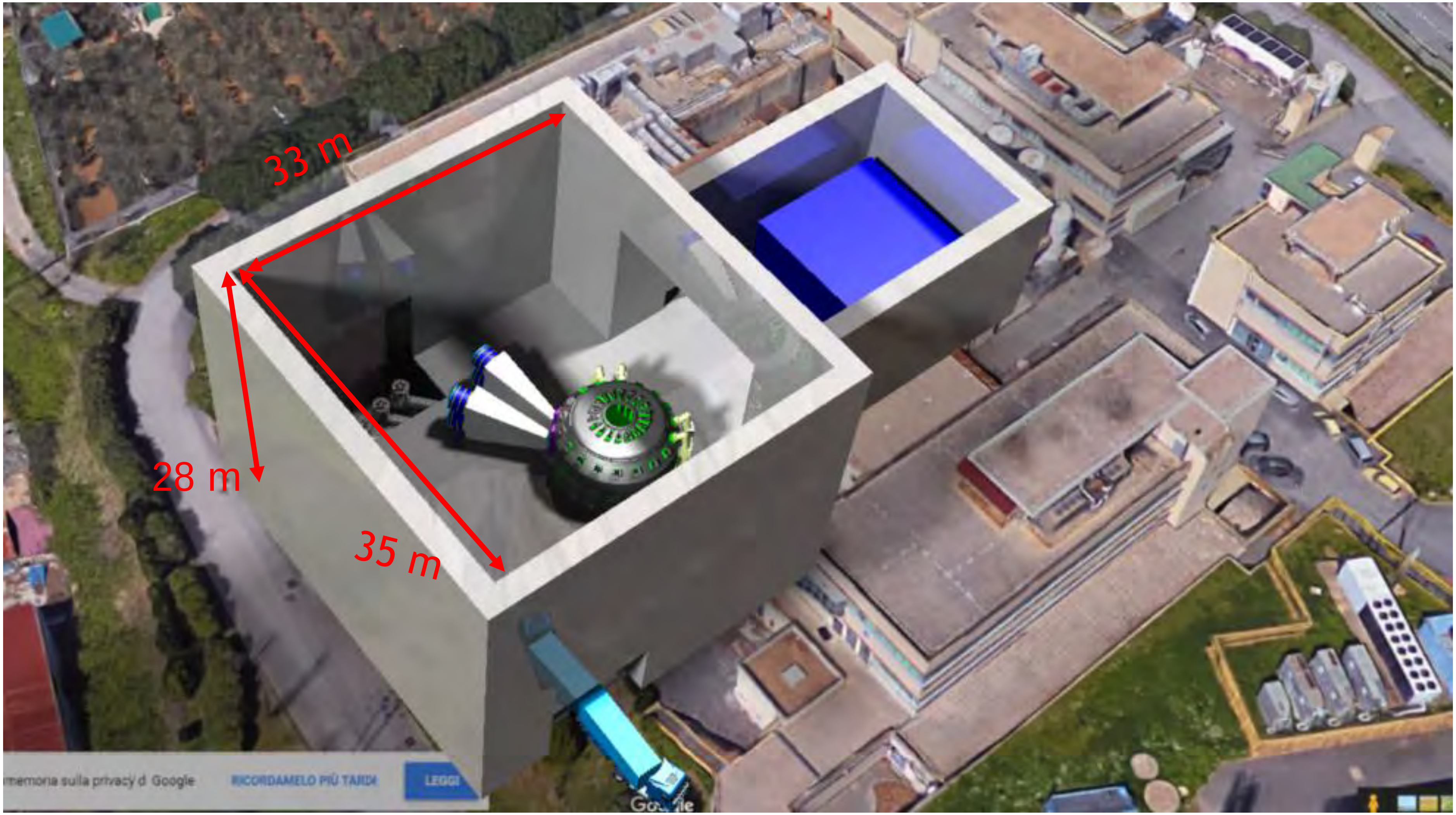
DTT Project organization in perspective



- Executive Project Board (EPB)
  - Project Leader (chair)
  - Scientific Coordinator
  - Chief Engineer
  - Head of adminastrion
  - Project Area Leaders
  - Scientific Advisory Board
- Project Leader (PL)
  - Secretariat
  - Communication (internal and external to the project)
  - Administration
    - Finance & Budget
    - Contract Service
    - Human Resources Office
    - Legal Office
  - Q A & Planning
  - Central Integration Office
    - Assembly & Testing
    - CAD
    - Safety
  - Project Areas
    - Physics
      - Scenarios Developm
      - Integrated Modeling
    - Magnets
      - SC Cables
      - Coils
    - Power Supplies
      - AC/DC Converters
      - Sub Station
      - HV GRID
    - Mechanical Structure
      - VV & Cryostat
      - Divertor
      - Remote Handling
    - Additional Heating
      - ICRH
      - ECRH
      - NBI
    - Buildings
      - Civil Works
      - Services
    - Diagnostics & Control
      - Plasma Diagnostics
      - Control System
    - Cooling
      - Helium plant
      - Water Plant

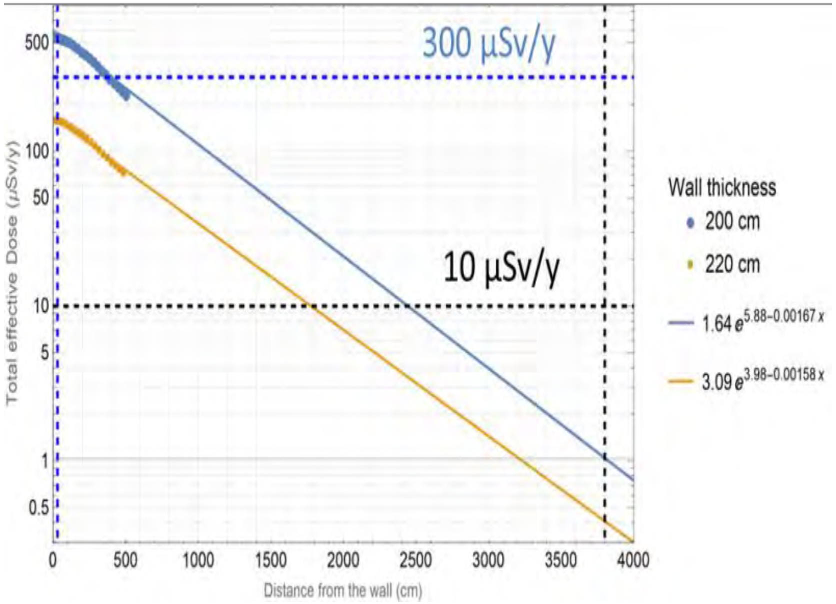
DTT layout: site – ENEA Research Center

DTT layout: site - torus hall



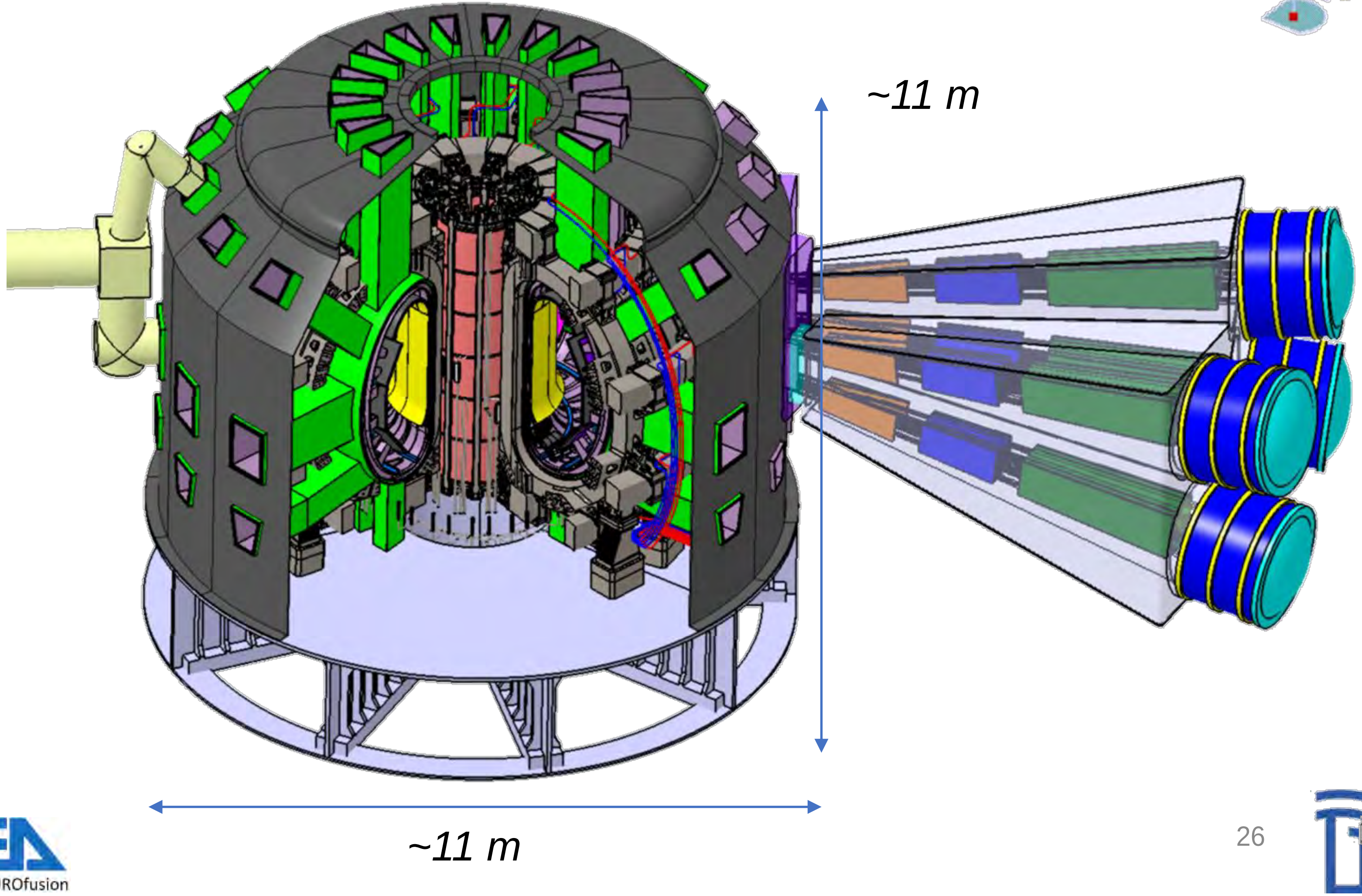
DTT layout: Neutronics

- Neutron yield is significant for a DD device (1.5×10^{17} n/s from DD and 1.5×10^{15} n/s DT)
- Radiation & loads to be taken into account for the design of DTT components
- Neutron induced radioactivity calls for remote handling
- Tokamak building walls at least 220 cm to comply with limits for professional workers (300 μSv/yr) outside the building and for public (10 μSv/yr) at about 40 m distance from the building



DTT layout: DTT machine at a glance

Item	TF	CS	PF	VV	Cryostat	NBI	Total
Mass [ton]	270	45	126	153	302	80	~ 1000



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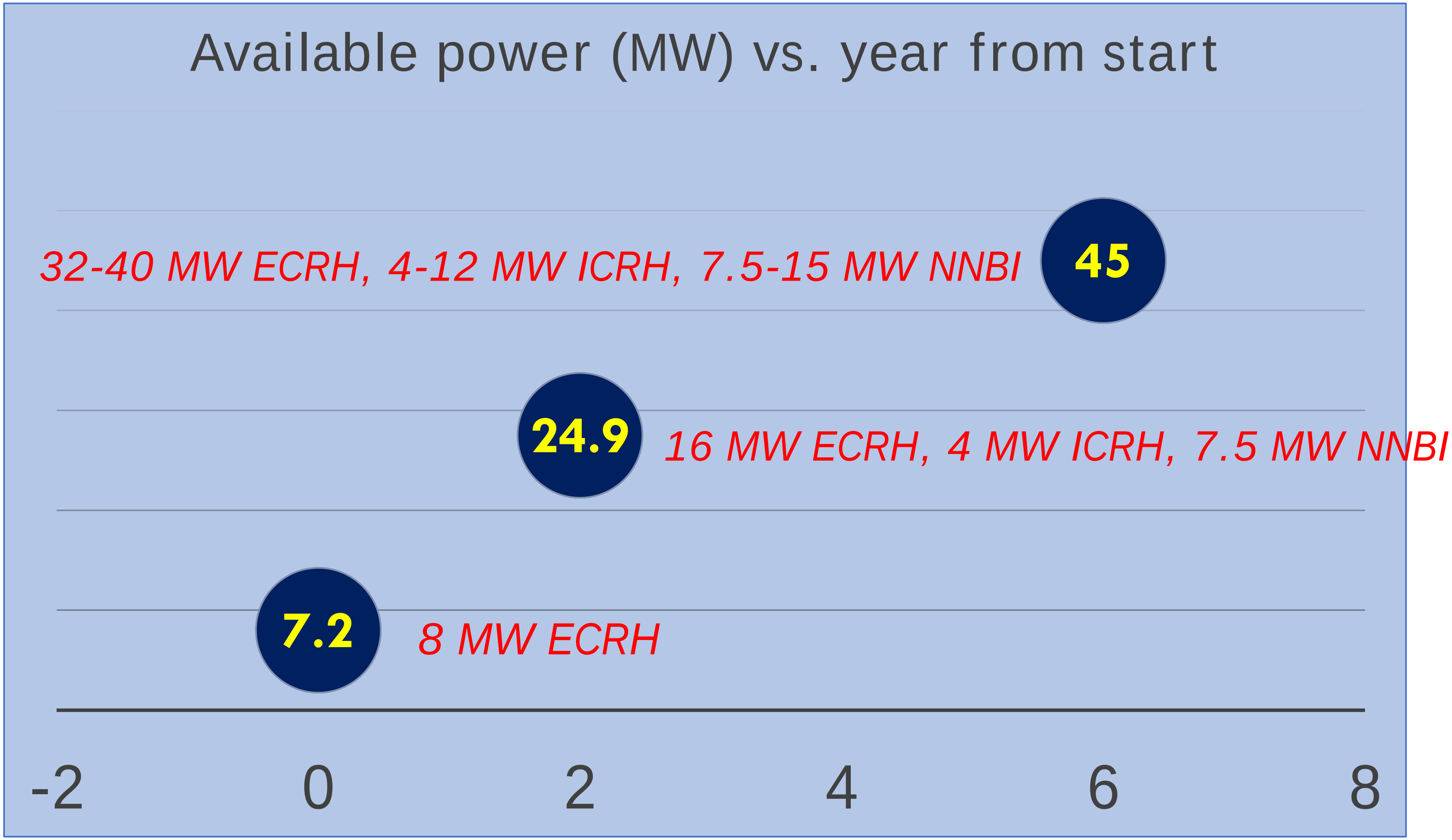
Heating system: plans



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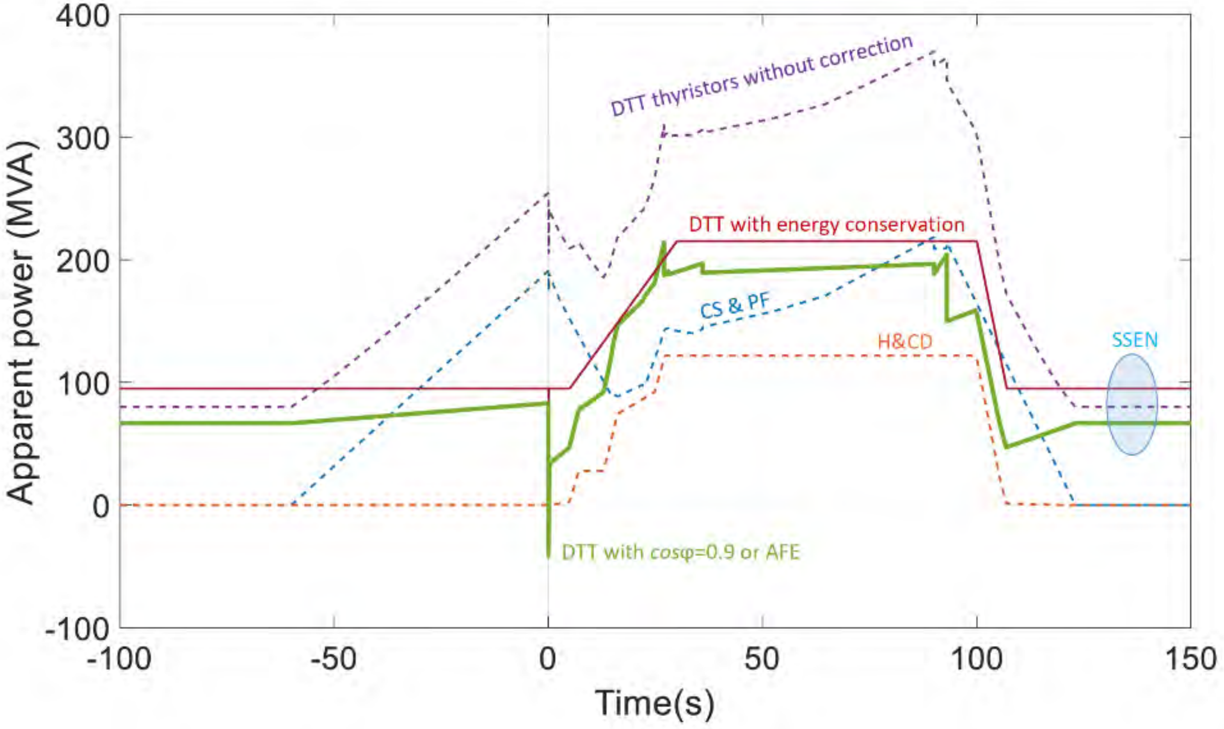
DTT components: Power supply system

The power supply system has to feed 6 superconducting modules of the central solenoid, 6 poloidal field superconducting coils, 18 toroidal field superconducting coils designed for a current up to 45 kA, the in-vessel coils for plasma fast control and vertical stabilization, the ELM/RWM coils, the negative neutral beam injectors, the electron and ion cyclotron additional heating systems, and, finally, the auxiliary systems and services.



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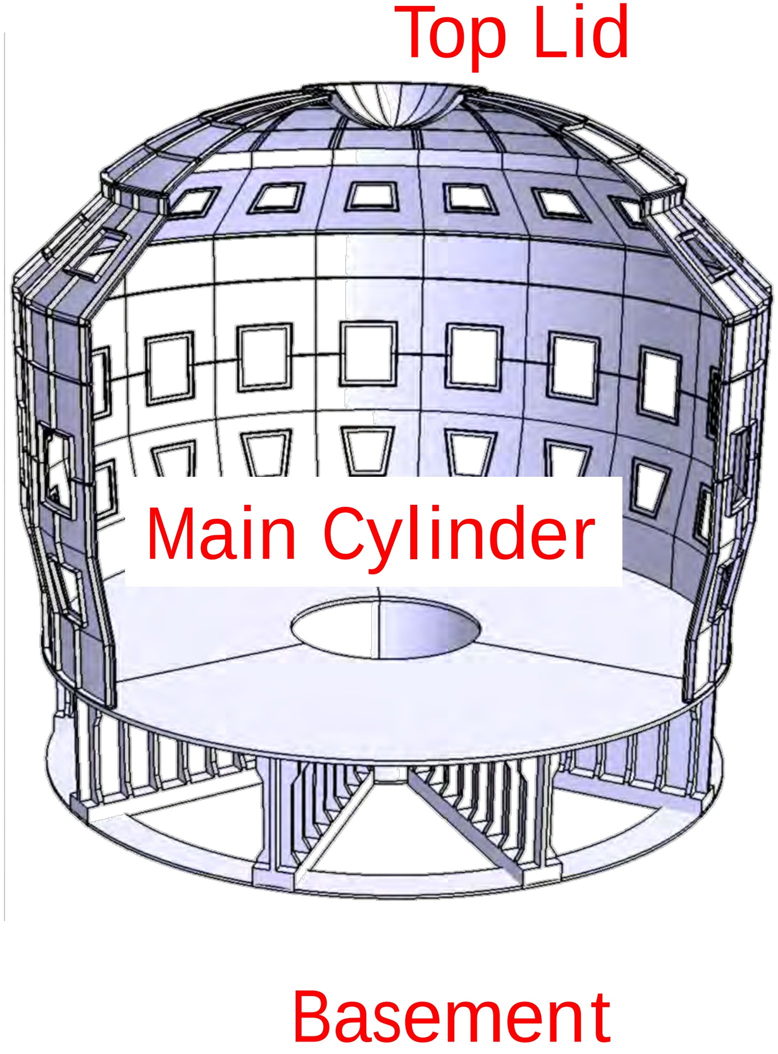
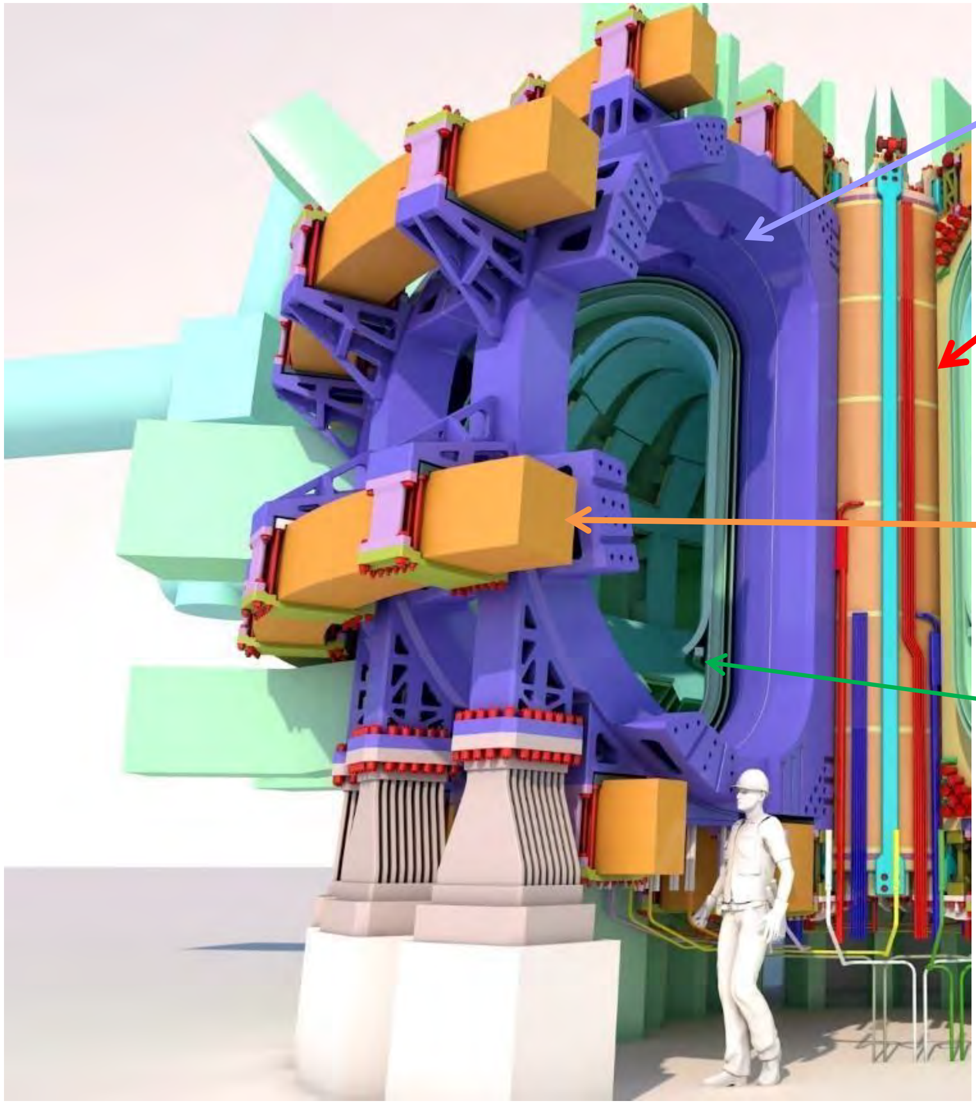
DTT Cryostat



Major diameter at equatorial section	~11.2m
Maximum height including basement	~11 m
Structural Material	SA-240 304LN
Operational pressure (Vacuum)	10^{-3} Pa
Design temperature of cryostat wall	293 K
Thickness of the cryostat walls	30 mm
Thickness of the external ribs	25 mm
Estimated Mass of CV main cylinder	~66 tons
Estimated Mass of CV top lid	~16 tons
Estimated Mass of CV basement	~220 tons

Magnet system: overview



18 Toroidal Field coils

Nb_3Sn Cable-In-Conduit Conductors

5 *Double-Pancakes* (3 regular + 2 side)

6 Central Solenoid module coils

Nb_3Sn Cable-In-Conduit Conductors

6 *independent modules*

6 Poloidal Field coils

4 NbTi Cable-In-Conduit Conductors

2 Nb_3Sn Cable-In-Conduit Conductors

6 *independent modules*

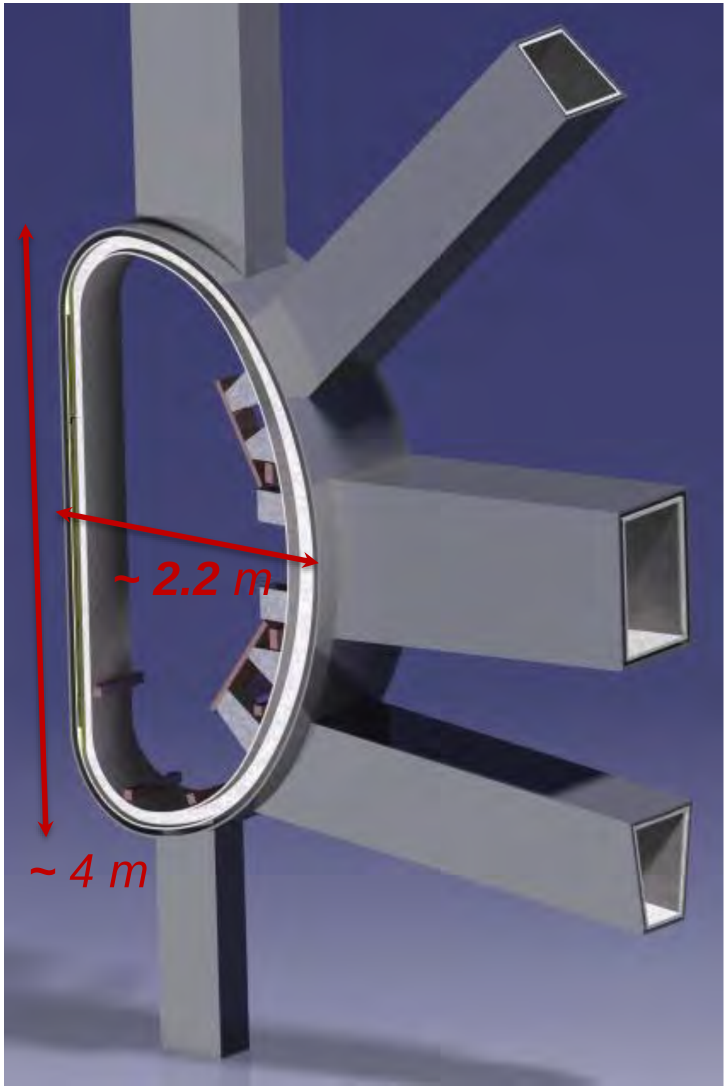
6 In-vessel Cu coils

Present design based on proven and reliable technologies

Possible future upgrade: innovative additional HTS coil to be inserted in the CS → 10% flux increase + test bed for next generation magnets

Double-walled vacuum vessel

Shell Thickness (inboard)	15 mm
Shell Thickness (outboard)	15 mm
Ports Thickness	25 mm
Ribs thickness	10 mm
Volume VV	75 m^3
Material	AISI 316-L(N)
Weight of main vessel body	36900 kg
Operating Temperature of the VV (max)	60 °C
Baking temperature of the VV (max)	110 °C

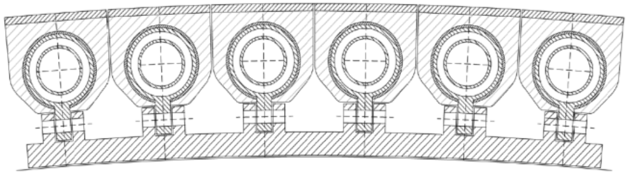


DTT components: In-vessel components

Design requirements compatibility:

- liquid lithium divertor (closed cycle)
- remote handling system
- In-vessel magnetic diagnostics
- In-vessel control coils
- DEMO Materials
- electromagnetic loads

FW inboard module: 2 modules per VV sector for RH limitations



FW outboard: plane modules plus a top part per VV sector for RH limitations and loads

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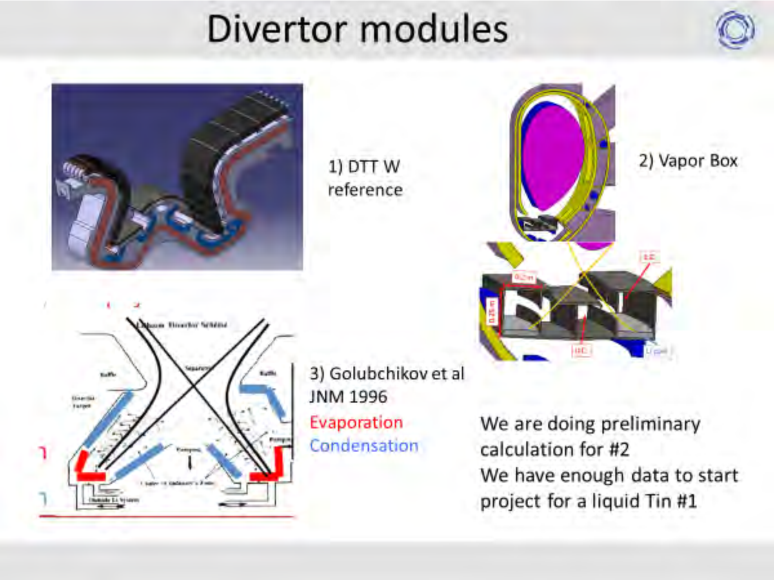
DTT divertor

DTT makes it possible to test different divertor concepts: both conventional and advanced solutions:



Divertor modules

1) DTT W reference

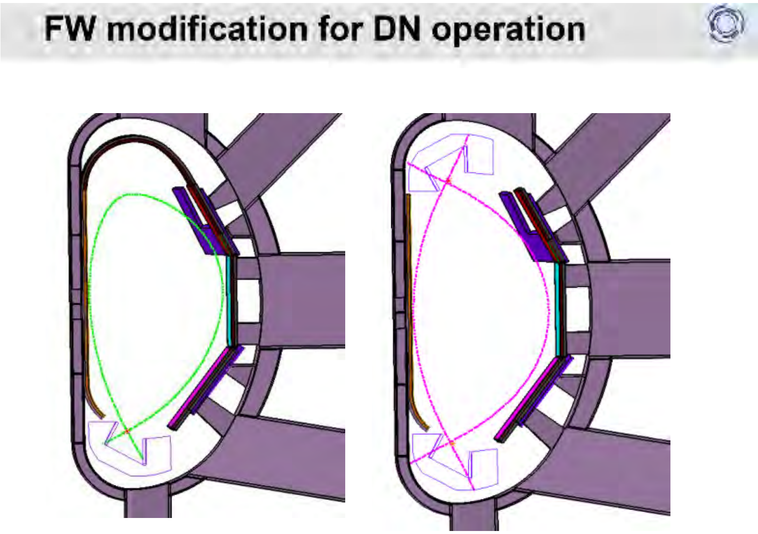
2) Vapor Box

3) Golubchikov et al JNM 1996

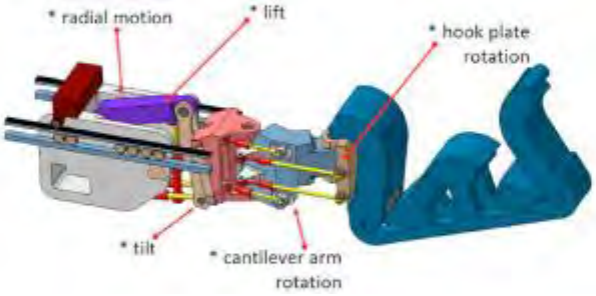
Evaporation

Condensation

We are doing preliminary calculation for #2
We have enough data to start project for a liquid Tin #1



FW modification for DN operation



The challenge is that the EUROfusion decision on the <u>first</u> divertor concept is planned around 2023 and we should be so flexible to incorporate it inside the DTT vessel

DTT divertor: agreement with EUROfusion

- The project milestones have been agreed together with the EUROfusion consortium

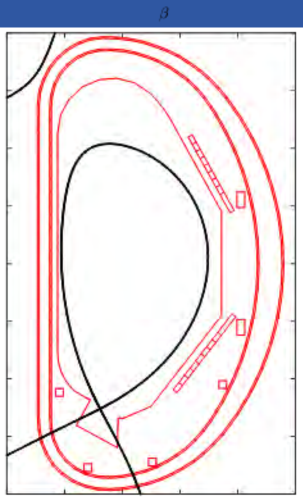
- Eurofusion will provide divertor concept and plasma scenario to adopt in the first day of operations at the beginning of 2023.

- DTT is being designed allowing the necessary flexibility to allocate the different options from now (reference scenario is SN and reference divertor is the solid one)

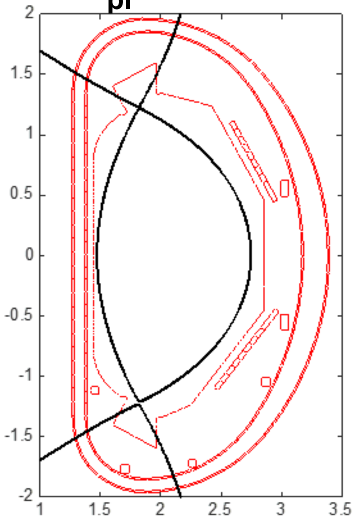
Plasma scenarios: DTT flexibility

The facility will offer **sufficient flexibility** to incorporate the best candidate divertor concept even at a later stage of its realization, on the basis of the EUROfusion studies carried out in present tokamaks involved in the PEX activities (around 2022-2023).

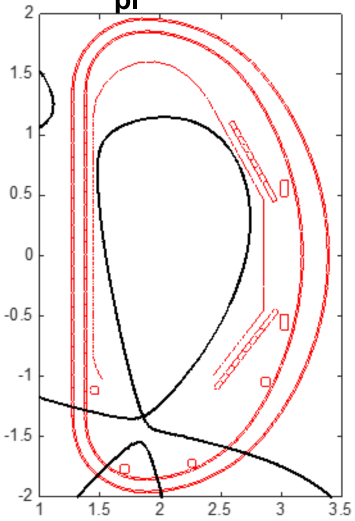
Single Null
I_{pl}=5.5 MA



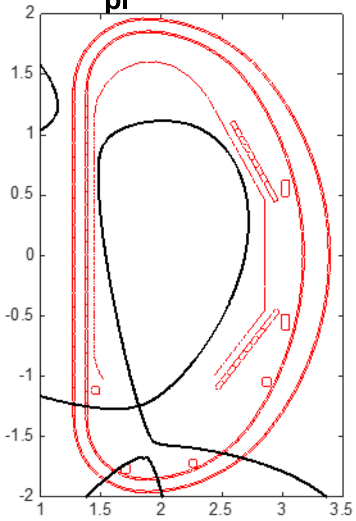
Double Null
I_{pl}=5 MA



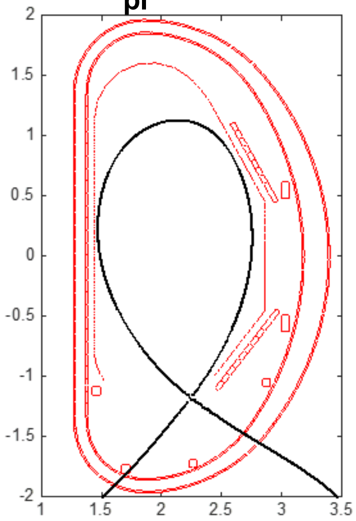
Snowflake
I_{pl}=4.5MA



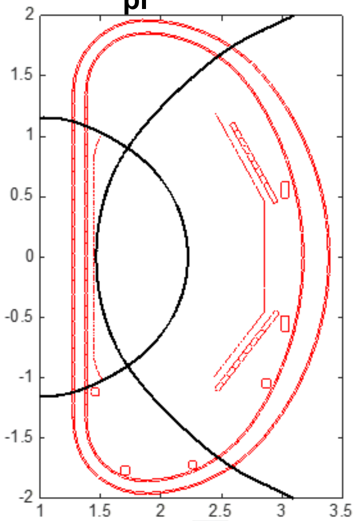
X-divertor
I_{pl}=4.5MA



Neg. triangularity
I_{pl}=5MA



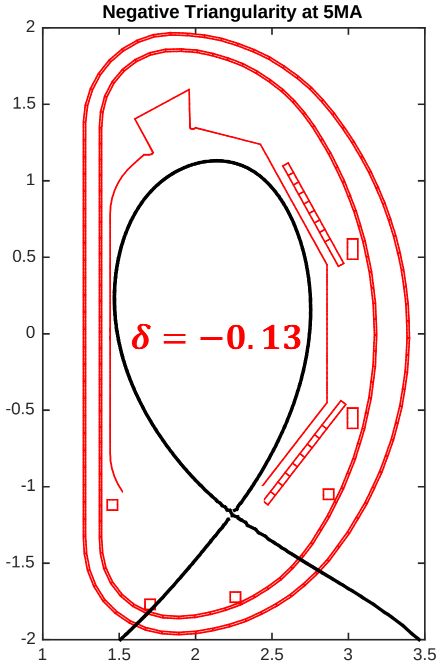
Double Super-X
I_{pl}=3MA



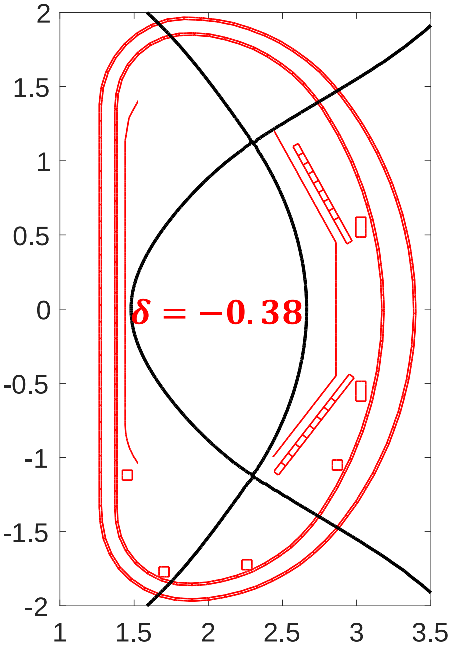
Plasma scenarios: DTT flexibility

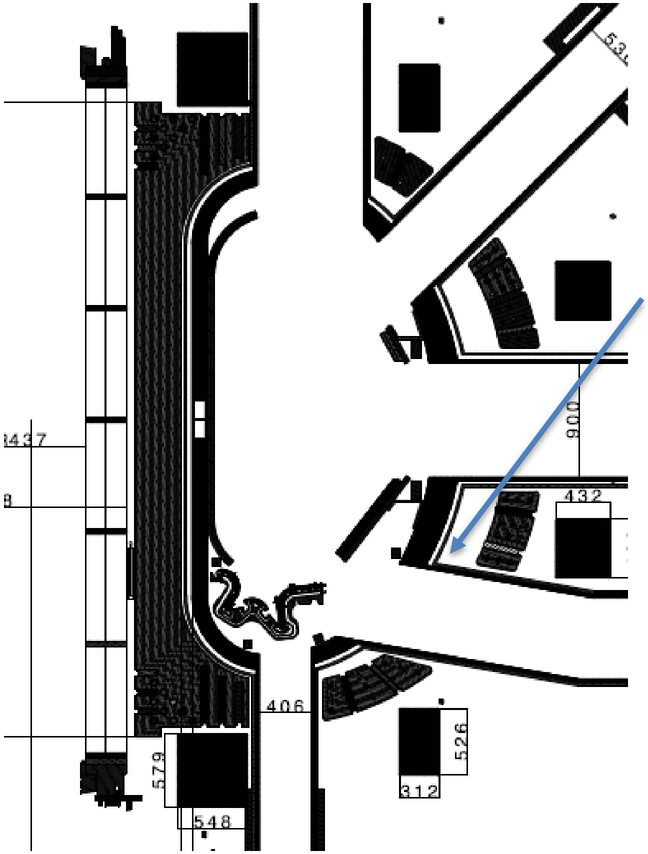
DTT poloidal field coils system allows 3.5 MA double null with negative triangularity **$\delta = -0.38$**

Neg. triagularity
Ipl=5MA



Double Neg. triagularity
Ipl=3.5MA





The space available inside the TF coils allows optimization of the first wall, the stabilizing plates and the vessel shells

Significant range for I-mode operation while avoiding H-mode

Outline

1. EU Roadmap toward fusion electricity
2. Introduction to the DTT Project
3. DTT design status
4. Planning and conclusions

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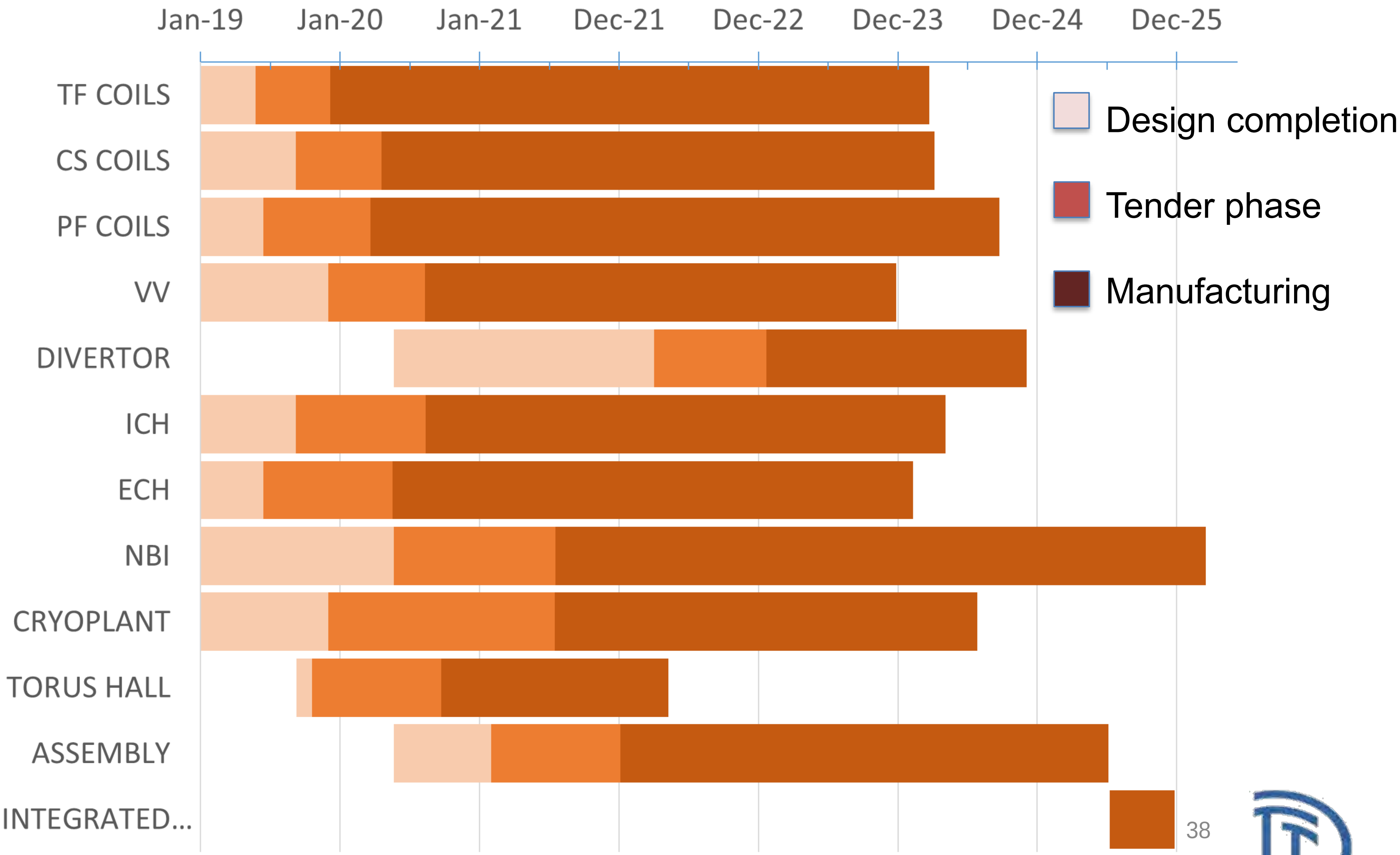
How? Planning of main components



DTT management: Main procurements and services

1.Superconducting Magnets:

Strands: Nb_3Sn and NbTi *
Cables**
Magnets (coils+casings)**
External structure

2. Vessel/In-Vessel:

Vacuum Chamber
First Wall
Divertor

3. Power Supplies:

CS, PF, TF & protection systems
Additional heating
Auxiliaries
Distribution systems

4. Heating system:

Ion Cyclotron
Electron Cyclotron
Neutral Beam Injector

5. Cryocooler

6. Control & data acquisition

7. Remote maintenance

8. Buildings

9. Assembly

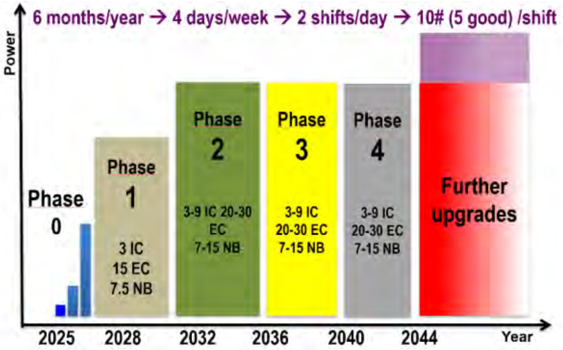
* Call for nomination + prequalification + call for tender + evaluation phases concluded: 2 lots out of 4 awarded

** Info day for the procurement of the DTT toroidal field magnets, Frascati, 8 Oct. 2019, in view of the call for tender procedures to be started soon

DTT management: Next steps

- Apr 2018: Frascati selected as DTT site
- July 2018: 1st Design Review Meeting of major components
- End 2018: Launched first call for tender procedure (for SC strands)
- End 2018: Recruitment of ENEA personnel started
- Mar 2019: 2nd Design Review Meeting
- Apr 2019: DTT Interim Design Report
- June 2019: 3rd Design Review Meeting
- June 2019: Availability of EFSI portfolio guarantee for **250 M€ EIB loan**
- Aug 2019: Partial award of SC strand contract
- Sept 2019: Establishment of DTT Consortium
- End 2022: 1/3 of the machine completed
  (6 TFCs, 3 VV sectors, cryostat base, main hall, …)
- 2022-2023: Decision on divertor configuration (PEX)
- 2022-2025: Assembly and commissioning
- End 2025: First experimental plasma: 3T, 2 MA

- 2025 – : Operations



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Concluding remarks

- From 2015 to 2018 the DTT roles & objectives fixed and baseline provided
- From October 2018 organization set-up
- In September 2019 DTT Consortium established
- Concerning design activity:
  - From September 2018 ENEA Frascati chosen for the DTT site
  - Design integration of all components is progressing in accordance with priorities defined by the detailed planning
  - Toroidal Field coil design almost completed: tender expected end-2019
- First plasma planned end-2025
- DTT open to collaboration (cooperation agreements already established with EUROfusion as well as outside EU)
- For further info see Interim Design Report ("Green book"):

www.dtt-project.enea.it/downloads/DTT_IDR_2019_WEB.pdf

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Further information

For further information:

www.dtt-project.enea.it

fsn@enea.it

raffaele.albanese@unina.it

The DTT Project

One of the main challenges in the [illegible] is to design a heat and power exhaust system able to withstand the large loads expected in the divertor of a DEMO fusion power plant.

News

- 2 May 2019 - Signed Memorandum of Understanding between ENEA and Eni finalised to the DTT Realization
- 11 April 2019 - Released the DTT Interim Design Report ("Green Book")
- 13 e 14 March 2019 - 2° DTT Design Review Meeting - C.R. ENEA Frascati (Aula B. Brunelli)

All News

Login Form

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The Nuclear Fusion

Currently nuclear fusion is deemed as one of the options useful to ensure a large-scale, safe, environmentally-friendly and virtually inexhaustible source of energy.

Further information

DTT Site
Via E. Fermi, 45
00044 Frascati (Rome) - Italy

Legal Notes
Privacy

[illegible] Data in the format of Portal EU MERIL
Contacts

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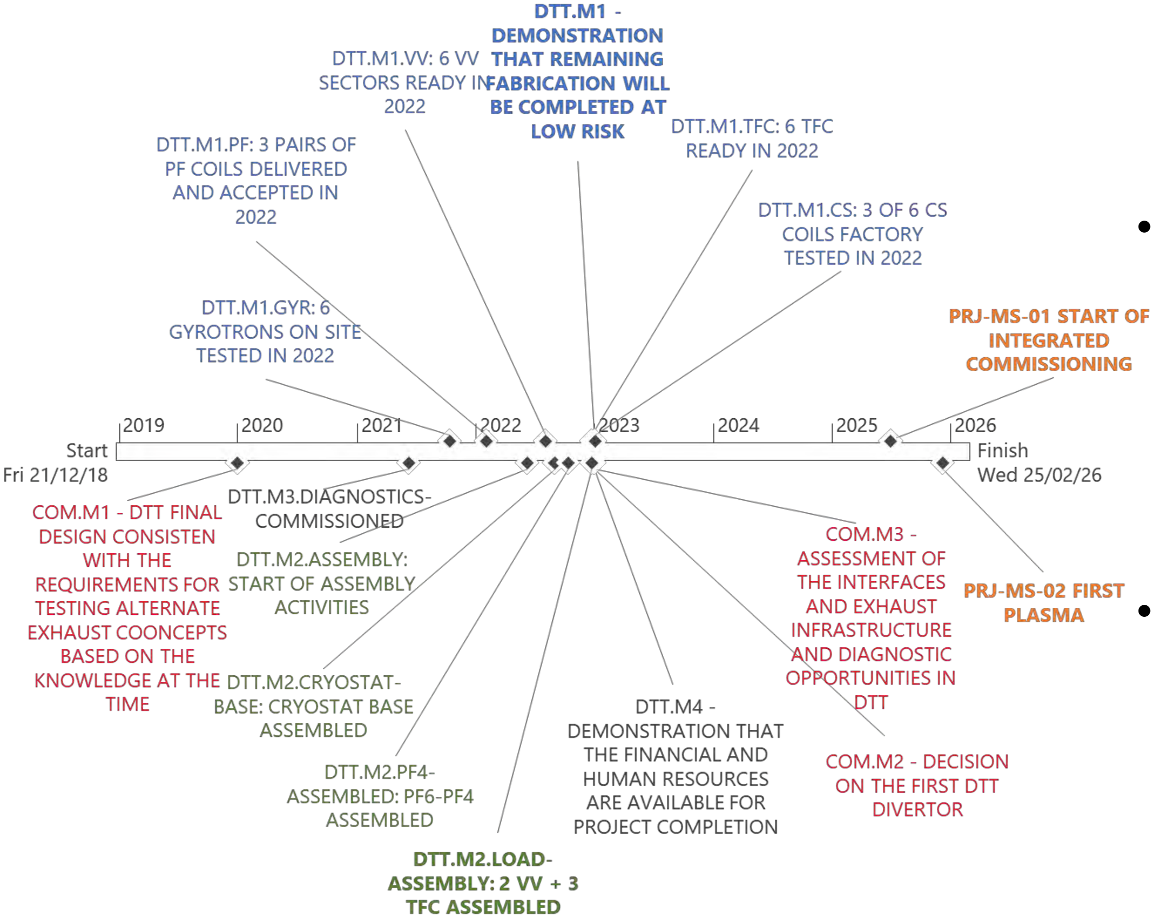
Extra slides

- EXTRA SLIDES

DTT divertor: agreement with EUROfusion



DTT.M1 - DEMONSTRATION THAT REMAINING FABRICATION WILL BE COMPLETED AT LOW RISK

DTT.M1.VV: 6 VV SECTORS READY IN 2022

DTT.M1.PF: 3 PAIRS OF PF COILS DELIVERED AND ACCEPTED IN 2022

DTT.M1.TFC: 6 TFC READY IN 2022

DTT.M1.CS: 3 OF 6 CS COILS FACTORY TESTED IN 2022

DTT.M1.GYR: 6 GYROTRONS ON SITE TESTED IN 2022

PRJ-MS-01 START OF INTEGRATED COMMISSIONING

2019

2020

2021

2022

2023

2024

2025

2026

Start
Fri 21/12/18

Finish
Wed 25/02/26

COM.M1 - DTT FINAL DESIGN CONSISTEN WITH THE REQUIREMENTS FOR TESTING ALTERNATE EXHAUST COONCEPTS BASED ON THE KNOWLEDGE AT THE TIME

DTT.M3.DIAGNOSTICS-COMMISSIONED

DTT.M2.ASSEMBLY: START OF ASSEMBLY ACTIVITIES

DTT.M2.CRYOSTAT-BASE: CRYOSTAT BASE ASSEMBLED

DTT.M2.PF4-ASSEMBLED: PF6-PF4 ASSEMBLED

DTT.M2.LOAD-ASSEMBLY: 2 VV + 3 TFC ASSEMBLED

DTT.M4 - DEMONSTRATION THAT THE FINANCIAL AND HUMAN RESOURCES ARE AVAILABLE FOR PROJECT COMPLETION

COM.M3 - ASSESSMENT OF THE INTERFACES AND EXHAUST INFRASTRUCTURE AND DIAGNOSTIC OPPORTUNITIES IN DTT

COM.M2 - DECISION ON THE FIRST DTT DIVERTOR

PRJ-MS-02 FIRST PLASMA

- Project milestones and have been agreed together with EUROFUSION consortium
- Eurofusion will provide divertor concept and plasma scenario to adopt in the first day of operations at the beginning of 2023.
- DTT is being designed allowing the necessary flexibility to allocate the different options from now (reference scenario is SN and reference divertor is the solid one)

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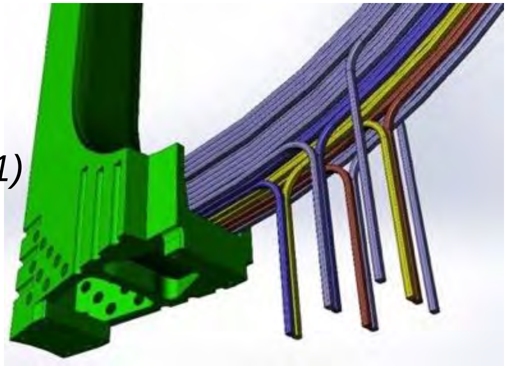
DTT : Toroidal Field coils

- CICC operating current: 44.8 KA
- B_{peak}: 11.9 T
- Double pancake-winding: 80 turns

(3 Regular pancakes 9x2 and 2 Side panc. 9x1-4x1)

- Max. hydraulic length: 110 m
- Cable: 504 / 144 S.c./Cu wires
- ΔT_{margin} > 1.4 K
- Jacket: 2 mm 316 LN
- Turn insulation: Fiber-glass + resin

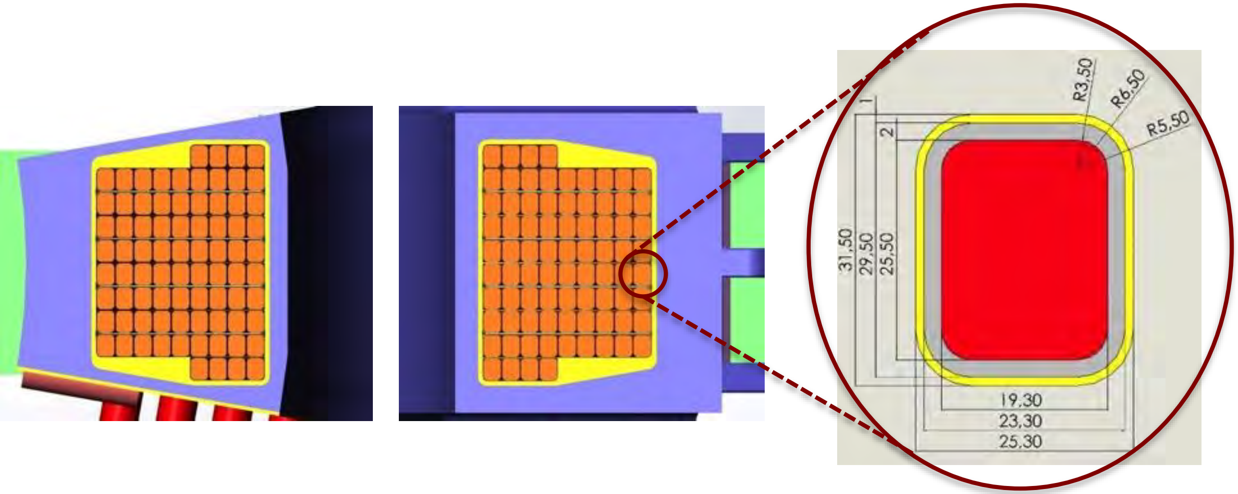


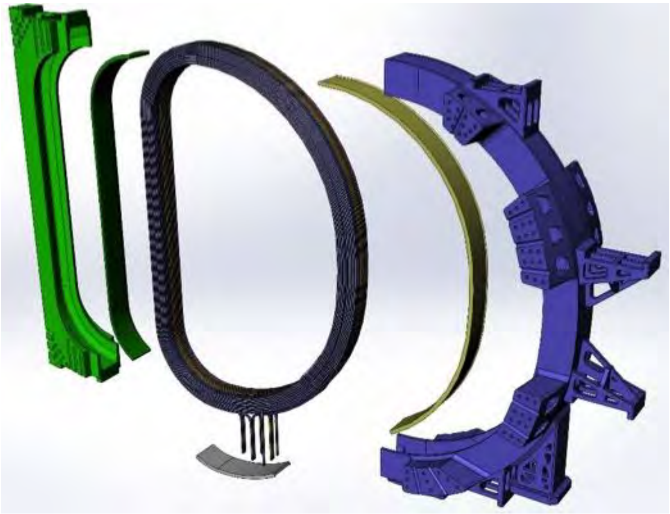
Overall TF energy: 2 GJ

L (1 TF coil): 41 mH

TF coil height ≈ 6 m

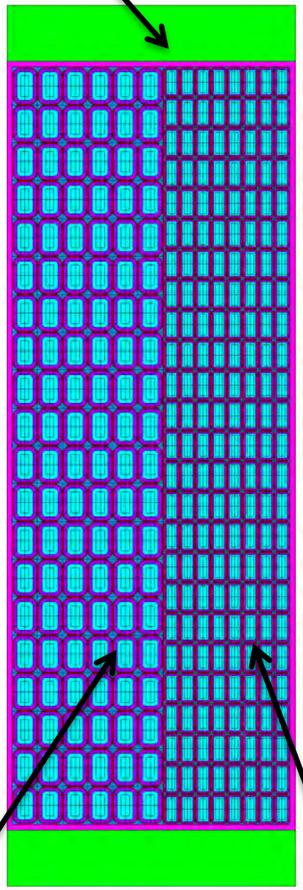
TF coil width ≈ 3.2 m

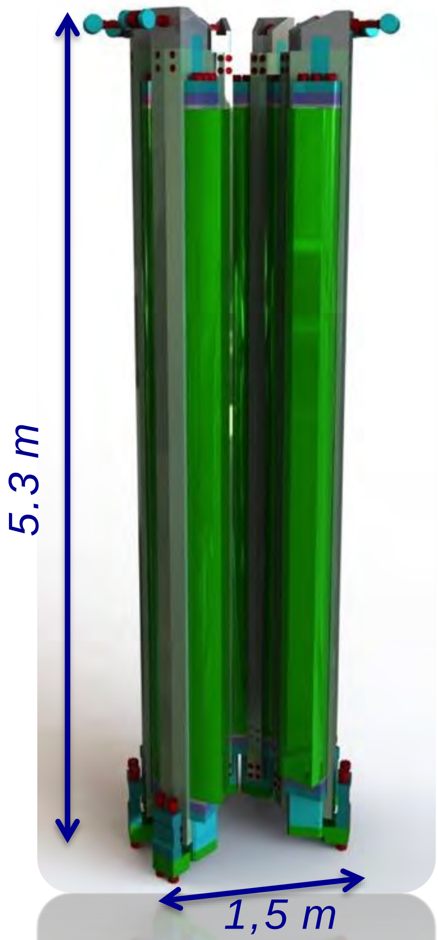




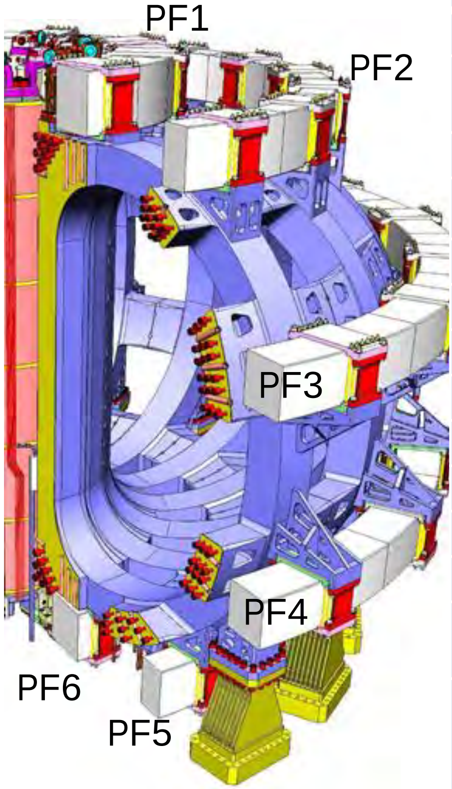
DTT: Central Solenoid

	HF (inner) section	LF (outer) section
CICC Op. Current	29.04 kA	
Peak field	13.4 T	8.5 T
# s.c. wires	648	180
Steel jacket thickn.	4.1 mm	2.0 mm
Turn insulation	1.0 mm (glass-fiber + resin)	
Ground insulation	6.0 mm (glass-fiber + resin + Kapton)	
J_{ENG} (A/mm^2)	26.2	52.2
# layers x turns	6 x 20	8 x 25
Magnetic Fux	16.2 Wb	
Coil height	**874mm** (CS1U,L) / **890mm** (CS2U,L; CS3U,L)	
Coil inner/outer radius	443 mm / 755 mm	
Target ΔT_{margin}	> 1.0 K	
Max. voltage	3.5 kV *(terminal to terminal)*	

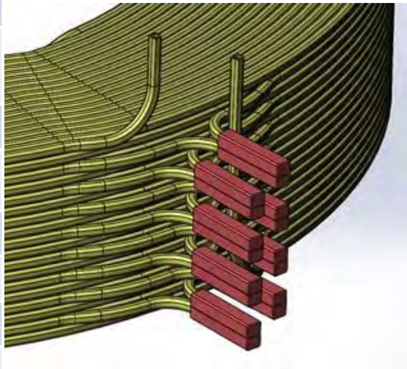




DTT: Poloidal Field coils



COIL	PF1/6	PF2/5	PF3/4
Bmax (T) (input data)	9.1	4.4	5.4
# turns (radial x vertical)	20 x 18	10 x 16	14 x 14
I_{op} max (kA)	28.3	27.1	28.6
ΔT_{margin} (T_{op}: 4.5K)	1.8	1.8	1.7
Hydraulic length (m)	178	193	381
L (H)	0.454	0.298	0.690
V_{max} (V)	2150	1350	3290
Weight (ton)	15	16	28
Delay / discharge const.	1.5 s / 6 s		
CICC dimensions (mm)	23.4 x 28.3	26.4 x 27.7	26.4 x 27.7
Jacket thickness (mm)	3.0	3.0	3.0
Central channel (in/out)	5 / 7 mm	5 / 7 mm	5 / 7 mm
# SC (1.9 Cu/noCu) / Cu strands; 0.82 mm	180 *(Nb_3Sn)* / 216	162 *(NbTi)* / 324	324 *(NbTi)* / 162
			



PF Double-pancake winding and joint boxes

How? DTT project management

1. Project integration organization
    a. Project team
    b. Work Breakdown Structure

2. Project meetings
    a. Technical Coordination Meeting (TCM)
    b. System Level Engineering meetings (SLE)
    c. Design Review Meeting (DRM)
    d. Project Review Meetings (PRM)

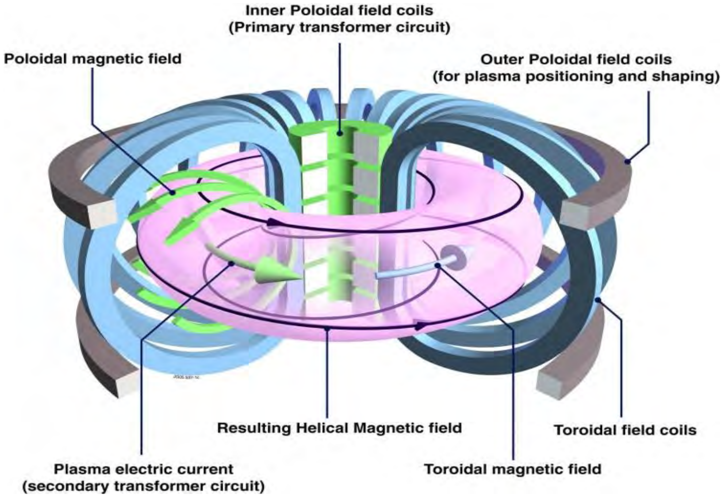
3. Project management tools
    a. Action list
    b. Plant Integration Document
    c. Project requirements documentation
    d. Document Management System
    e. Planning

FUSION: How

Tokamaks are among the most complex machines ever conceived by the mankind:

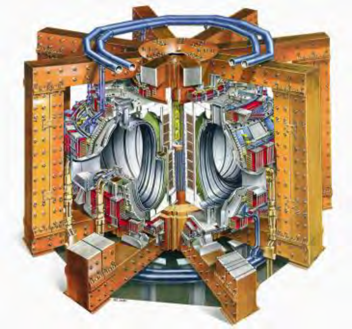
- **Coexistence of temperatures close to highest and lowest values in the universe**
- **Nuclear environment, high magnetic fields, vacuum requirements, large heat fluxes**
- **All fields of science and engineering involved: large teams needed**

Wesson J., "Tokamak", Oxford University Press 2011 – 4th Edition



Schematic view
(courtesy of EUROfusion)

Tokamaks




The JET project
— design proposal

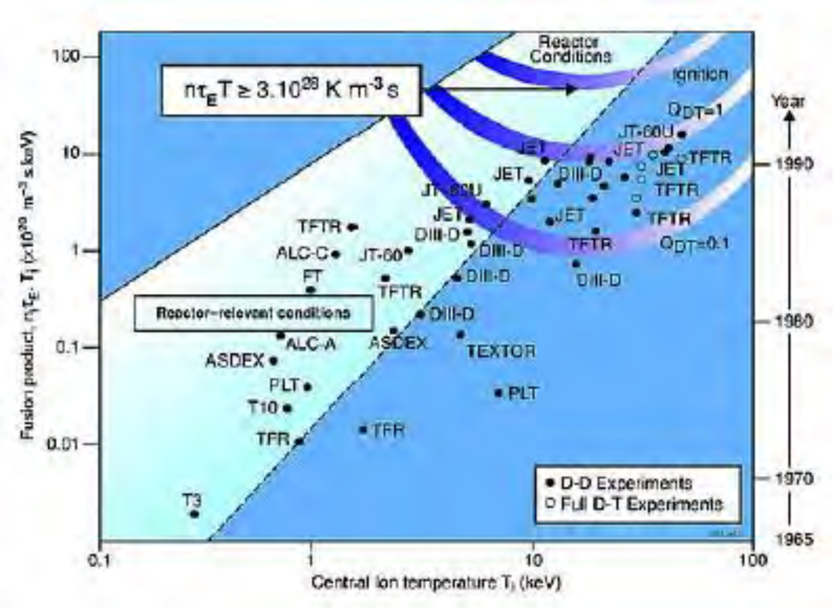

NEXT EUROPEAN TORUS
STATUS REPORT
DECEMBER 1985

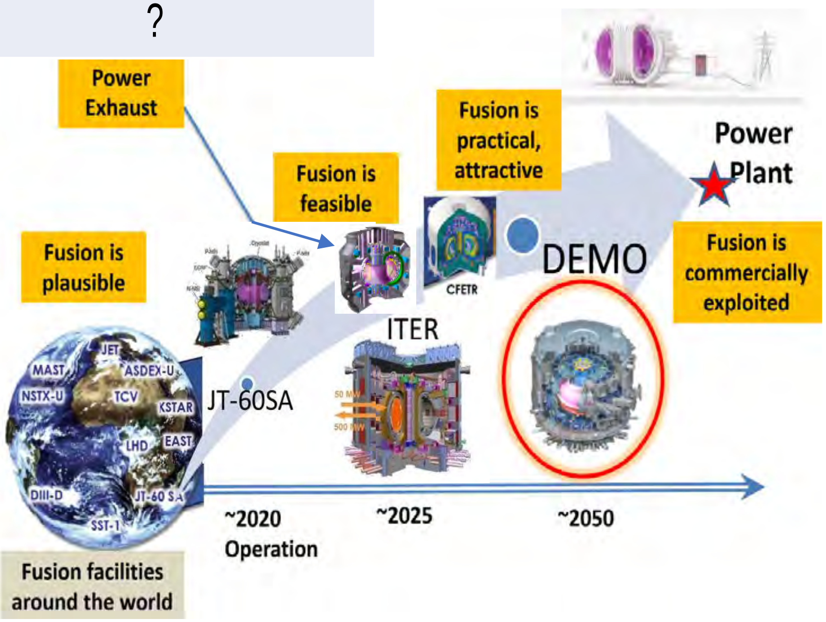

ITER CONCEPT DEFINITION
VOL.1


DTT
Divertor Tokamak Test facility
Interim Design Report

FUSION ELECTRICITY: When

	Military weapon	Commercial reactor
Fission	1945	1956-57
Fusion	1951-52	?





Power Exhaust

Fusion is plausible

Fusion is feasible

Fusion is practical, attractive

Power Plant

Fusion is commercially exploited

JT-60SA

ITER

DEMO

~2020 Operation

~2025

~2050

Fusion facilities around the world

Courtesy of EUROfusion

Member of EUROfusion