FEC2025

2758: The Divertor Tokamak Test Facility: Machine design construction and commissioning
2939: Design and qualification activity of the first divertor of the Divertor Tokamak Test Facility

GIAN MARIO POLLI & SELANNA ROCCELLA

DTT S.c.a r.l., ENEA NUC, C.R.Frascati

On behalf of the colleagues contributing to DTT project

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DTT Consortium (DTT S.C.a r.l. Via E.Fermi 45 I-00044 Frascati (Roma) Italy)

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Outline

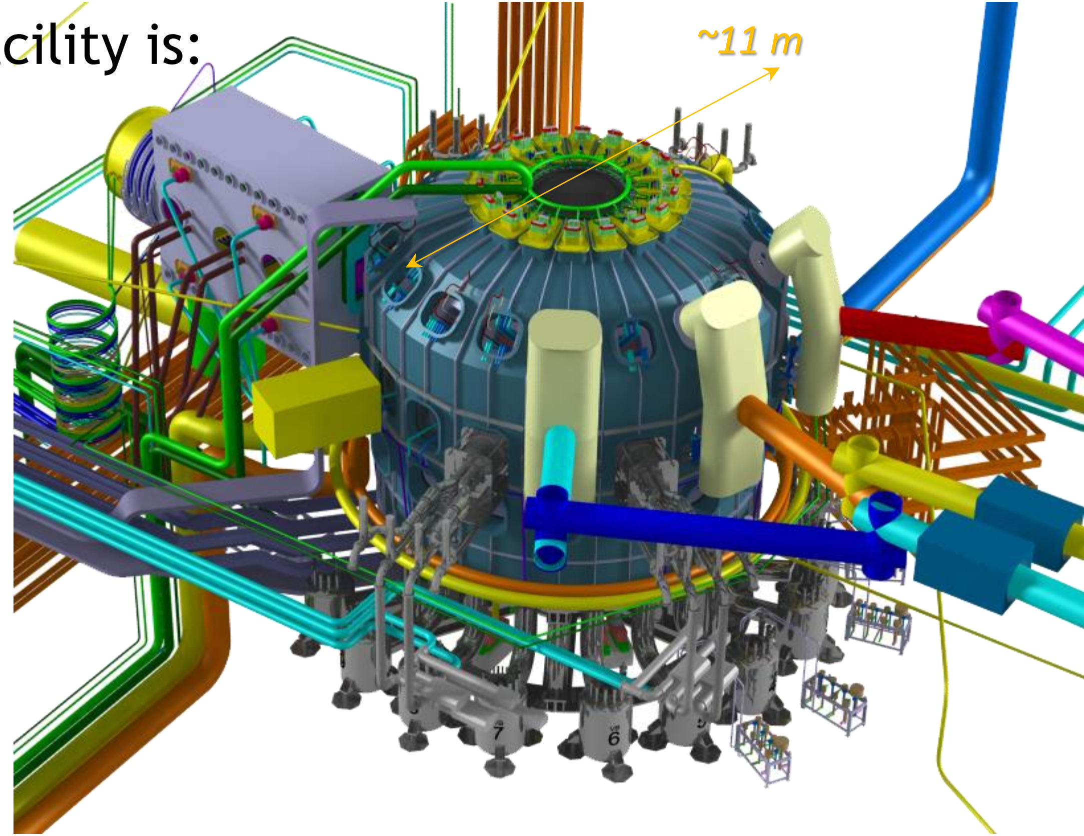
- Introduction
- Status of DTT tokamak design and construction
- Divertor system qualification and construction plan
- Concluding remarks

What's DTT?

DTT = Divertor Tokamak Test facility is:

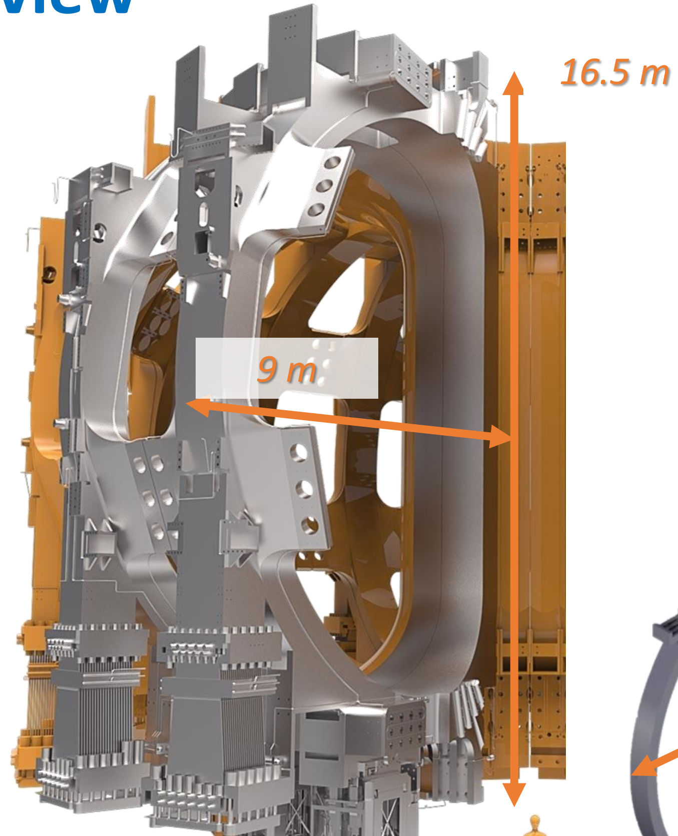
- a **breakeven-class** tokamak,
- **fully superconducting** to allow pulses of the order of 100s,
- with **water cooled, tungsten plasma facing components**
- designed to be **flexible**

• For the development of **credible solutions** for the **effective and reliable management of the power exhausts**

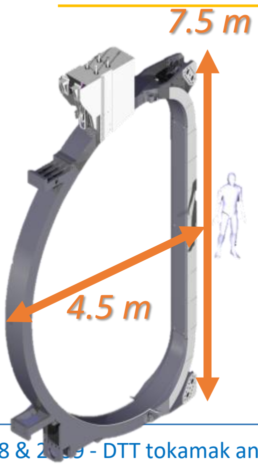


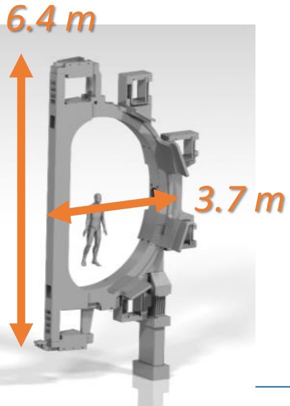
DTT compared to other machines: an engineering point of view

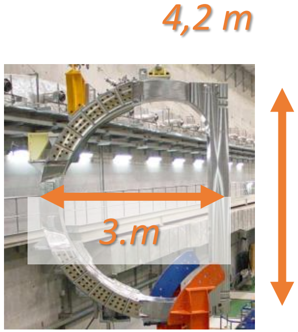
	ITER TFC	JT-60SA TFC	DTT TFC	KSTAR TFC	EAST TFC
Material	**Nb_3Sn**	NbTi	**Nb_3Sn**	**Nb_3Sn**	NbTi
B max [T] on conductor	**11,8**	5,65	**11,9**	7,2	5,8
I_turn [kA]	68	25,7	**42,5**	**35,2**	14,3
Turns	134	**72**	**84**	56	130
Major radius [m]	6,2	3,0	**2,19**	**1,8**	1,7
B max @ R [T]	**5,3**	2,3	**5,85**	3,5	3,5

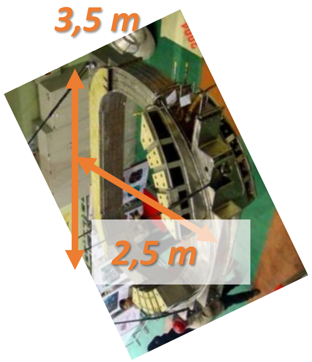


Courtesy of ITER Organization









DTT compared to other machines: a physics point of view

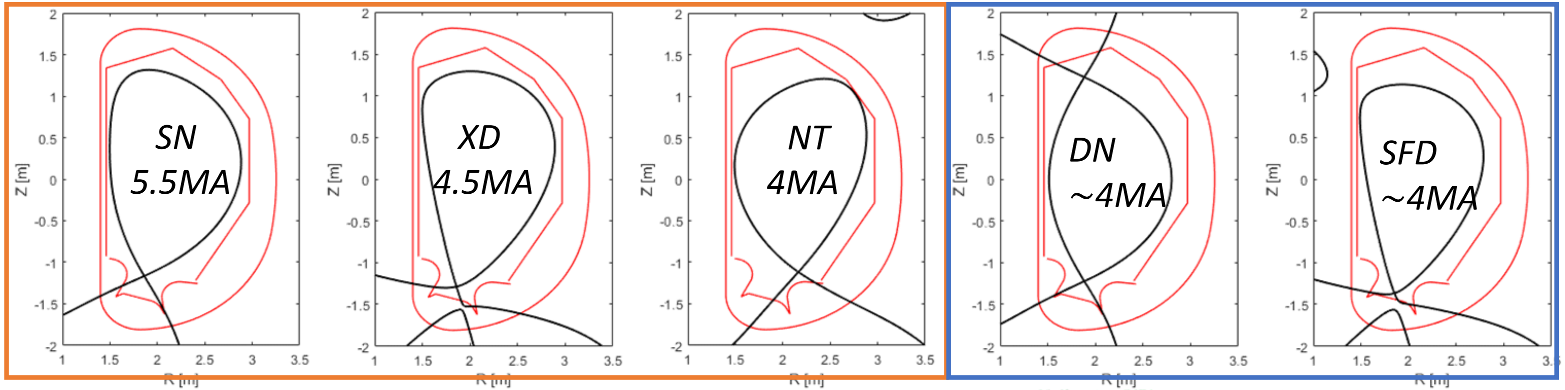
DTT aims at providing a **<u>unique, flexible, integrated environment, relevant to DEMO</u>**, where to test divertors with:

- novel HHF components;
- in a highly radiative plasma scenario;
- developing alternative plasma scenario shapes;
- utilizing liquid metals

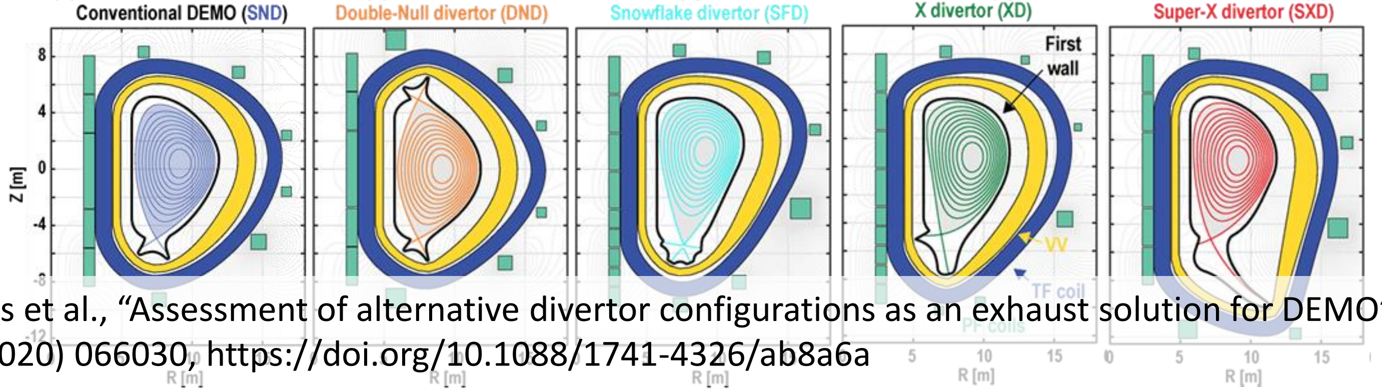
	AUG	JET	DTT	JT60-SA	ITER	DEMO
R (m)	1.65	3.0	2.19	2.96	6.2	9
a(m)	0.5	1.0	0.70	1.18	2.0	2.9
Ip (MA)	1.6	4	5.5	5.5	15	19.5
B_T (T)	3.1	3.45	5.85	2.25	5.3	5.7
Vp (m^3)	13	80	28	131	853	2218
<n> (10^{20} m^{-3})	1	1	1.8	0.56	1.0	0.8
P_{Tot} (MW)	27	40	45	41	150	450
P_{SOL} (MW)	**22**	**32**	**33**	**32**	**120**	**150**
P_{SOL}/R (MW/m)	**13**	**11**	**15**	**11**	**19.3**	**17**
P_{SOL}B/R (MW*T/m)	**40**	**37**	**88**	**24**	**102**	**99**
τ_E (s)	*	*	0.42	0.48	8.5	3.4
<T> (keV)	2	5	6.2	6.3	8.5	12.7
β (%)	*	*	3.1	3.1	2.2	2.5
ν*(10^{-2})	*	3.5	1.8	1.8	3.8	2.1
ρ*(10^{-2})	*	2.2	2.7	2.0	0.9	0.8

DTT scenarios flexibility

DTT reference scenarios



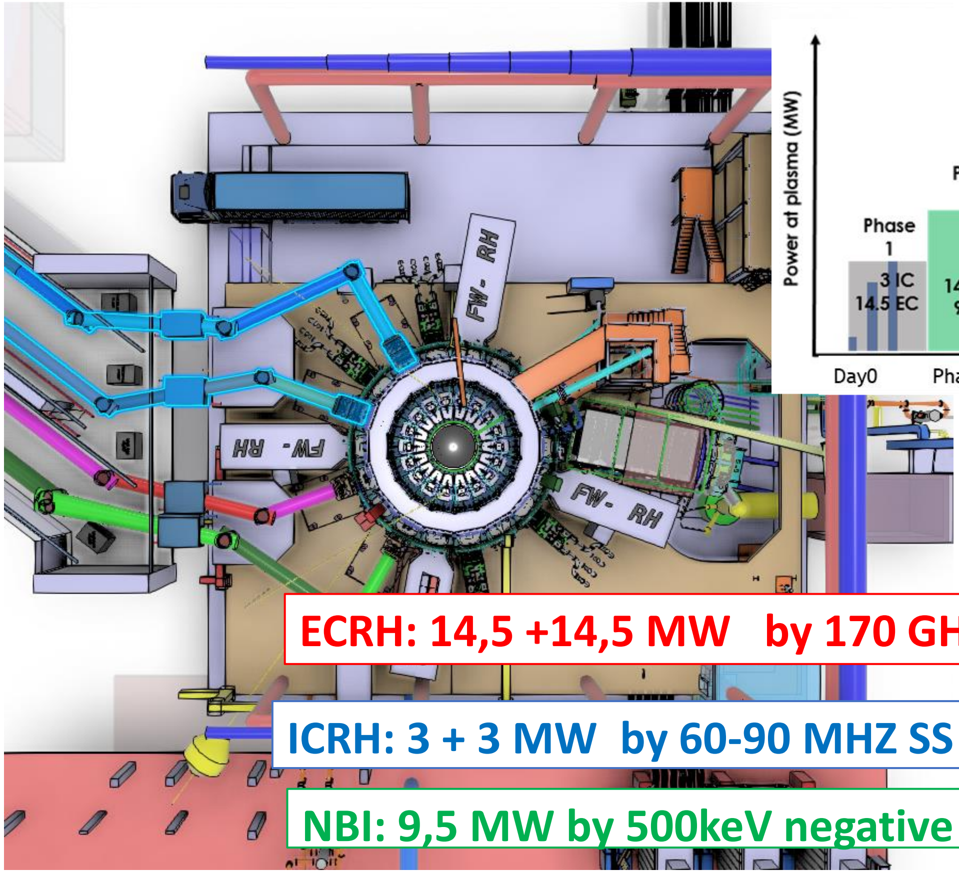
DTT future scenarios not optimized

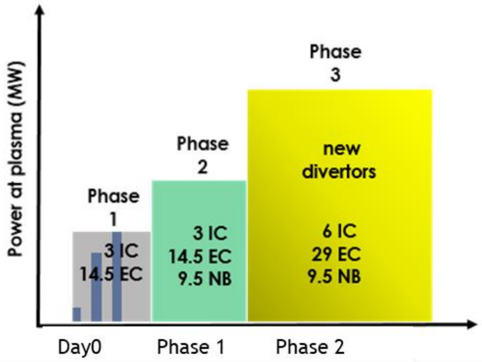


H. Reimerdes et al., "Assessment of alternative divertor configurations as an exhaust solution for DEMO", Nucl. Fusion 60 (2020) 066030, https://doi.org/10.1088/1741-4326/ab8a6a

DTT magnetic system can realize all foreseen Alternative Divertor Configurations considered for DEMO

Additional heating systems: the installation plan





ECRH: 14,5 +14,5 MW by 170 GHz Gyrotrons

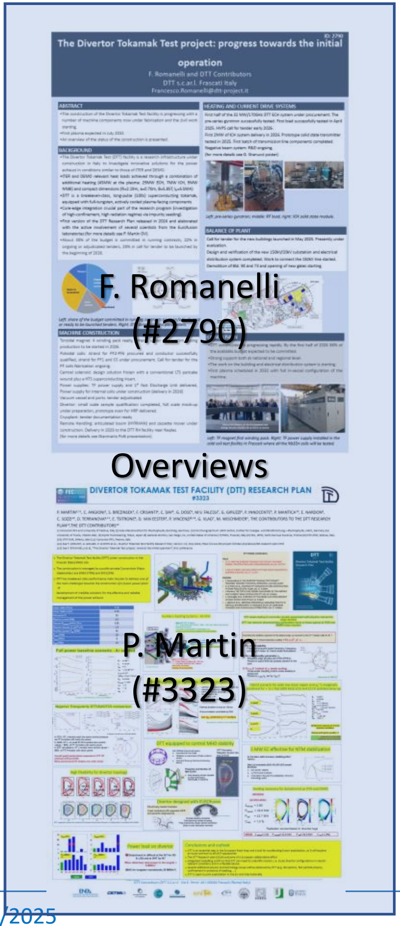
ICRH: 3 + 3 MW by 60-90 MHZ SS transmitter

NBI: 9,5 MW by 500keV negative ion injector

Tasks	EC	IC	NBI
Break down & Plasma start up	X	X	
Plasma Current Ramp up	X	X	X
H-mode access	X	X	X
Electron Heating	X	X	X
Ion Heating		X	X
Current Drive	X		X
MHD Control (NTM and ST)	X	X	
Fast Particle Generation		X	X
Kinetic Profiles Control	X	X	
Impurity Accumulation Avoidance	X	X	X
Momentum injection & Control		X	X
Transport Studies	X	X	X
Isotopic Studies			X
Diagnostics	X		X
Wall Cleaning and Conditioning	X	X	

Courtesy of G.Granucci & HCD team

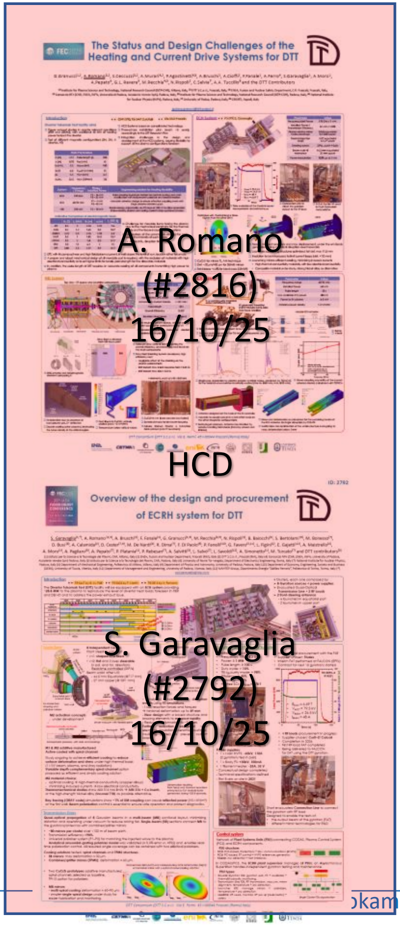
DTT at this conference



Overviews

F. Romanelli (#2790)

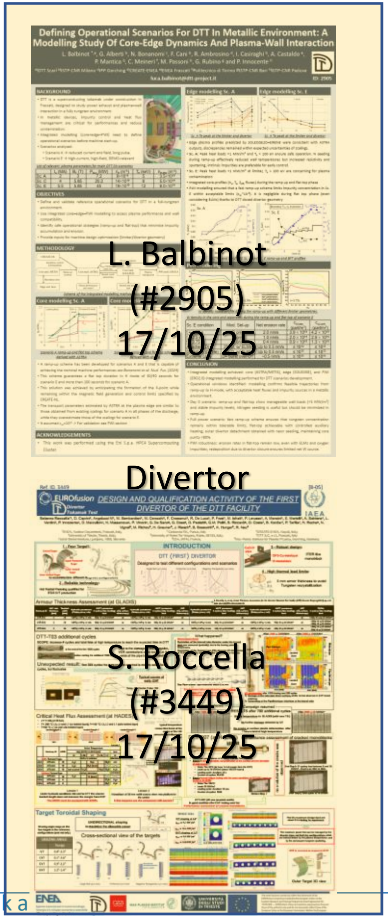
P. Martin (#3323)



HCD

A. Romano (#2816) 16/10/25

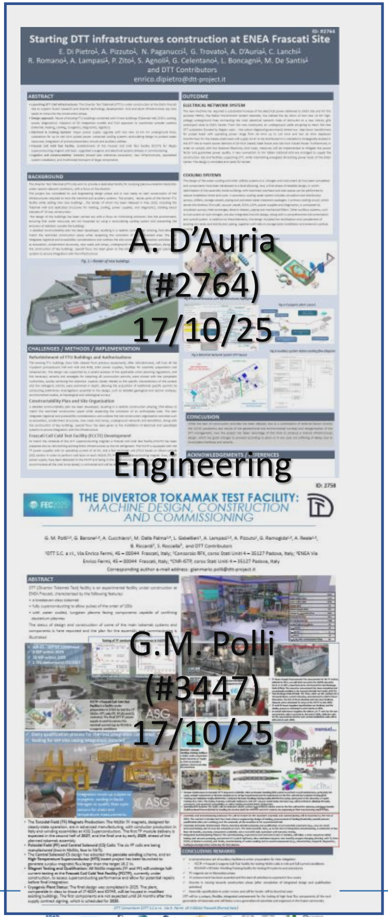
S. Garavaglia (#2792) 16/10/25



Divertor

L. Balbinot (#2905) 17/10/25

S. Roccella (#3449) 17/10/25



Engineering

A. D'Auria (#2764) 17/10/25

G.M. Polli (#3447) 17/10/25

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TF coil magnet system: supply chain

completed

55 tons Nb_3Sn strands

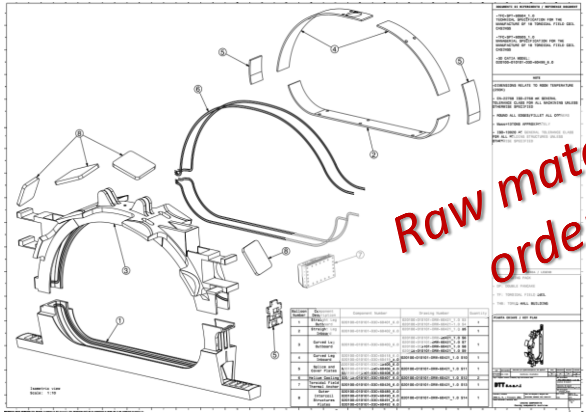
31 tons Cr coated Cu strands

In production

ICAS

(75% unit lengths delivered)

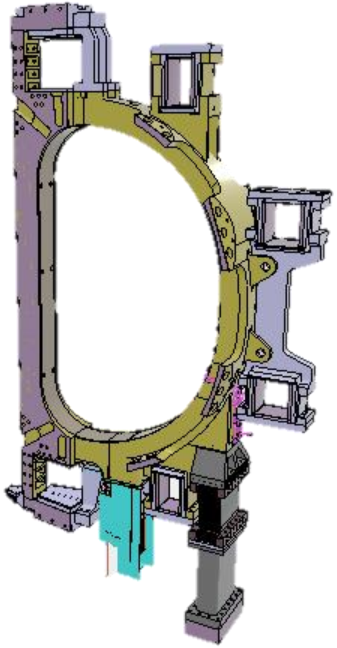
4 coils completed



Raw materials ordered

18 Casing components (~360 tons of 316LN material delivered)

De Pretto industrie



18 TF modules

ASG SUPERCONDUCTORS

TF coils

- ❑ WP-01 - WP-04 completed
- ❑ 6 WP within 2025
- ❑ 18 WP within 2026

Visit of the **Ministry of the Environment and Energy Security (26/05/25) to ASG in La Spezia**

<u>Casing contract restarted in April 2025</u>

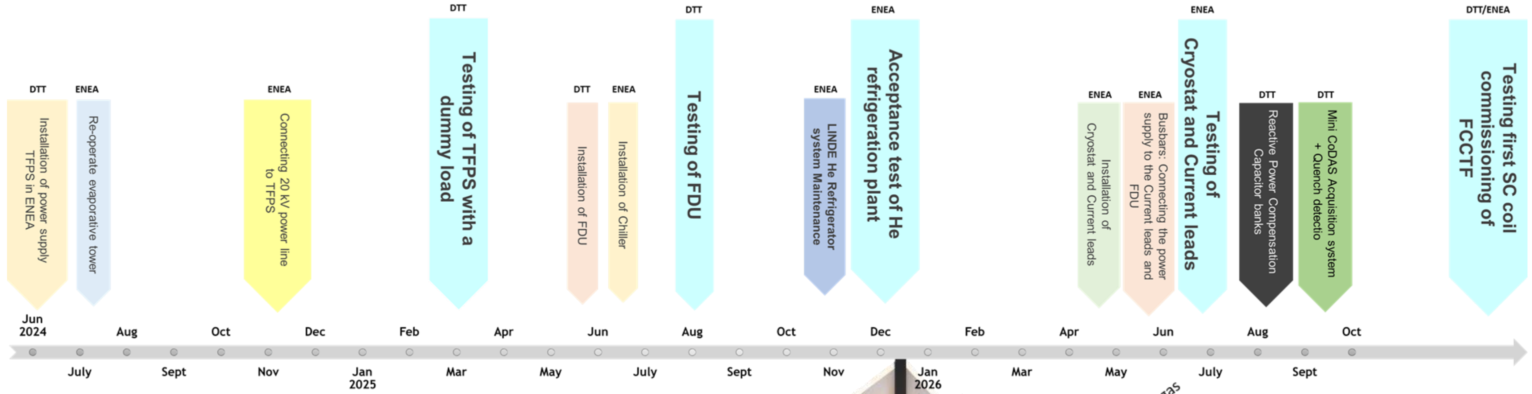
<u>1° Casing to be delivered 01/2027</u>

<u>1° TF module ready in 07/2027</u>

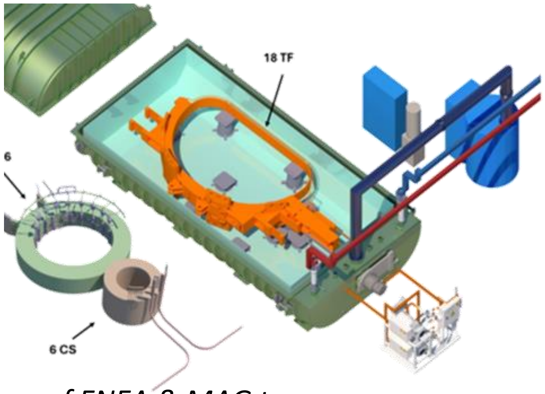
Material	Nb_3Sn
B max [T] on conductor	11,9
I_turn [kA]	42,5
Turns	84
Major radius [m]	2,19
B max @ R [T]	5,85

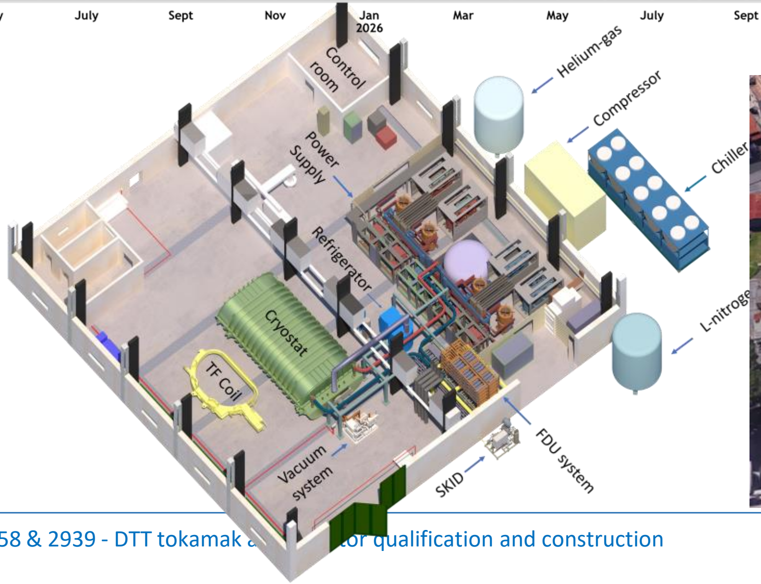
- ❑ All qualifications for integration completed
- ❑ Tooling assembled

Frascati Coil Cold Test Facility



Target: **Q1-2027**
FCCTF commissioned and ready for test

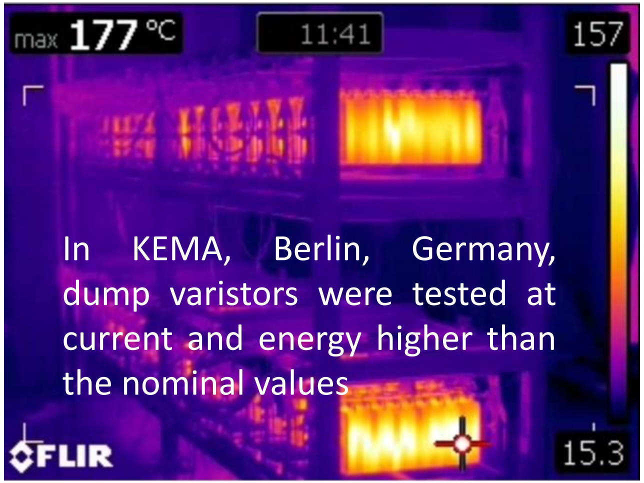




Courtesy of ENEA & MAG team

TF power supply

- ✓ **AC/DC converter** (42.5 kA at 100 V, manufactured by JEMA): initiated in 2022, completed and provisionally installed at the Frascati Coil Cold Test Facility (FCCTF).
- ✓ **Fast Discharge Units (FDUs):** The FDUs, which use **SiC varistors** for a 10-second linear current reduction, manufactured by OCEM Power Electronics. The first of three identical units has been finalized, shipped, and is scheduled for setup at the FCCTF by late **2025**



In KEMA, Berlin, Germany, dump varistors were tested at current and energy higher than the nominal values

In-vessel coils and related power supplies

Power transformer

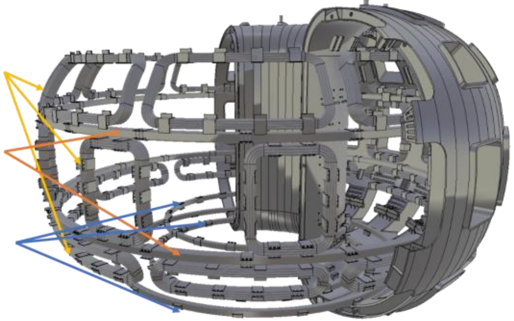
Protection coils

Parameter	DIV	VS	NAS
N.	3	2	27
Nominal current	±5 kA	±6 kA	±2.5 kA
Nominal voltage	±600 V	±4 kV	±550 V
Nominal duration	40 s	100 s	100 s

3x9 saddle coils

2 axisymmetric stabilization coils

3 divertor coils for fine sweeping of strike point



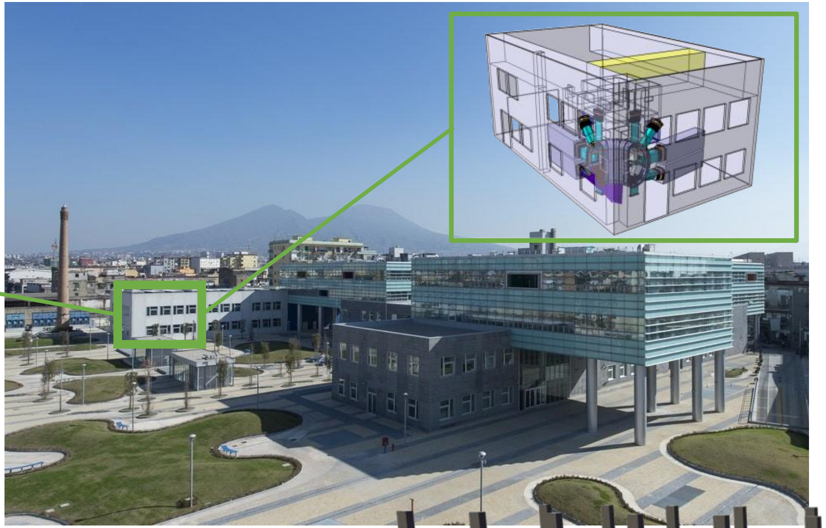
Imbalance inductor

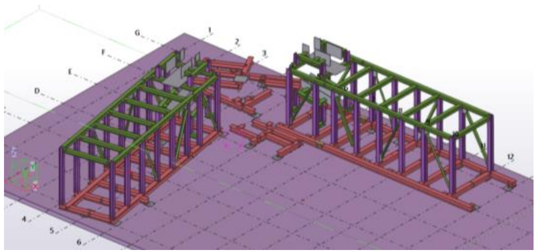
Inverter module

Supercap cabinet

Output cabinet

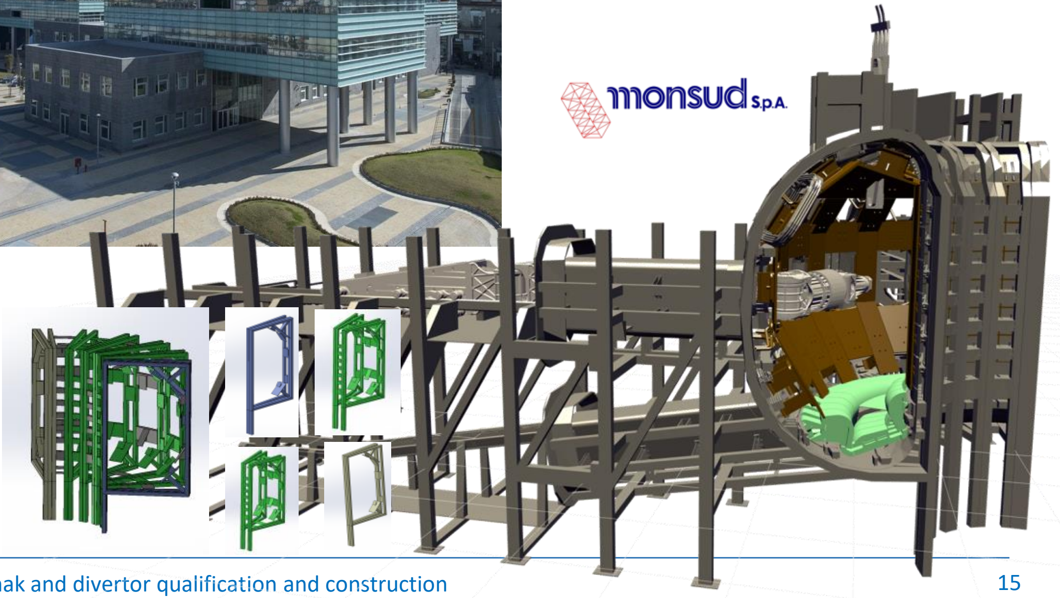
Remote handling system: Remote Handling Training facility (REMHAT)





REMHAT – Remote Handling Training Facility is a facility under preparation inside University of Naples by ENEA envisaged to provide a platform where to develop RH procedures before, during and after DTT start of operations

Full scale mockup of the VV 110° is under construction

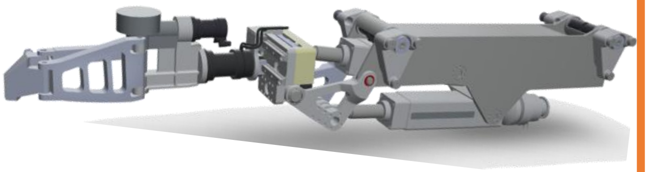


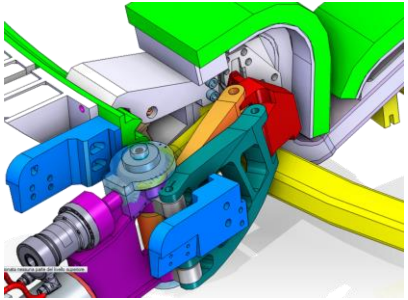
Remote handling system: Hyrman and CMM

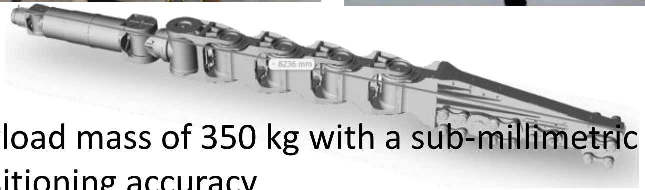
- ✓ Between March and May 2024 two contracts have been placed to OCIMA S.p.A., for the supply of:
  - **2 HYRMAN for the RH of the first wall**
  - **3 CMM for the RH of the divertor**

  Availability of Hyrman and CMM from the beginning will allow their use during assembly
- ❑ Delivery in H1 2026

Payload mass of 400 kg with a sub-millimetric positioning accuracy







Payload mass of 350 kg with a sub-millimetric positioning accuracy

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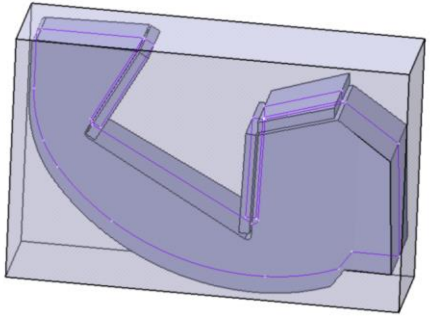
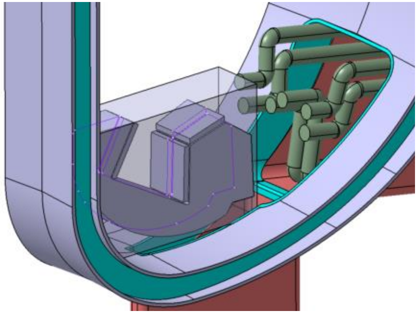
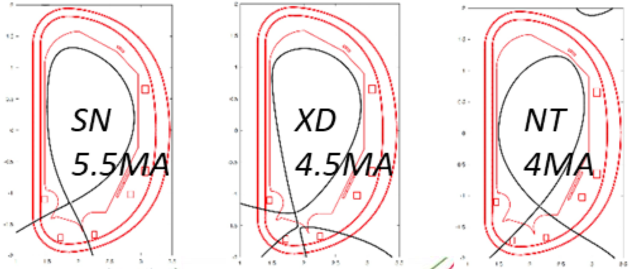
DTT first divertor

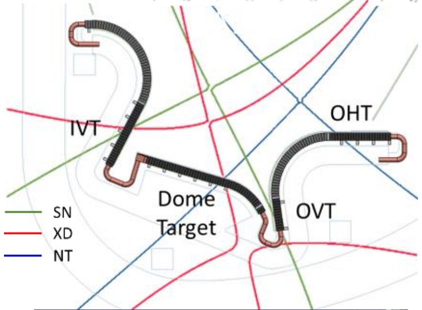


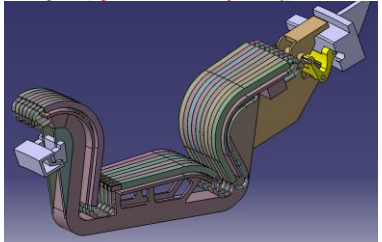


- ✓ 50 standard modules
- ✓ 4 test modules

2021 pre-conceptual design

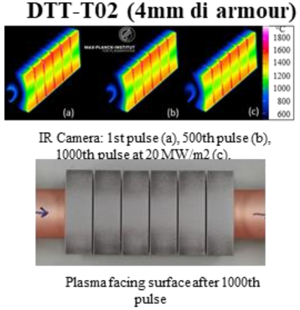


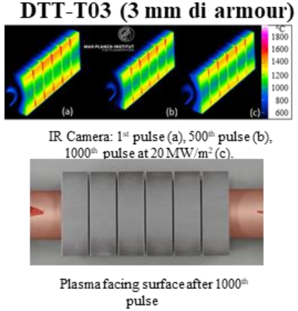




- ✓ Reference scenarios agreed with EF
- ✓ ITER-like monoblock technology chosen
- ✓ Poloidal shape frozen

2022 conceptual design achieved





- ✓ 1000 pulses at 20 MW/m^2 with **no degradation**

- ✓ Baffle and flat-tile for 90° transition mock-ups manufactured

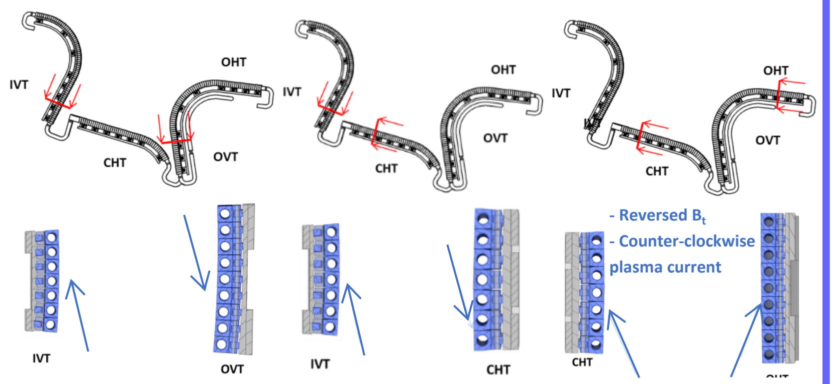
2023 design validation confirmed

Courtesy of S.Roccella and B.Riccardi & IVC team

DTT first divertor

Plasma Facing Unit's toroidal shaping

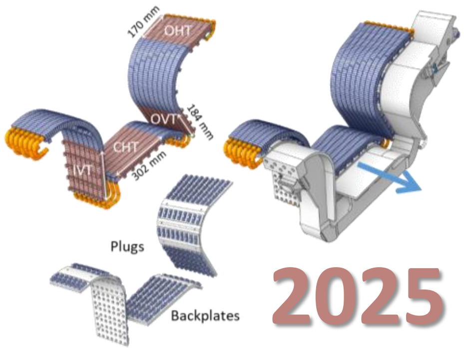
UNIDIRECTIONAL shaping
to <u>maximize the allowable power</u>



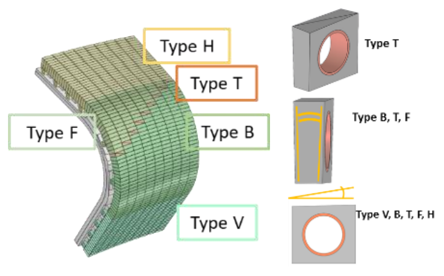
2024

Divertor Design Review Meeting II

Plasma Facing Unit's and Cassette body's **Technical specifications finalized**

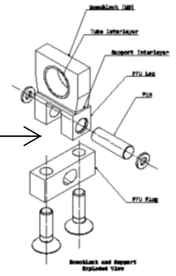


2025



Outer Target 3D view

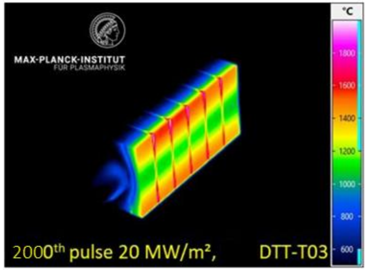
Item	Description	Notes
Type H + Type V	W monoblocks with parallel sides	Without stainless-steel support.
Type H (L) + Type V (L)	W monoblocks with parallel sides	With stainless steel support
Type B+Type F	W monoblocks with NO-parallel sides	Without stainless-steel support.
Type B (L)+Type F (L)	W monoblocks with NO-parallel sides	With stainless steel support
Type T	W monoblocks with NO-parallel sides and double Chamfered	Without stainless-steel support.
Type T (L)	W monoblocks with NO-parallel sides and double Chamfered	With stainless steel support

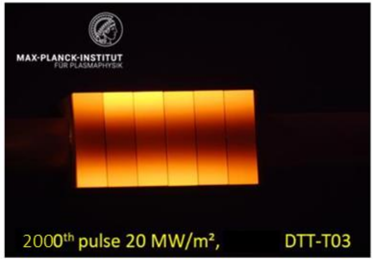


Courtesy of S.Roccella and B.Riccardi & IVC team

Manageable power by the final Divertor design

20 MW/m² Tests in GLADIS @ IPP-Garching

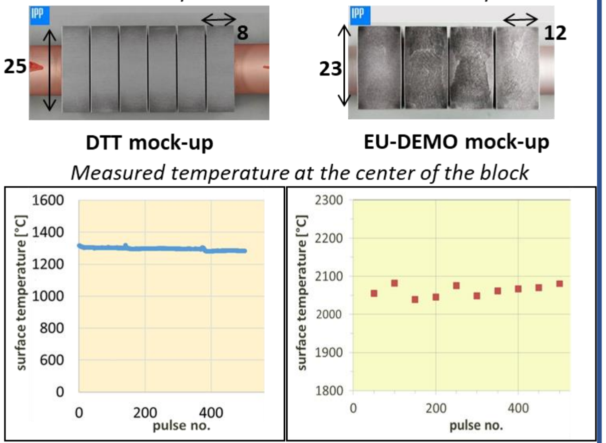




After 500 cycles

After 1000 cycles

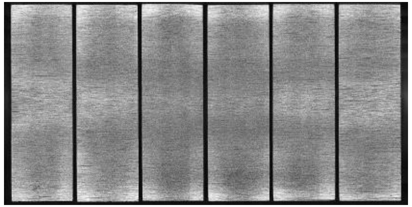
After 2000 cycles



Armour thickness: **3 mm**

Armour thickness: **8 mm**

After **2000** x **20** MW/m²

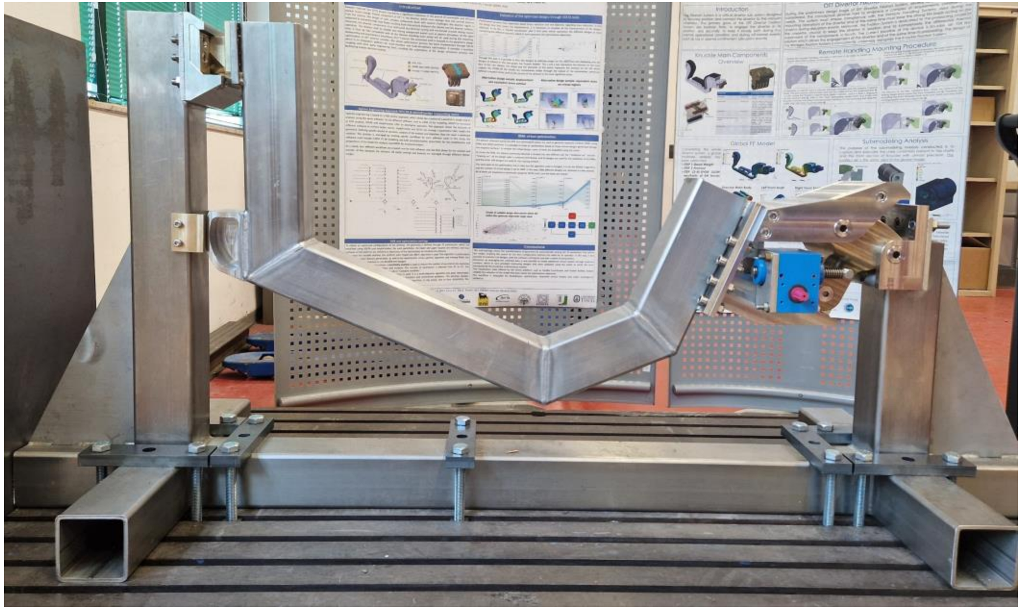


20 MW/m² in steady state (after 2000 pulses) with no damage

- No cracks or surface plastic deformation after 7 hours total at high temperature

Divertor cassette and Plasma facing units

Knuckle Test Rig-Wedges Fixation System Test Rig



Tooling for PFU full scale prototype acquired

Call for tender under preparation:

- Cassette body
- W monoblocks for IVT PFU (~50000)

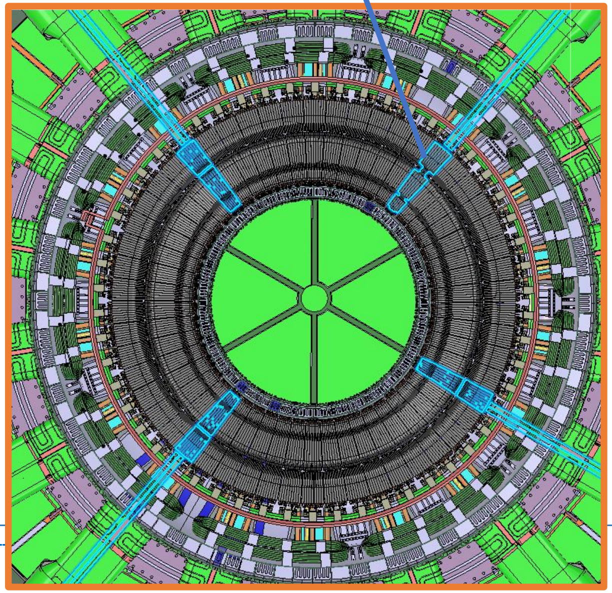
Divertor system

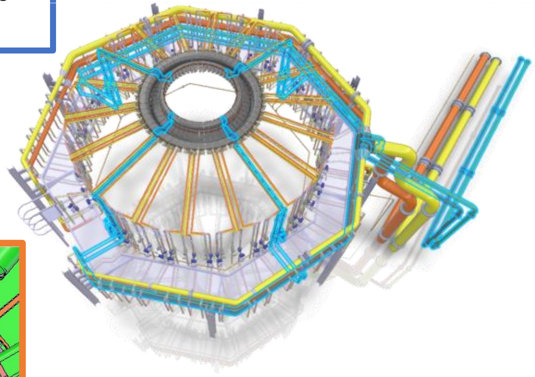
54 actively water-cooled **modules** (3 for each 20° sector) and supplied in parallel.

Water Cooling System:

- inlet pressure: **5MPa**
- total mass flow rate up to: **577 kg/s (11m/s in the PFU pipes)**
- inlet temperature: **within 30-130°C**

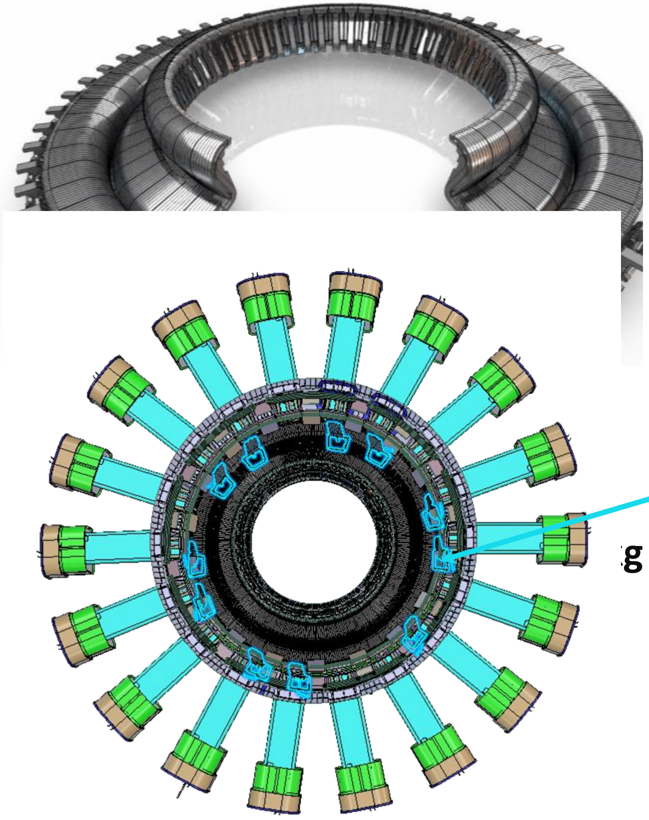
The **4 central cassettes** in the RH ports to **test materials, technologies** and **diagnostics**.
This central cassettes are **easily replaced** and supplied by a **dedicated water cooling** system (43 kg/s; up to **250°C**, up to **15 MPa**)

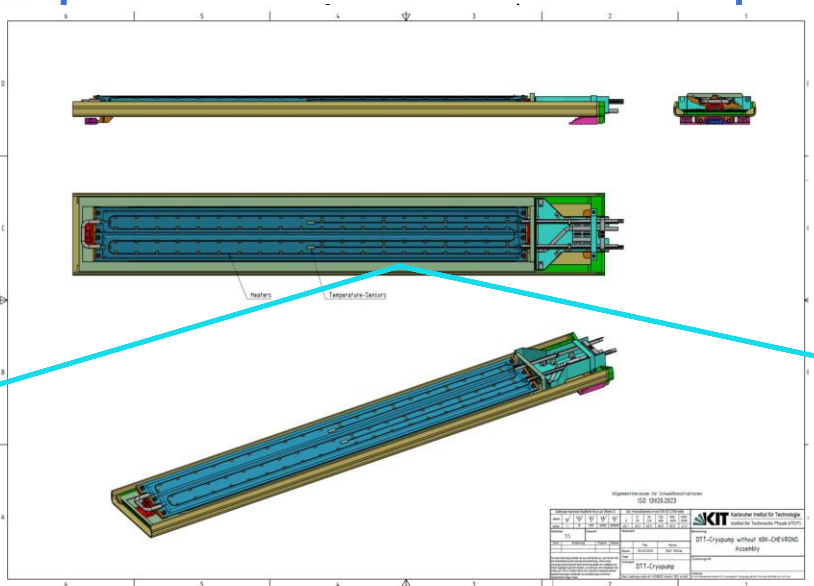


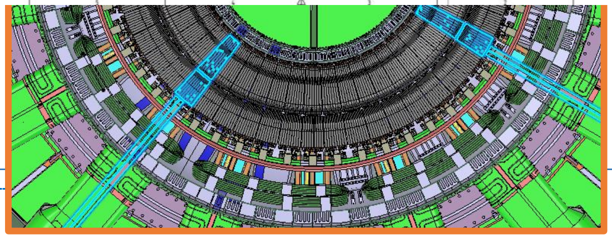


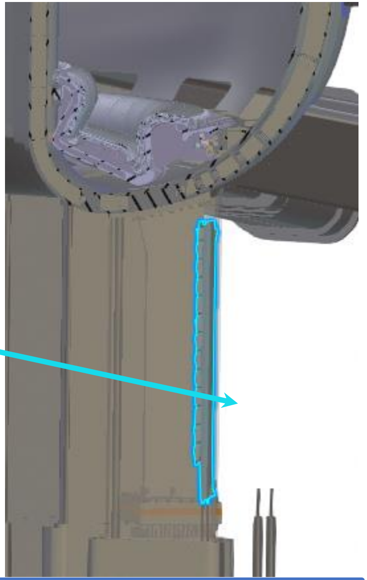
Divertor system

The **4 central cassettes** in the RH ports to **test materials, technologies** and **diagnostics**.
This central cassettes are **easily replaced** and supplied by a **dedicated water cooling** system (43 kg/s; up to









10 Cryopumps will provide target deuterium throughput equals to **103 m3/s**
Operable in 3/4/6/7/10 groups

Assembly contract

Assembly contract organized in **10 steps**:

- Step 1: engineering:
  - Final assembly procedures development;
  - Qualification tooling design;
  - Assembly tooling design

2026

- Step 2: Tooling manufacturing and installation

2027

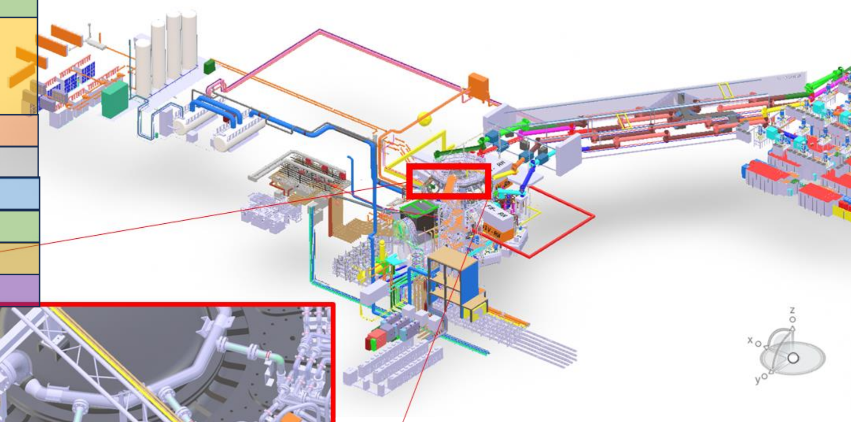
- Step 3: Qualification activities (in particolare nell'F87):
  - Full scale mock-up (like Asdex-U)
  - In-vessel coils
  - VV welding trials
  - Diagnostics assembly trials

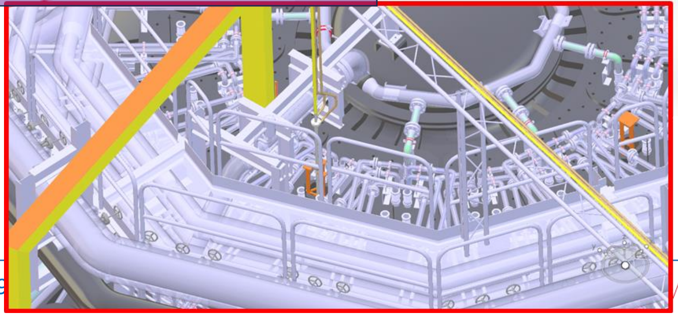
2027-2028

- Step 4: Assembly
  - Cryostat base, PF6-4 + 2 VV sectors
  - Ex-vessel diagnostics and thermal shield
- Step 5 -> TFC assembly
- Step 6 -> ex-vessel assembly (ports, cryolines, feeders, cryostat and CTS)
- Step 7 -> in-vessel assembly (In-vessel coils, FW, Divertor)
- Step 8 -> out-of-cryostat assembly (port plugs, valve box, HCD, grounding, mezzanine)
- Step 9 -> Auxiliaries (pumping, WCS, busbars, pipes)
- Step 10 -> Integrated commissioning

2029-2032

Assembly contract specifications completed
Tender preparation in progress





Target: first plasma in July 2032

Concluding remarks

- ✓ A comprehensive set of auxiliary facilities is under preparation for risks mitigation:
  - FCCTF = Frascati Cryogenic Coil Test Facility for testing Nb3Sn coils in relevant full current conditions
  - REMHAT = REMote HAndling Training facility for testing RH systems and procedures
- ✓ TF magnets are in fabrication phase
- ✓ VV procurement has been awarded and the start of activities is expected in few weeks
- ✓ Divertor is moving towards construction phase (after completion of integrated design and qualification activities)
- ✓ Assembly specification is under review and call for tender will be launched soon

DTT will be a **unique**, **flexible**, **integrated testbed** for the testing of power exhaust solutions for the next generation of tokamaks and will foster a new generation of scientists and engineers in the fusion community

Acknowledgments

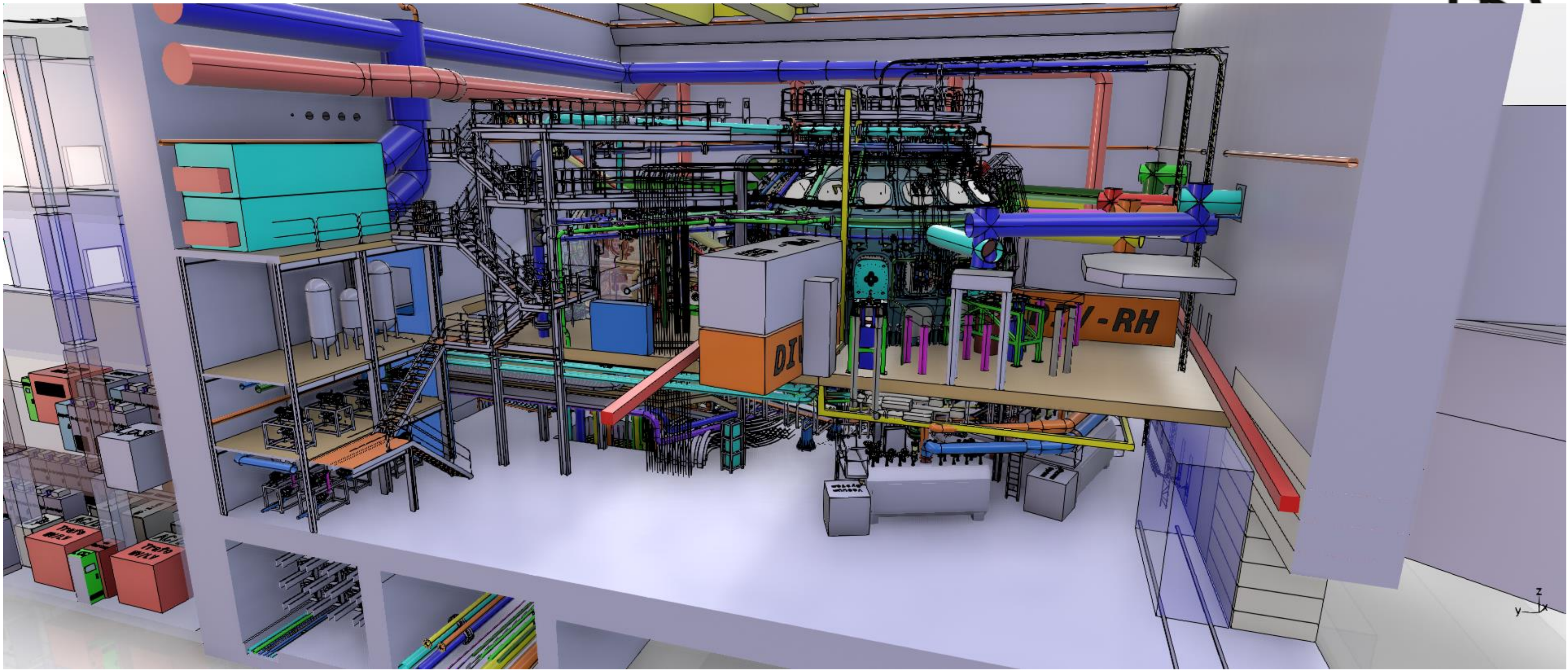
EF consortium

DTT consortium

gianmario.polli@dtt-project.it - www.dtt-project.

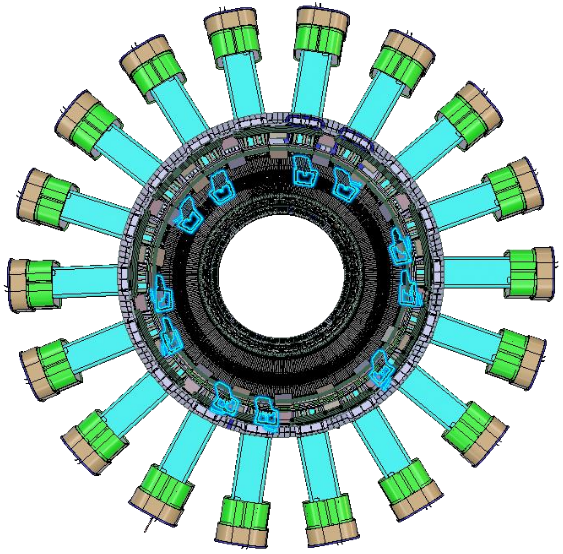
The Divertor Tokamak Test (DTT) Project

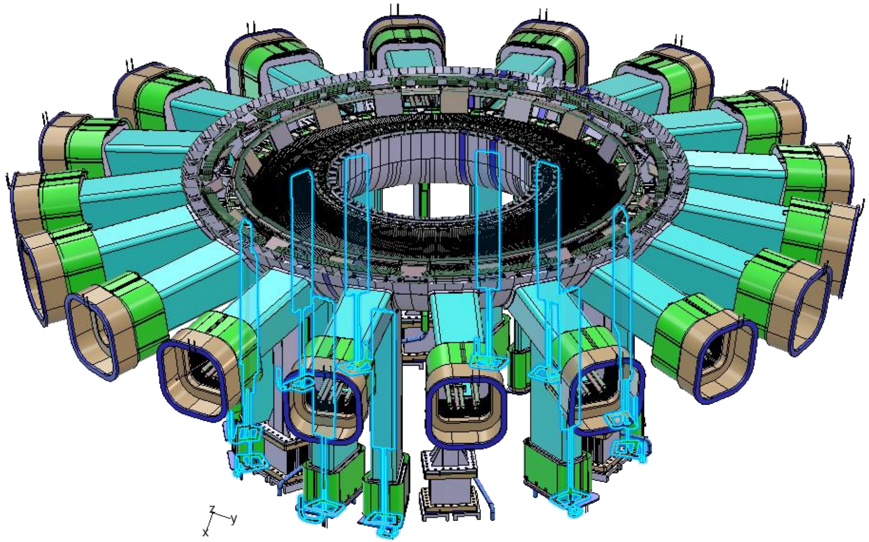
Thank you for your attention


DIV-RH
DIV
Trafo
Trafo

Divertor pumping system

- Divertor pumping system has been completed jointly with KIT.
- Based on cryogenic pumps operated at 4.5 K.
- 10 pumps will provide target deuterium throughput equals to 103 Pa m^3/s
- Working pressure between 0.1 Pa and 1 Pa
- Modularity requirement (3/4-6/7-10 different pumps operations) for optimal pumping at every scenario

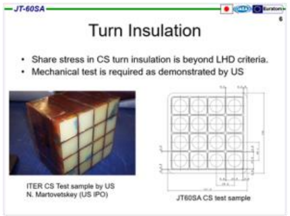




Courtesy of C.Day and P.Innocente & VAU team

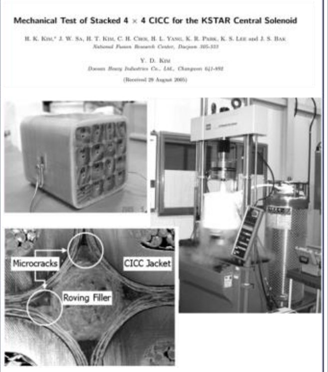
CS coils: testing insulation under loading

JT-60SA

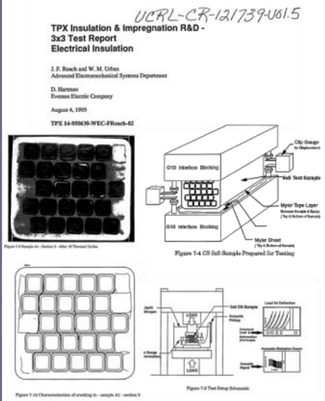


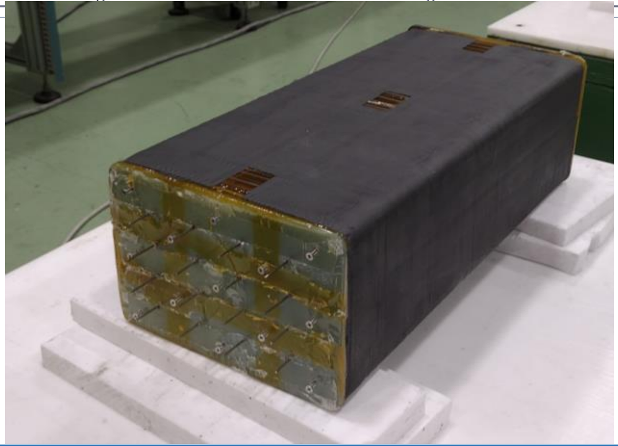
K. Yoshida, et al. Third JT-60SA Technical Coordination Meeting at Naka Japan, 9-12 September 2008

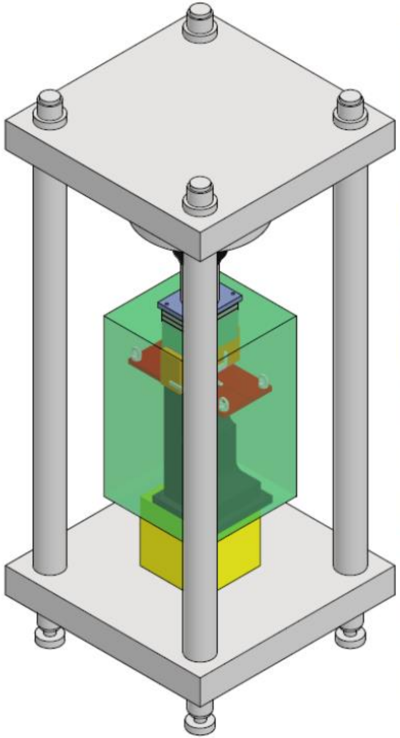
KSTAR



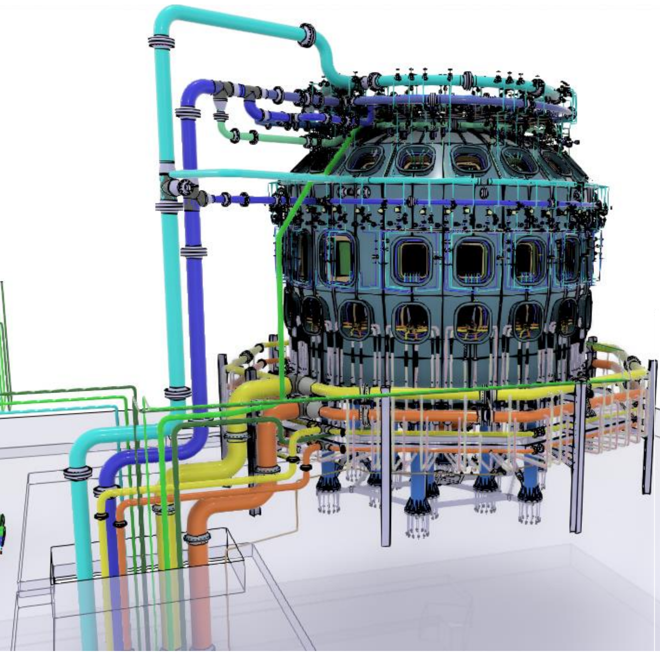
TPX

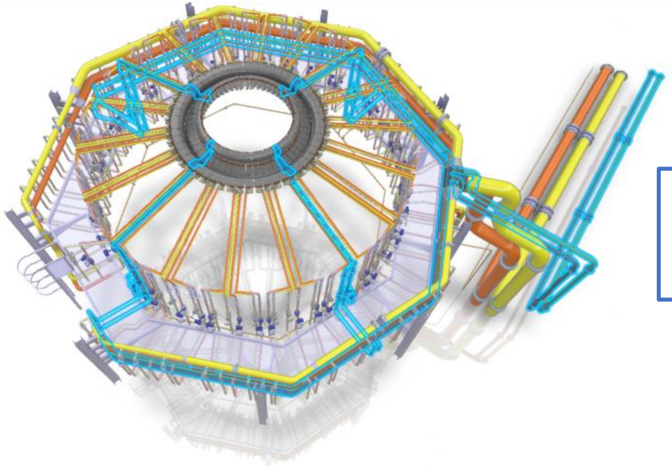






Divertor cooling circuit

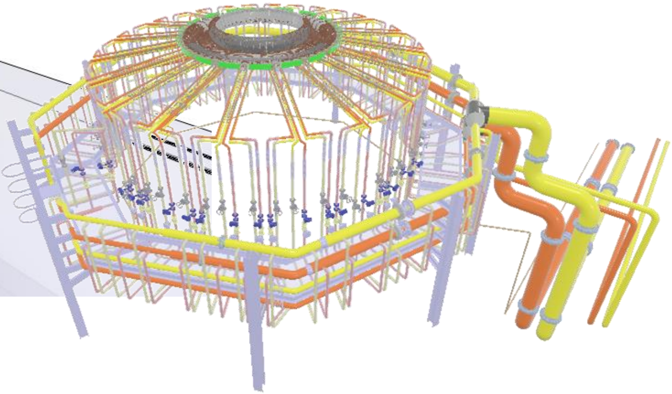




- inlet pressure: up to **15MPa**
- total mfr up to: up to **43 kg/s**
- T_in: **up to 250°C**

Liquid metal divertor (e.g.CPS)

Note: pipes of test modules WCS will be in place from Phase 1, instead pumps and heaters shall be assembled later



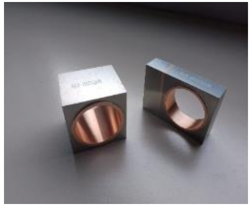
- inlet pressure: **5MPa**
- total mfr up to: **577 kg/s**
- T_in: **within 30-130°C**

Courtesy of A.Cucchiaro and M.Utili & ASSEMBLY team

DTT first wall: from concept to final engineering design

Limiter modules

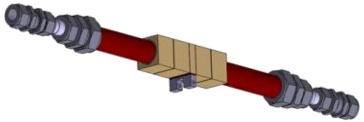
W monoblocks (axially thick 30 mm & 12 mm) provided by an OF-Cu interlayer, internally

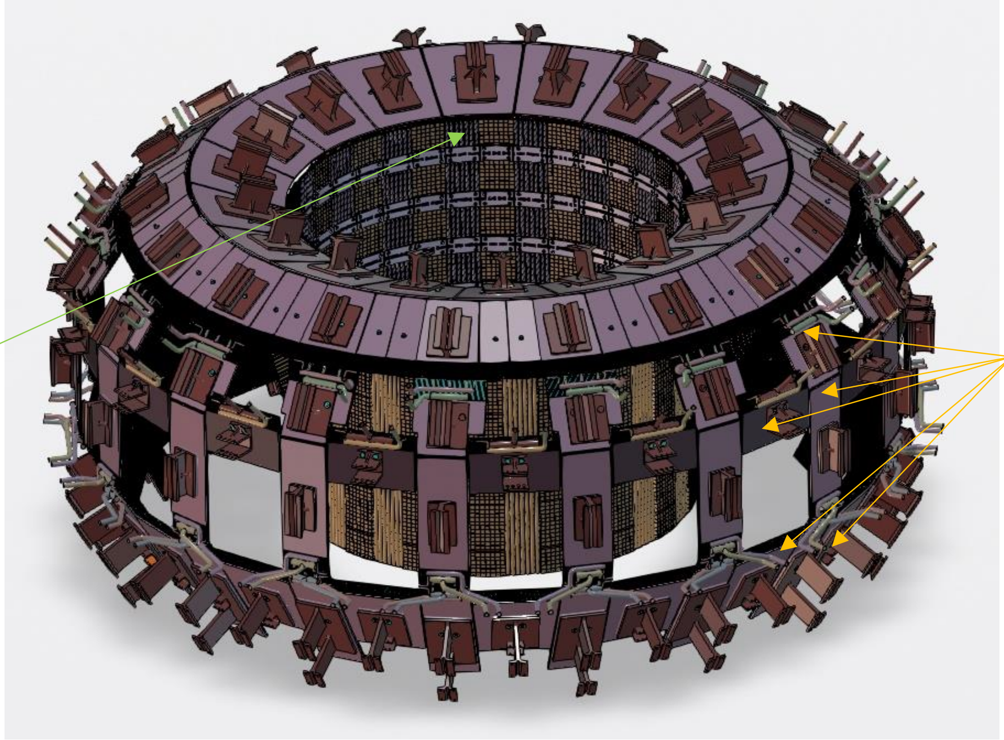


Qualification tests:

- **High heat flux** at 10 MW/m^2 x 2000 cycles;
- **Critical heat flux** – Inlet water conditions: 60°C, 4 Mpa,

mass flow up to 0,6 kg/s





OFW modules

Selective laser melting additive manufacturing technique fully qualified wrt geometry, mechanical performances, surface roughness

W-coating will be deposited on some mock-ups. Then, a high heat flux campaign will be carried out

Interactions with ITER on W coating have started

DTT master research plan – first release

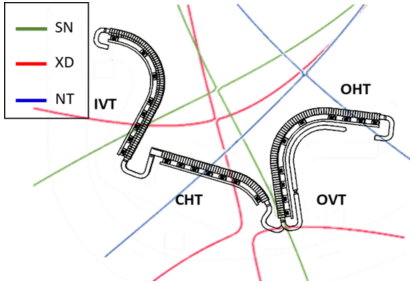
Published on June the 12th 2024
Edited by F. Crisanti, G. Giruzzi and P. Martin

- 9 Chapters
- 9 Appendices
- 195 pages

- **Voluntary participation by:**
- 100 authors and contributors
- 20 Research Institutes
- 10 countries

The basis for further development for which the participation of internation qualified institutions and researchers is welcomed

Manageable power by the final Divertor design



Scenarios as Power increases in the SOL (net of impurity radiation)

SINGLE NULL					IVT	OVT
Case Study	n_sep *10^19	P_SOL (MW)	T_sp1 (eV)	T_sp2 (eV)	q_perp_sp1 (MW/m^2)	q_perp_sp2 (MW/m^2)
BD6_SN_1001	7	3,5	4	1,5	0,58	0,34
BD6_SN_1002	7	5	4	1,5	0,89	0,49
BD6_SN_1003	7	7	3,5	1,5	1,32	0,67
BD6_SN_1004	7	14	40,7	47,9	9,1	9,9
BD6_SN_1005	7	25	114,7	85,2	25,3	16,8

X-DIVERTOR					IVT	CHT
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BD11_XD_1005	7	25	230	229	16.4	2.45
BD11_XD_1006	7	35	298	313	25.9	3.95
BD11_XD_1007	7	45	434	448	37.3	5.9

NEGATIVE TRIANGULARITY					CHT	OHT
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BD15_NT_1005	6	25	193	207	8.73	14.81
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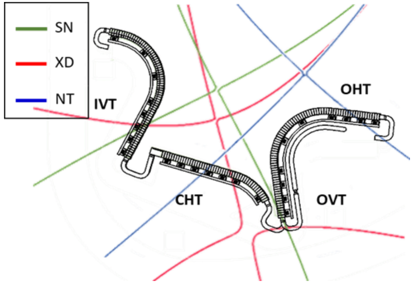

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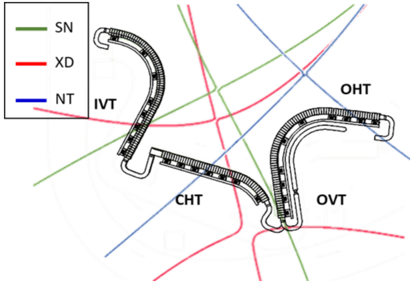

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SINGLE NULL

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OVT shaping at 2.2°

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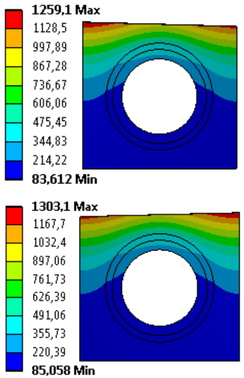
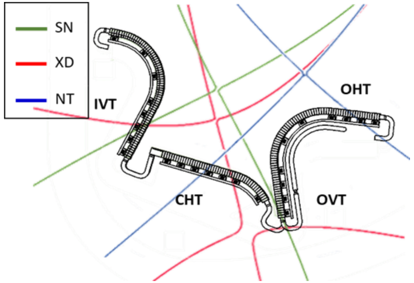
TEMPERATURE



h_{tc} at 5MPa. 60 C°. 11m/s

Manageable power by the final Divertor design



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[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
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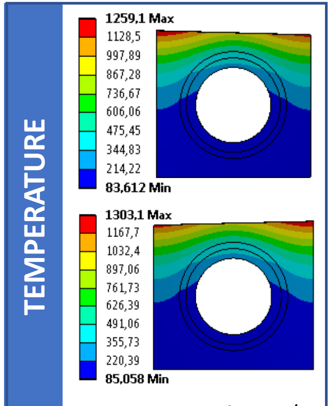
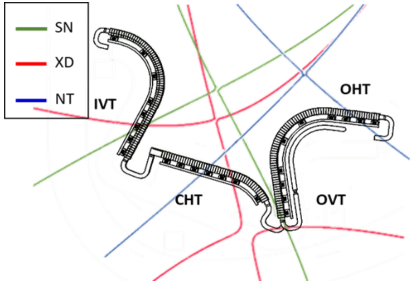


h_{tc} at 5MPa. 60 C°. 11m/s

Manageable power by the final Divertor design



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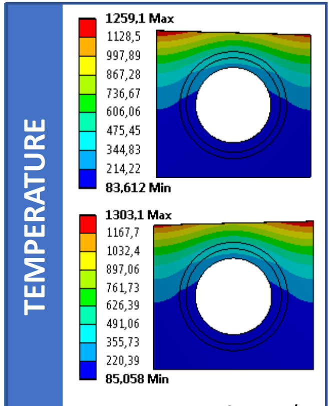
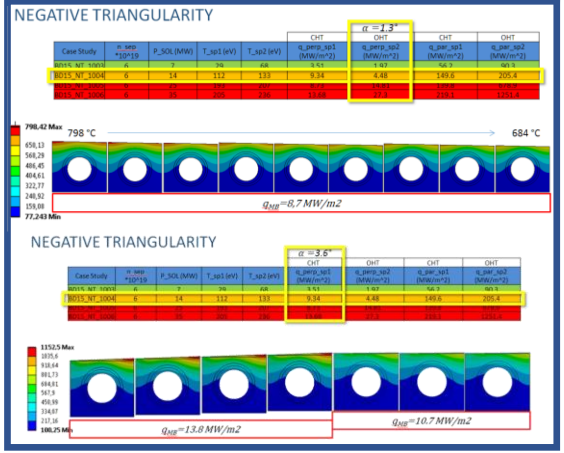
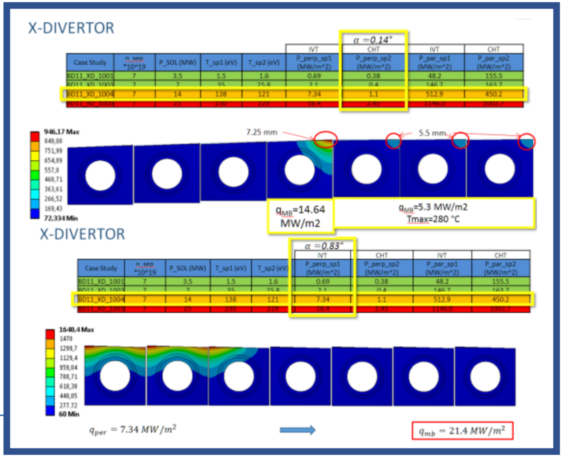


h_{tc} at 5MPa. 60 C°. 11m/s





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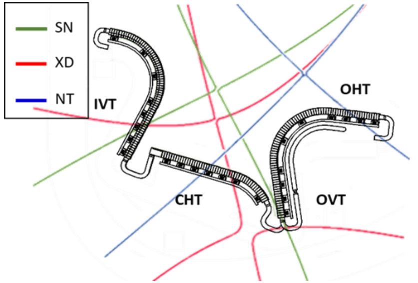

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BD6_SN_1001	7	3,5	4	1,5	0,58	0,34
BD6_SN_1002	7	5	4	1,5	0,89	0,49
BD6_SN_1004	7	14	40,7	47,9	9,1	9,9
BD6_SN_1005	7	25	114,7	85,2	25,3	16,8

X-DIVERTOR

Case Study	n_sep *10^19	P_SOL (MW)	T_sp1 (eV)	T_sp2 (eV)	IVT q_perp_sp1 (MW/m^2)	CHT q_perp_sp2 (MW/m^2)
BD11_XD_1001	7	3.5	1.5	1.6	0.69	0.38
BD11_XD_1004	7	14	138	121	7.34	1.1
BD11_XD_1005	7	25	230	229	10.4	2.45
BD11_XD_1006	7	35	298	313	25.9	3.95
BD11_XD_1007	7	45	434	448		

NEGATIVE TRIANGULARITY

Case Study	n_sep *10^19	P_SOL (MW)	T_sp1 (eV)	T_sp2 (eV)	CHT q_perp_sp1 (MW/m^2)	OHT P_perp_sp2 (MW/m^2)
BD15_NT_1004	6	14	112	133	9.34	4.48
BD15_NT_1005	6	25	193	207	8.73	14.81
BD15_NT_1006	6	35	205	236	13.68	27.3

SINGLE NULL

IVT shaping at 2.3°

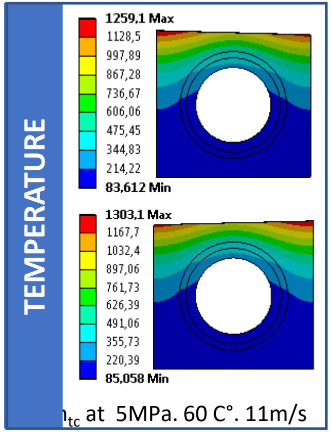
$$q_{per} = 9.1\ MW/m^2$$

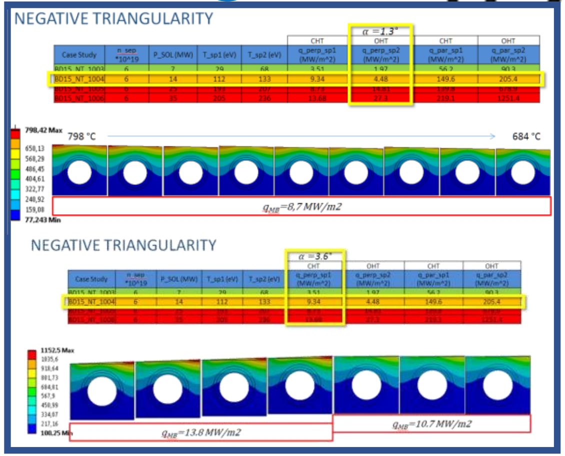
$$\boxed{q_{mb} = 16.4\ MW/m^2}$$

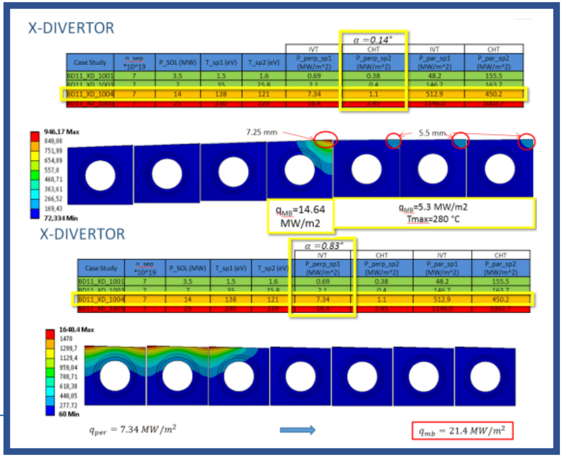
OVT shaping at 2.2°

$$q_{per} = 9.9\ MW/m^2$$

$$\boxed{q_{mb} = 16.8\ MW/m^2}$$







Manageable power by the final Divertor design

- For the 3 reference configurations, a power of 14 MW can be handled without damaging the monoblock (T below recrystallization at the center).
- The plasma temperatures at this power even in the pure deuterium case (shown in the table) are at the limit for admissible sputtering of W.

The **maximum power** that can be **manage by the divertor** seems **not limit the experimentation** of physics scenarios.

Case Study	n_sep *10^19	P_SOL (MW)	T_sp1 (eV)	T_sp2 (eV)	(MW/m^2)	(MW/m^2)
BD11_XD_1001	7	3.5	1.5	1.6	0.69	0.38
BD15_NT_1006	6	35	205	236	13.68	27.3