A Versatile Divertor for the Italian Divertor Tokamak Test Facility

S. Roccella

R. Neu, P. Innocente, R. Ambrosino, A. Castaldo, C. Day, J. Gunn, H. Greuner, K.Hunger

D. Marzullo, G.M. Polli, A. Reale, H. Roche, C. Tantos, N. Vignal &

In-Vessel Component Team

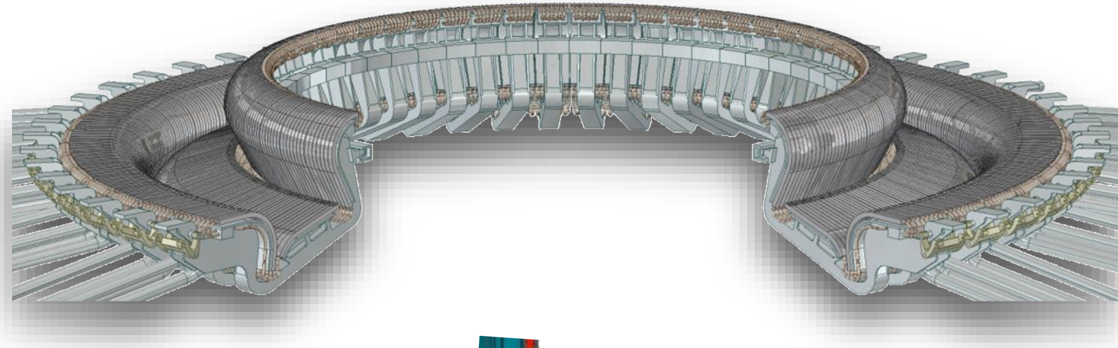
ISFNT15 International Symposium on Fusion Nuclear Technology, 10-15 Sept 2023, Auditorio Alfredo Kraus, Las Palmas de Gran Canaria, Spain

EUROfusion

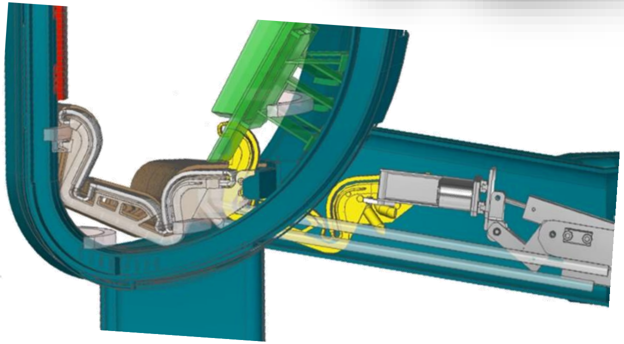
This work has been carried out within the framework of the EUROfusion Consortium and has received funding from the Euratom research and training programme 2014-2018 and 2019-2020 under grant agreement No 633053. The views and opinions expressed herein do not necessarily reflect those of the European Commission.

First DTT Divertor

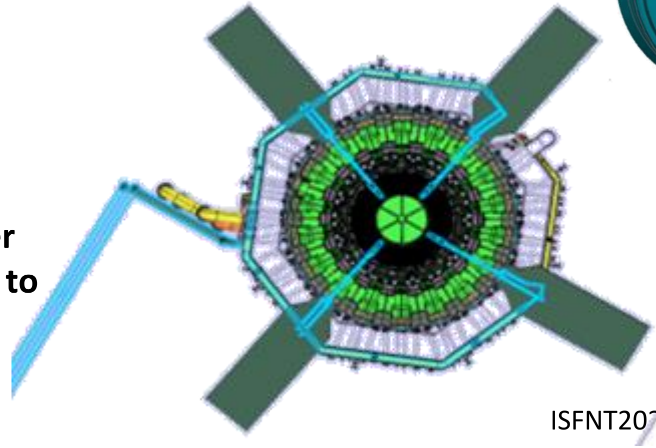
The Divertor consists of:
54 actively water-cooled **modules**
(3 for each 20° sector) and supplied in parallel.



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 **are devoted to testing materials and technologies.**
This central **cassettes have to be easily replaced (**without removing adjacent cassettes and piping)
and can be supplied by **a dedicated water cooling system (43 kg/s; up to 250°C, up to 15 MPa)**



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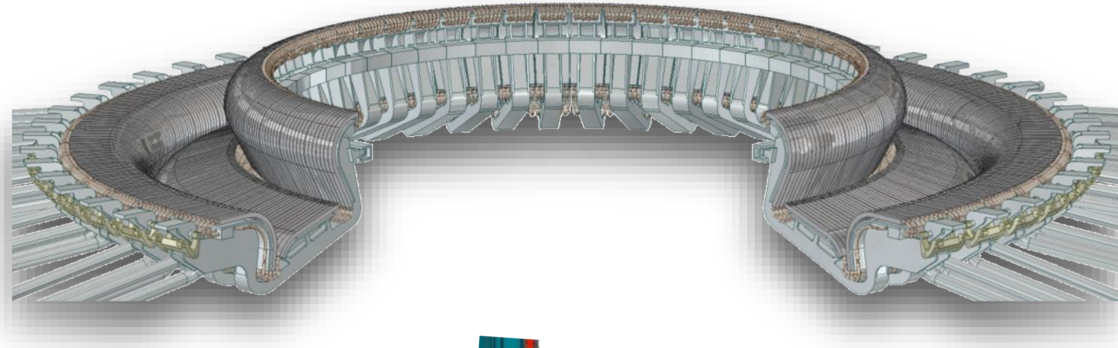
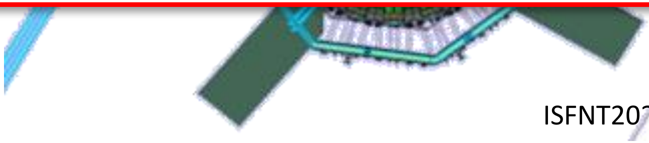


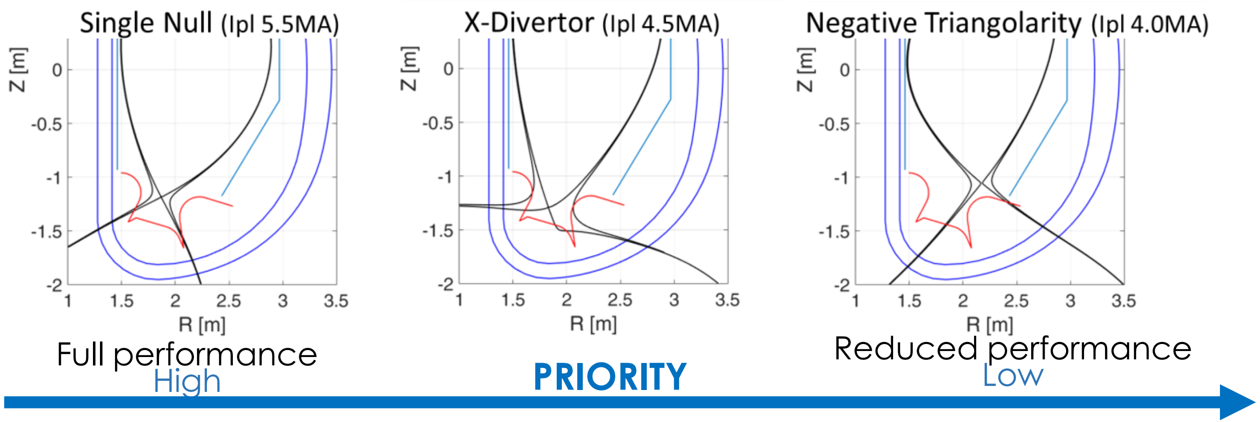


More details
PL 9 *(on Thursday): G. M. Polli, The role of the DTT facility for the development of high heat flux tokamak components,*
and
*see **PS1-21**(on Monday): Marco Utili, Overview of the DTT Assembly Plan*

First DTT Divertor: conceptual design

Conceptual design: poloidal shaping

- **<u>Compatibility with different magnetic configurations</u>**



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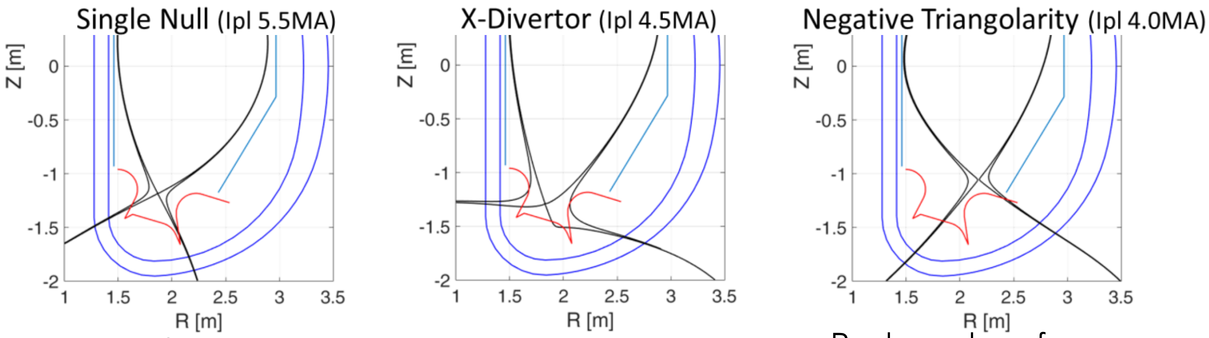
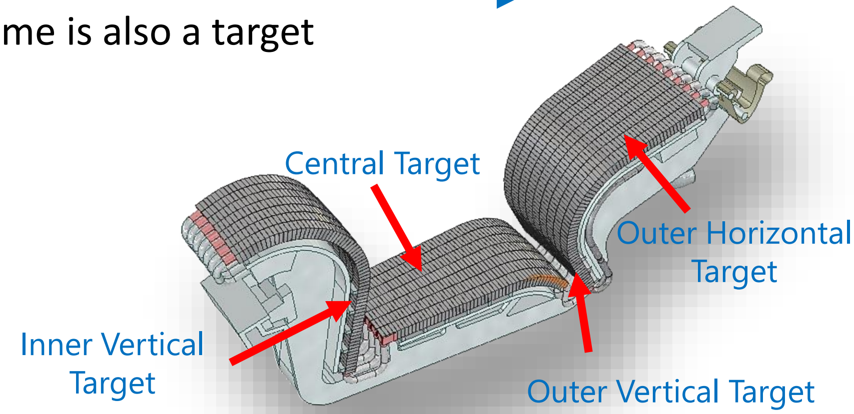


Full performance
High

PRIORITY

Reduced performance
Low

- **<u>4 targets</u>** in the DTT Divertor: the straight part of the Dome is also a target



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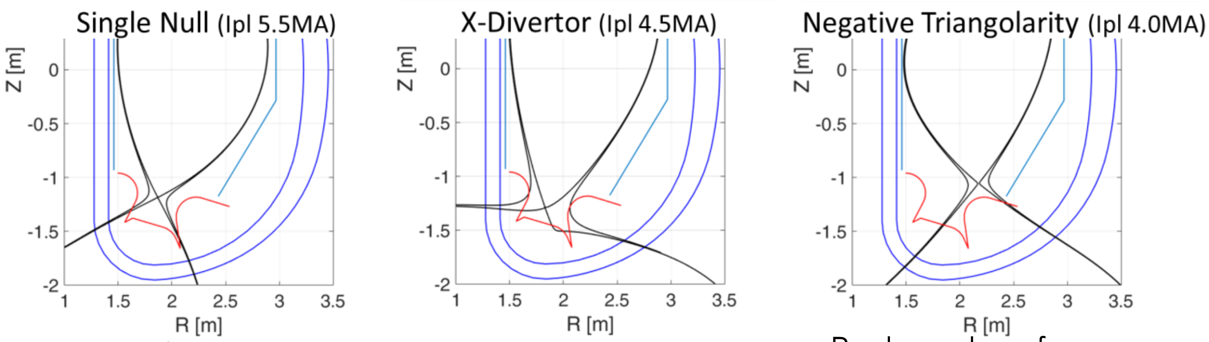
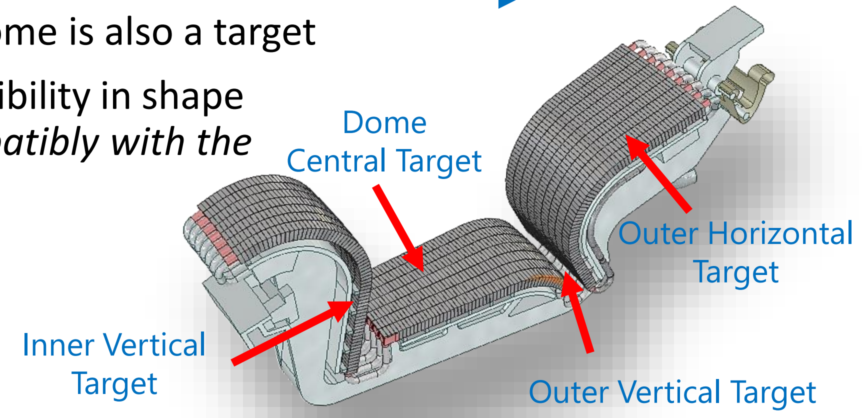


Full performance — High

PRIORITY

Reduced performance — Low

- **<u>4 targets</u>** in the DTT Divertor: the straight part of the Dome is also a target
- The Flat Dome **<u>leave room to the private region</u>** for flexibility in shape and in leg length of the alternative configurations *(compatibly with the space reserved to the cassette body)*



Conceptual design: poloidal shaping

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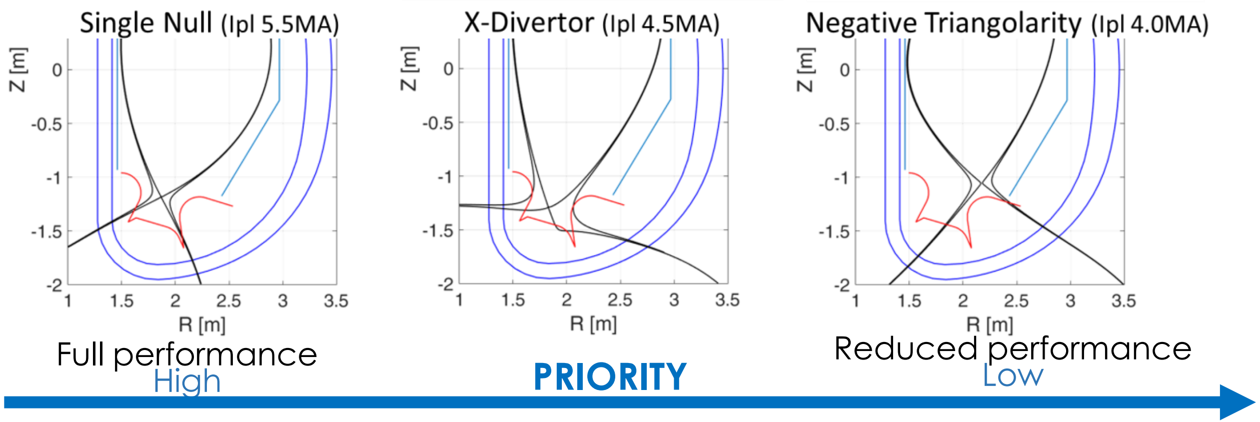

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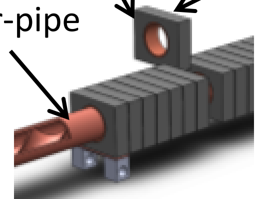
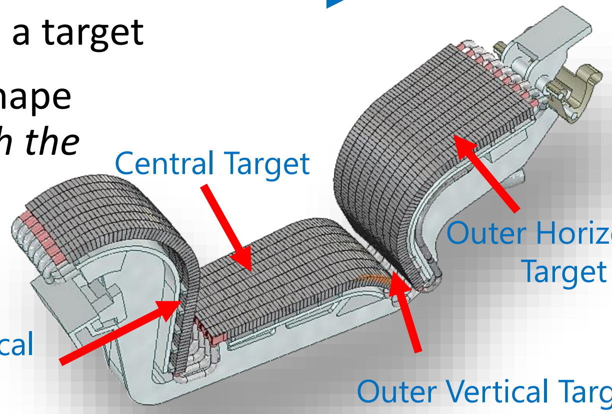
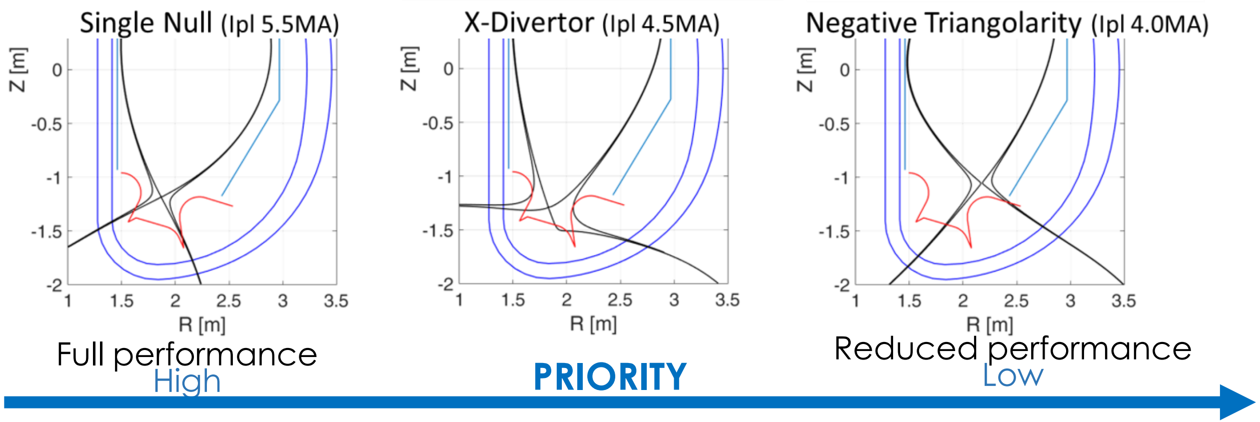


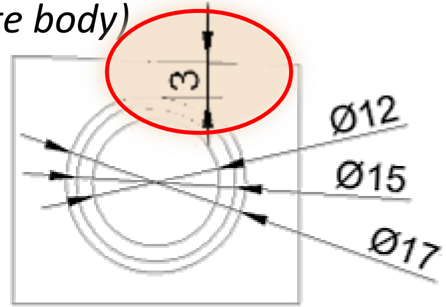


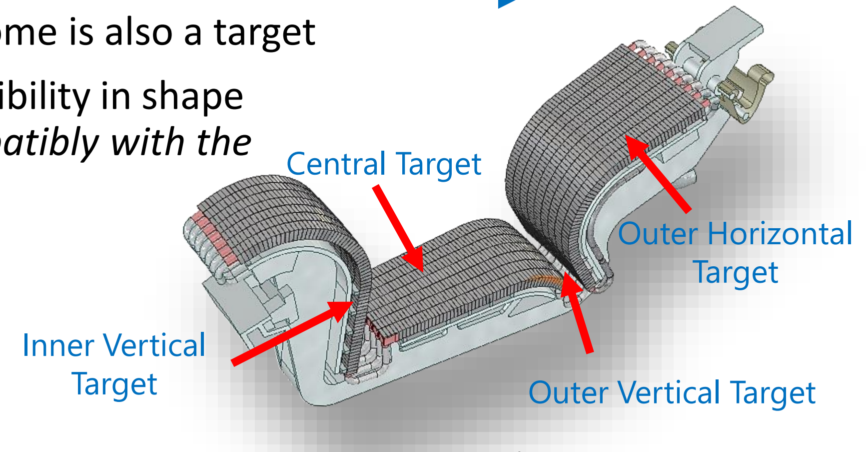
Conceptual design: poloidal shaping

- **Compatibility with different magnetic configurations**



- **4 targets** in the DTT Divertor: the straight part of the Dome is also a target
- The Flat Dome **leave room to the private region** for flexibility in shape and in leg length of the alternative configurations *(compatibly with the space reserved to the cassette body)*
- the **entire plasma facing surface is in W monoblock** with **reduced armour thickness** to maximize the allowable thermal loads

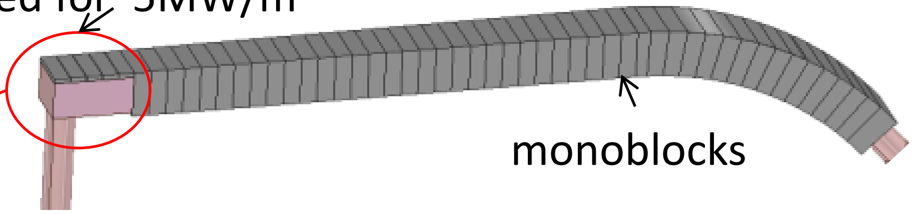


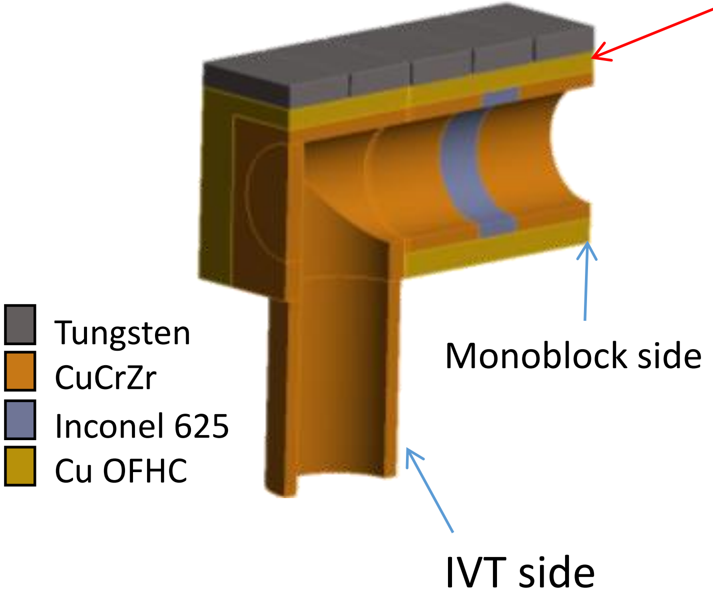


Conceptual design: poloidal shaping

The Flat Dome requires a 90° bend at the straight end

Flat tiles solution to shield the 90 ° curve is under study





Conceptual design: poloidal shaping

The Flat Dome requires a 90° bend at the straight end

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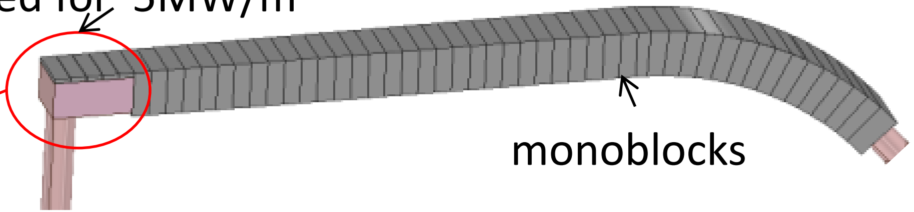
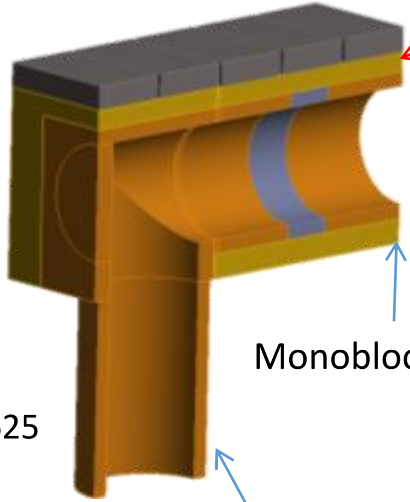
Flat tiles
Designed for 5MW/m^2



monoblocks



- Tungsten
- CuCrZr
- Inconel 625
- Cu OFHC

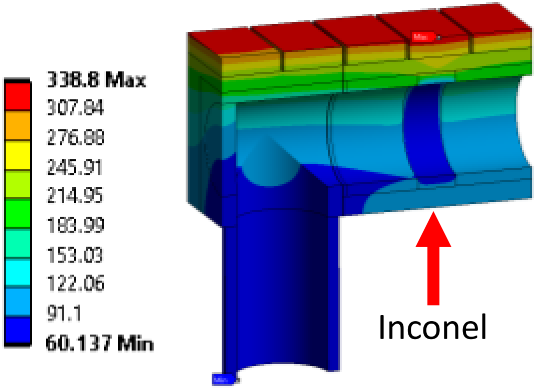
Monoblock side

IVT side

Thermo-mechanical analysis

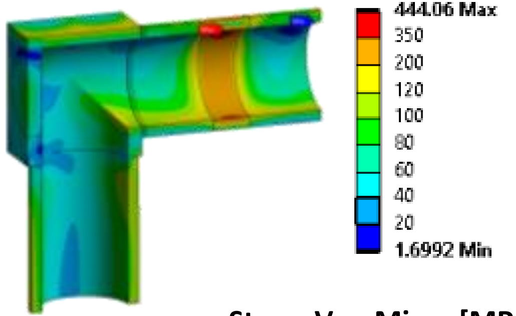
Boundary Conditions:

- **5 MW/m^2** on the W tile surface
- **convection: 10 m/s, no swirl**



Inconel

Temperature [°C]



Stress Von Mises [MPa]

Conceptual design: poloidal shaping

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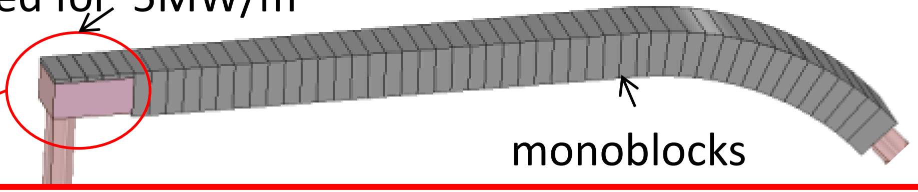
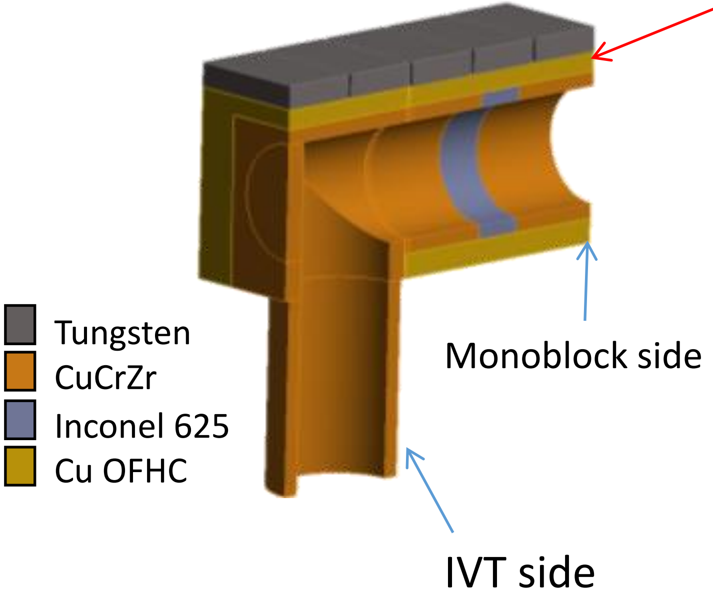




ISSUES RELATING TO THE 90° BEND

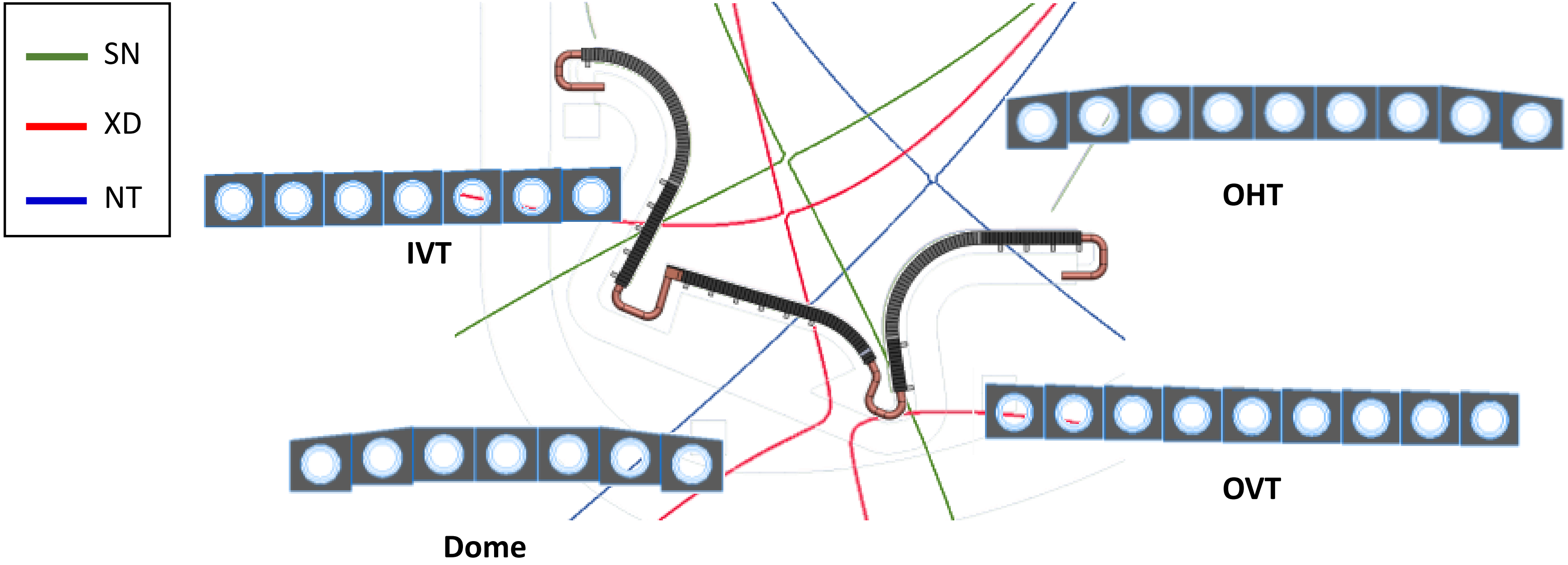
- **The manufacturing process** have to be **defined and qualified experimentally**
- The **possibility to insert** the **Twisted Tape** into the central target **has to be evaluated** because it has to be inserted after the PFU manufacturing (and then after bending the tube)
- So the **impact of the Critical Heat Flux** on the allowable loads on the central target **without Twisted Tape** must be evaluated.

Conceptual design: toroidal shaping

Requirements

IVT e **OVT** toroidal shaping : to **maximize the allowable power** on the targets → UNIDIRECTIONAL

Dome e **OHT** toroidal shaping: for **higher flexibility** → SIMMETRICAL

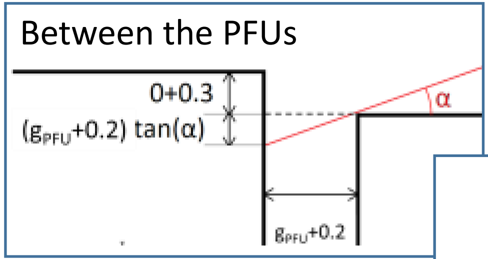


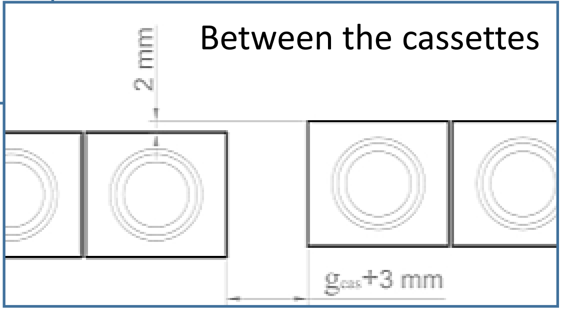
Conceptual design: toroidal shaping

Toroidal shaping

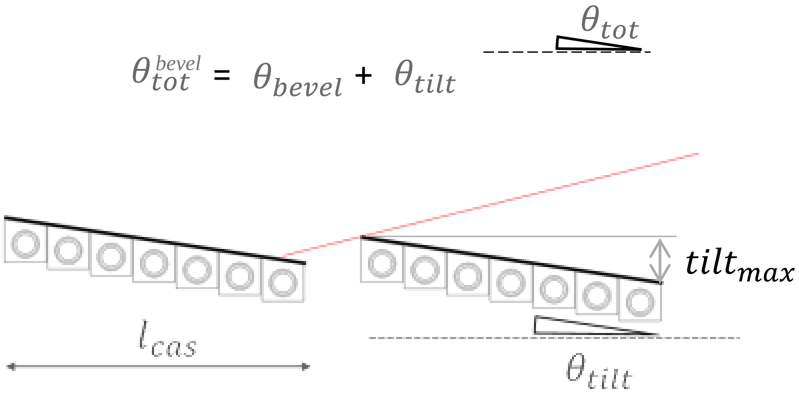
	α [°]	l_{mb}[mm]	g_{cas}[mm] $(Toll\ \pm 3mm)$	$Step_{cas}$[mm] $(Toll\ \pm 2mm)$	g_{PFU}[mm] $(Toll\ \pm 0.2mm)$	$Step_{PFU}$[mm] $(Toll\ \pm 0.3mm)$	θ_{tot}^{bevel}[°]	$tilt_{max}$[mm]
IVT	2 (SN)	24	8	0	0.4 ÷0.5	0	1.65	1.1
OVT	2 (SN)	24.5	10	0	0.4 ÷0.5	0	1.45	1.0
Dome	5.2 (NT)	25.5	9.5	0	0.4 ÷0.5	0	8.6	6.0
OHT	1.3 (NT)	27.5	12	0	0.4 ÷0.5	0	4.6	2.7

XD equilibrium does not constrain the toroidal shaping (high flux expansion + shallow grazing angle)





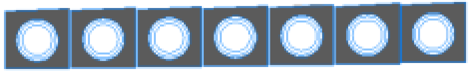
$$\theta_{tot}^{bevel} = \theta_{bevel} + \theta_{tilt}$$



Conceptual design: toroidal shaping

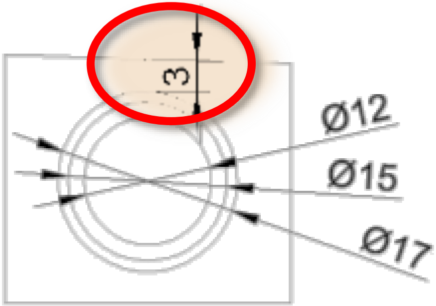
SS and slow transient limit loads

Inner Vertical Target



θ_{tot}^{bevel} =1.65°

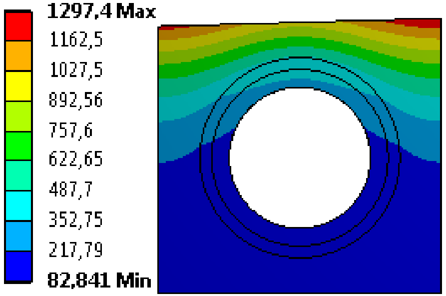
3 mm of armor is compatible with the estimated erosion rate



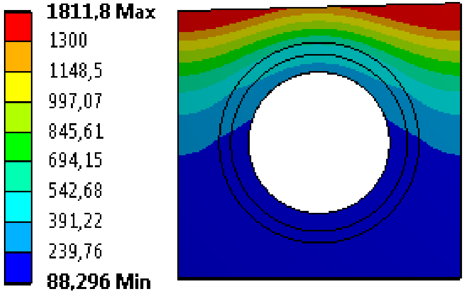
h_{tc} at 5MPa, 60 C°, 11m/s

whole block **below** the **recrystallization temp.**	**Central part below** the recrystallization temp.

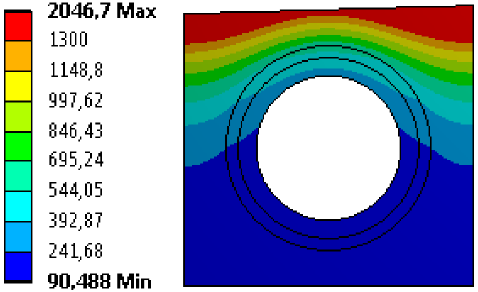
q=17.2 MW/m2



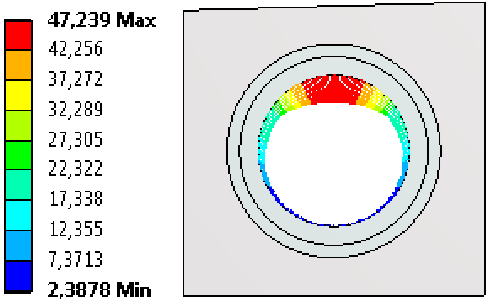
q=24 MW/m2



1.4 margin from CHF



q=27.2 MW/m2

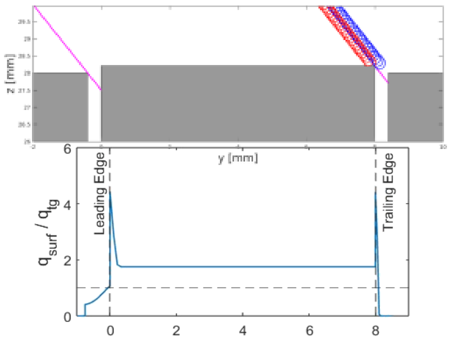


Conceptual design: toroidal shaping

SS and slow transient limit loads: ion orbit modelling

Gyrokinetic effects on the toroidal leading edges in SN configuration

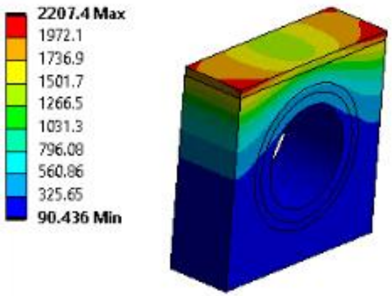
Inner vertical target



$Step_{MB}$ inside the same PFU

0.2 mm

$\mathrm{IHF_{max}} = 26.3\ \mathrm{MW/m^2}$



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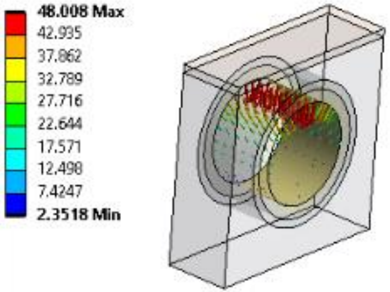
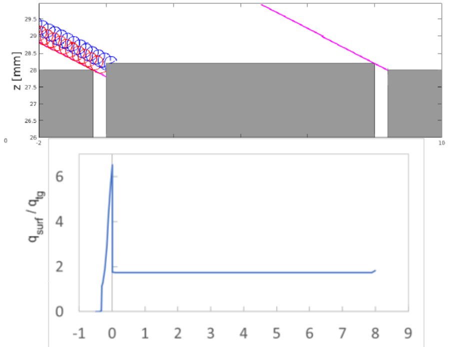


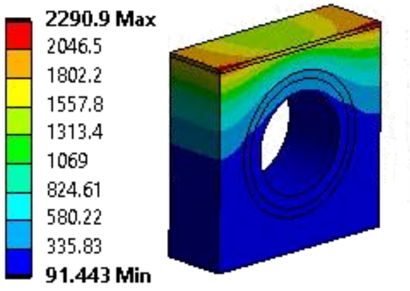
Outer vertical target



$Step_{MB}$ inside the same PFU

0.2 mm

$\mathrm{ICHF} = 24.6\mathrm{MW/m^2}$



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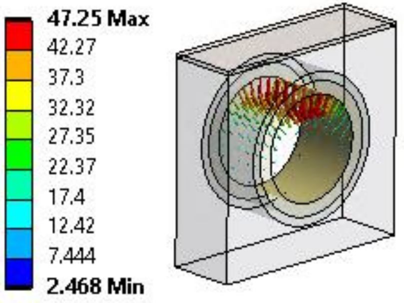

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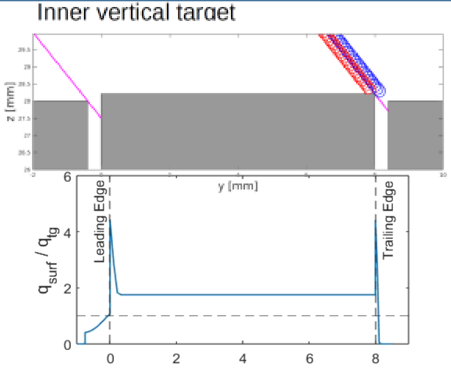

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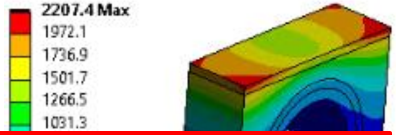

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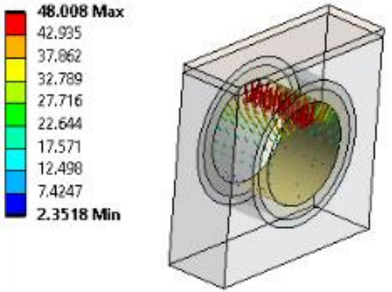
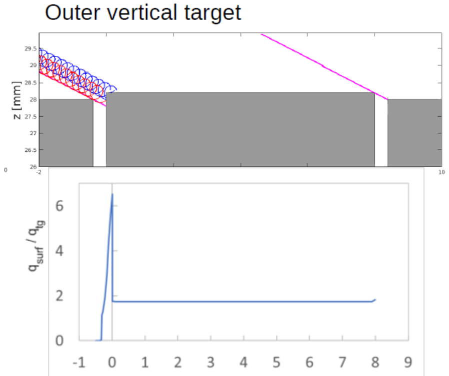


PRELIMINARY RESULT CONSIDERATIONS:

A decrease in the maximum allowable heat flux is observed, in particular at the OVT.

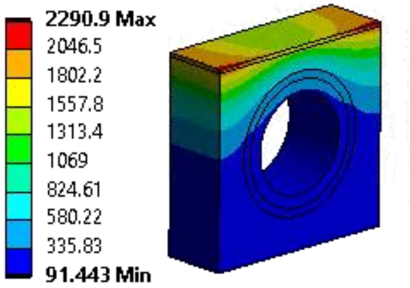
The decrease does not justify the adoption of a polydal bevel

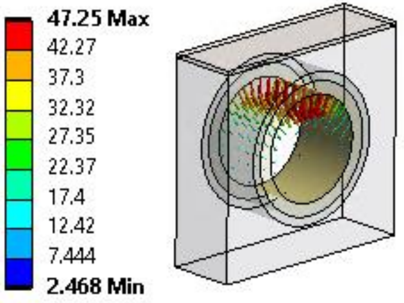


same PFU

0.2 mm

1.4 margin from the CHF





First DTT Divertor: qualification activities

Armour thickness assessment

By reducing the thickness of the armor MB plastic deformation is limited and mechanical and physical characteristics of the plasma-facing surface preserved.
The fatigue life must be assessed

Margin from the Critical Heat Flux evaluation

In particular to evaluate how a Dome without twisted tape is penalizing

Feasibility study of Flat Tiles design for a 90 ° curve

Small mock-ups have to be manufactured to be tested at thermal fatigue up to 10 MW/m^2

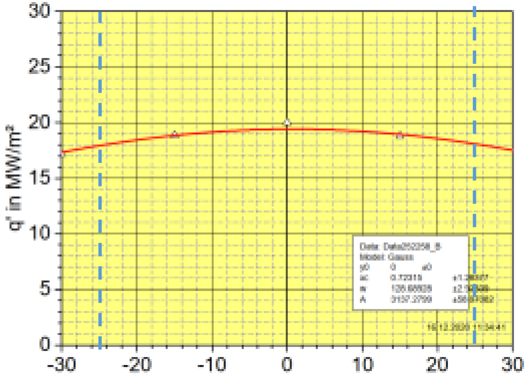
Qualification activities: armour thickness assessment

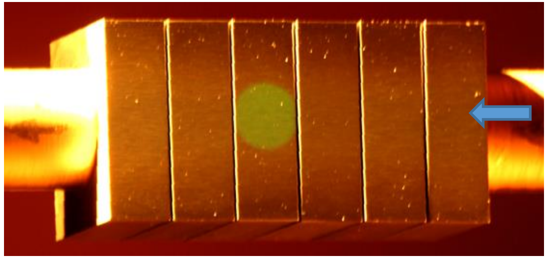
two mock-ups were manufactured **by HRP in ENEA lab.** to be tested at **20 MW/m2** per **1000 cycles** in the GLADIS Facility

DTT-T02 mock-up with 4 mm di armour thickness

DTT-T03 mock-up with 3 mm di armour thickness

Applied 20 MW/m² heat flux profile





Focus of the two-colour pyrometer

Technical capabilities of GLADIS

- Power 2 x 1 MW ion source, H_2
- U_{ex} 15 – 55 kV
- Heat flux 3 - 45 MW/m², 150 mm FWHM
  ∅ 50 mm (95% q'max)
- Pulse length 1 ms - 45 s
- Cycle rate 80 - 100 /h
- Target dim. mm size up to 60 cm (max. 2m)
- Target cooling: 20-230 °C inlet, 1-4 MPa, < 8l/s
  „high purity water" fulfils ITER requirements
- Capability for operation with H/He beam

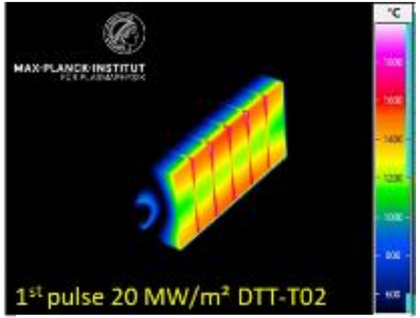
hydraulic conditions during the test

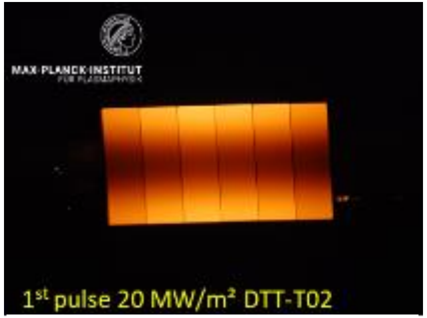
T_{in}=130°C;
p_{in} 40 bar; ← p_{in} 50 bar;
v= 14 m/s; ← v 11m/s

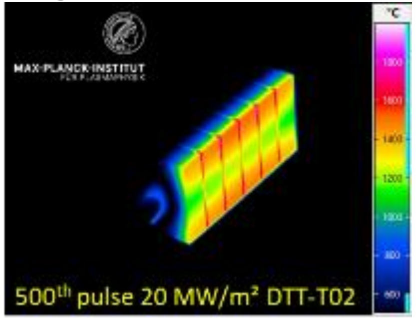
lower available pressure -> increased the flow rate to verify the margin 1.4 from the critical heat flux

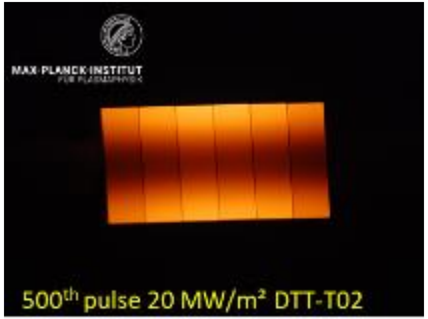
Ongoing HHF tests

DTT-T02 (4 mm) during the HHF test

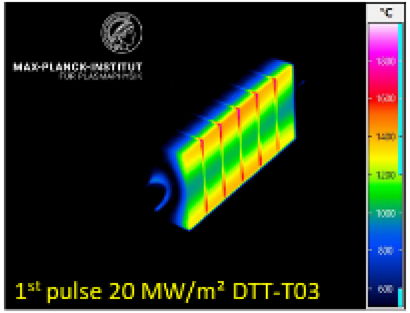


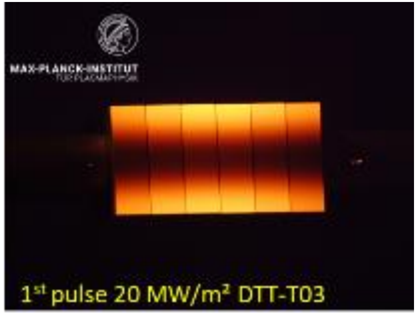


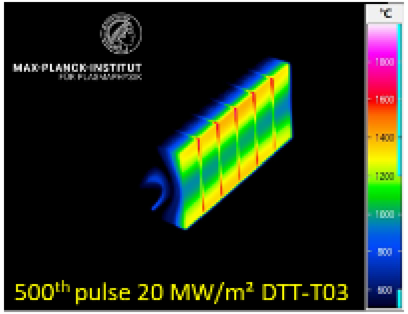


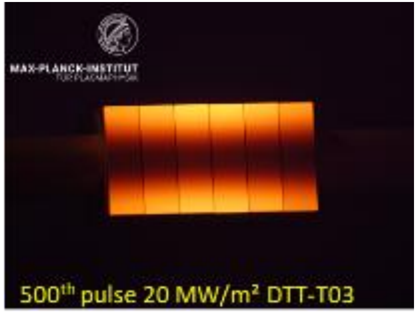


infrared camera — CCD camera — infrared camera — CCD camera







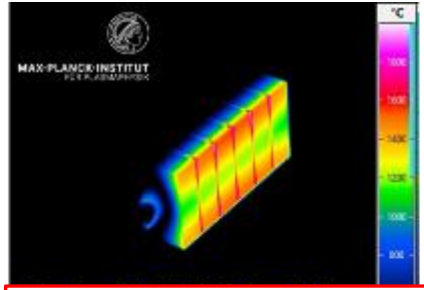


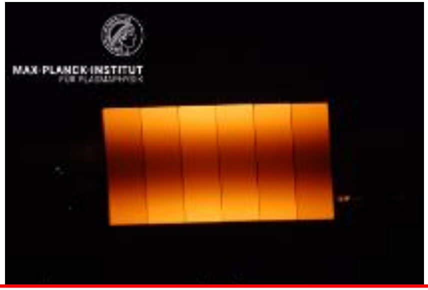
DTT-T03 (3 mm) during the HHF test

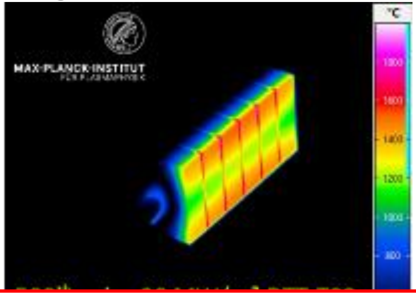
By H. Greuner and Bernd Böswirth

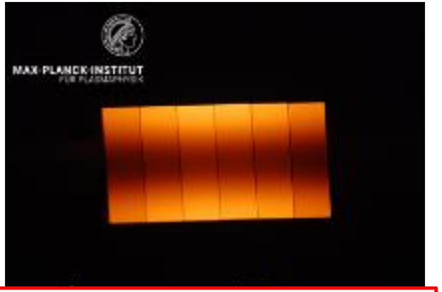
Ongoing HHF tests

DTT-T02 (4 mm) during the HHF test

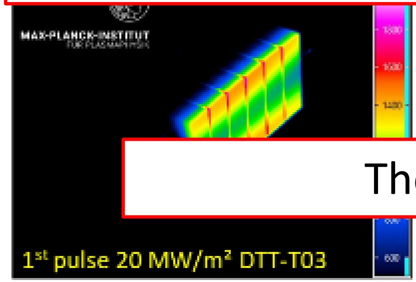


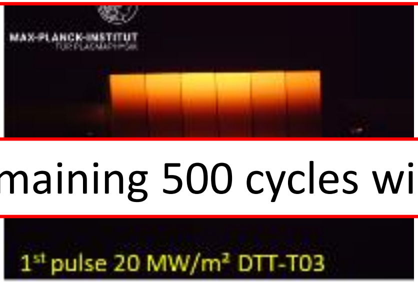


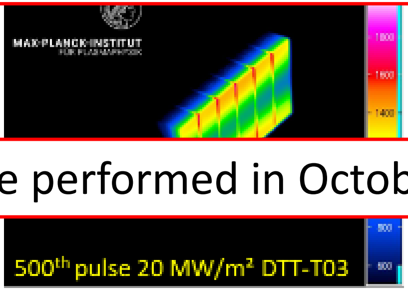


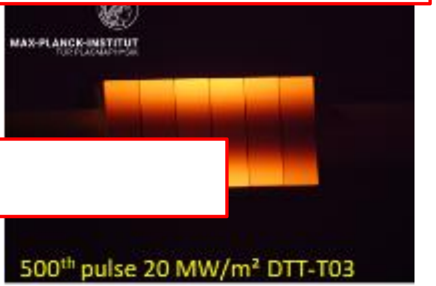


➔ No indication of any defects and no change of temperature distribution during cycling on both mock-ups.









The remaining 500 cycles will be performed in October

DTT-T03 (3 mm) during the HHF test

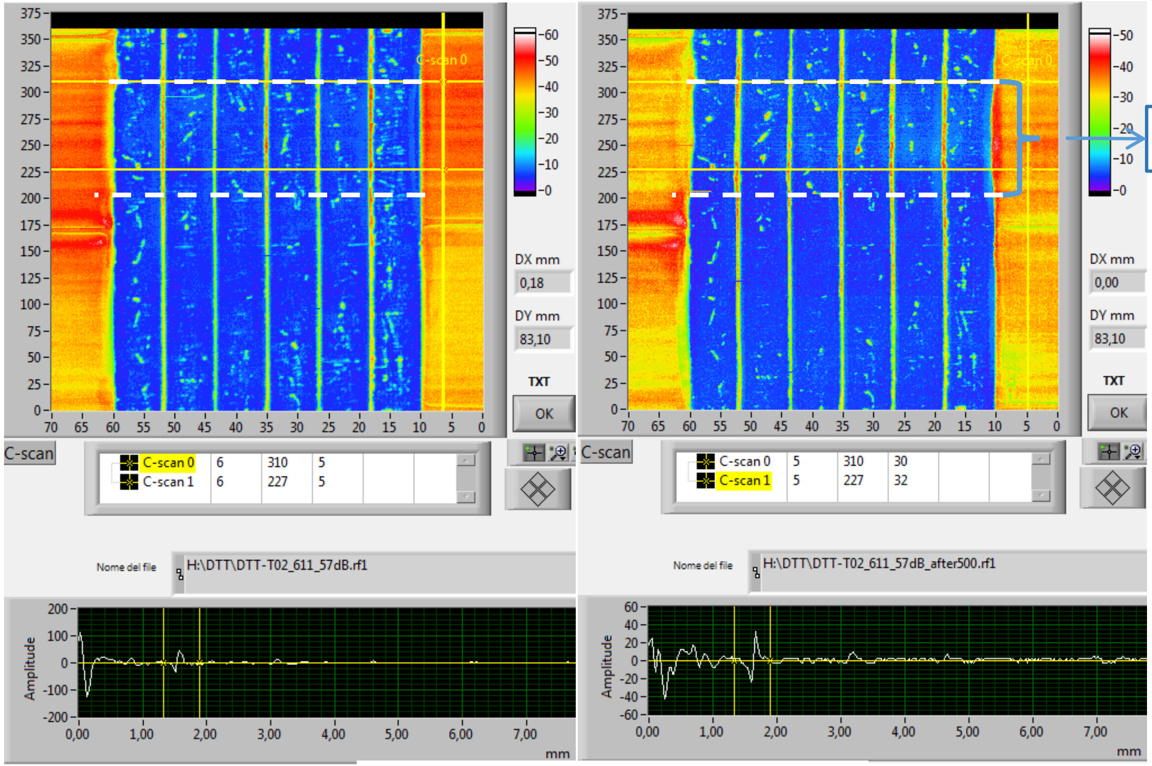
By H. Greuner and Bernd Böswirth

Qualification activities: armour thickness assessment

Intermediate results: UT results after 500 x 20 MW/m² - DTT-T-02

BEFORE

AFTER 500 CYCLES



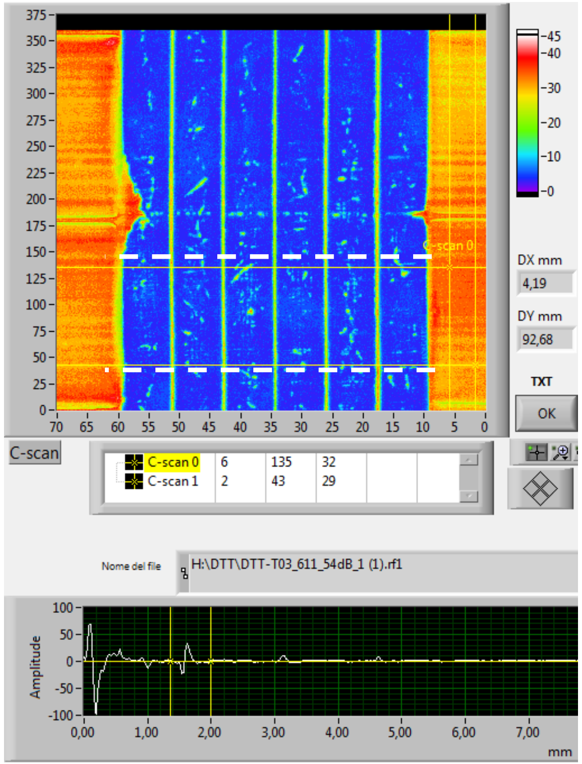
HHF side

C-scan at HRP interface

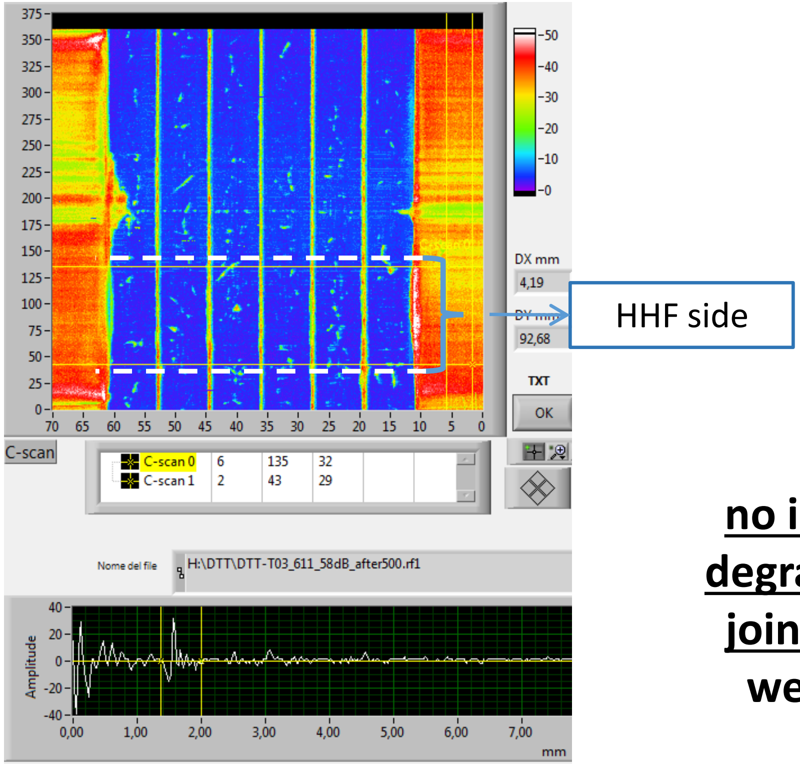
<u>no indications of degradation of the jointed interface</u> **were detected**

Intermediate results: UT results after 500 x 20 MW/m² - DTT-T-03

BEFORE



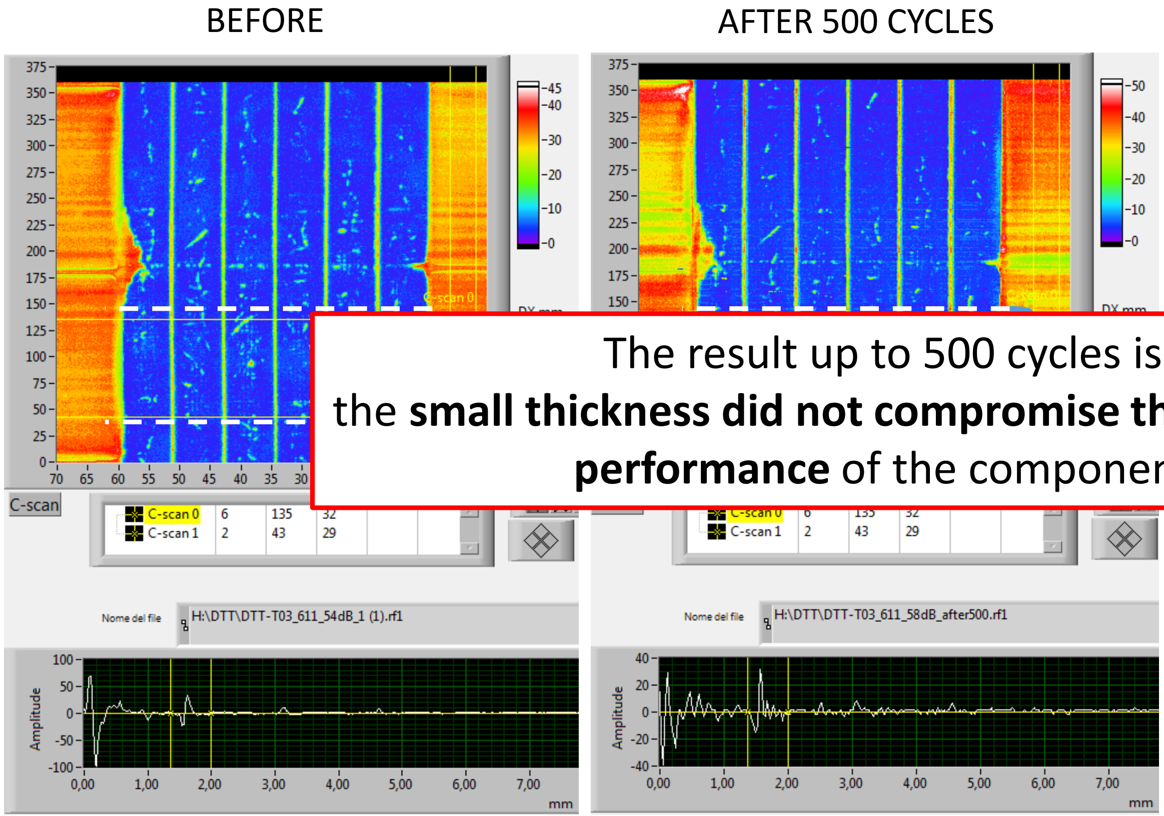
AFTER 500 CYCLES



C-scan at HRP interface

no indications of degradation of the jointed interface were detected

Intermediate results: UT results after 500 x 20 MW/m² - DTT-T-03



The result up to 500 cycles is the **small thickness did not compromise the mechanical performance** of the component

C-scan at HRP interface

<u>**no indications of degradation of the jointed interface**</u> **were detected**

Qualification activities: CHF Margin Assessment

Motivation for the experimental campaign

standard operating conditions for the first divertor

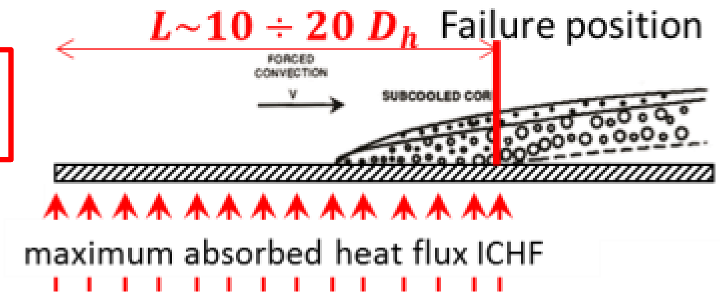
	WCHF* [MW/m^2]		WHF_{max} =**WCHF/1.4** [MW/m^2]		**IHF_{max}**** [MW/m^2]	
	IVT/OVT Swirl	Dome No Swirl	IVT/OVT Swirl	Dome No Swirl	IVT/OVT Swirl	Dome No Swirl
T=30 °C	86.98	58.8	62.1	41.9	35.5	23.5
T=60 °C	**66.3**	**45.2**	**47.3**	**32.3**	**27.3**	**18.46**

*by $TONG_{Dh}$-CEA correlation

**by ANSYS simulations*

Swirl: Twisted Tape, Y=pitch/2Dh=2, Thickness=0.8 mm, v=11 m/s P=5MPa

The CHF depends on:
Loaded axial length



the **semi-empirical correlations estimate the CHF** in case the loaded length is between **10 and 20 times the hydraulic diameter**

Motivation for the experimental campaign

standard operating conditions for the first divertor

	WCHF* [MW/m^2]		WHF_{max} =**WCHF/1.4** [MW/m^2]		**IHF_{max}**** [MW/m^2]	
	IVT/OVT Swirl	Dome No Swirl	IVT/OVT Swirl	Dome No Swirl	IVT/OVT Swirl	Dome No Swirl
T=30 °C	86.98	58.8	62.1	41.9	35.5	23.5
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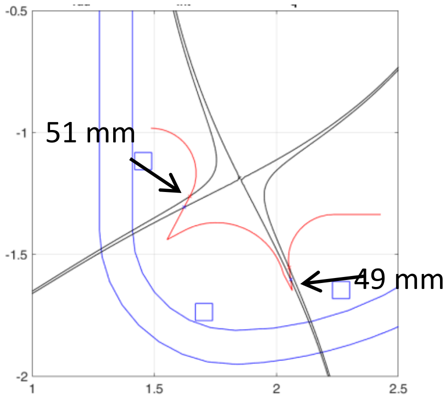
Swirl: Twisted Tape, Y=pitch/2Dh=2, Thickness=0.8 mm, v=11 m/s P=5MPa

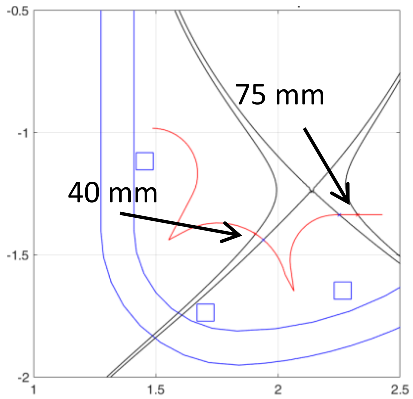


SN

The DTT PFU have the same hydraulic diameter as in ITER and DEMO, but a **much smaller loaded area**

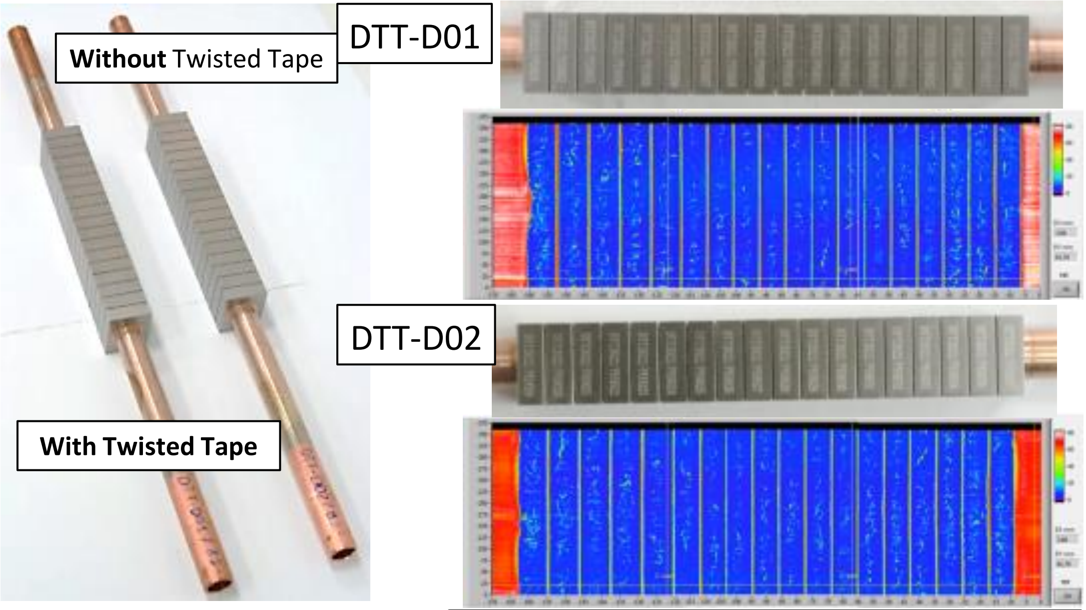
1.4 of Margin may be too conservative when applied to DTT

NT



Purpose of the tests

Two 18 monoblock mock-ups were manufactured by HRP to be tested at the HADES Facility (electron-beam gun).
Two more identical mock-ups will be manufactured and tested later this year



The UT examination show the good manufacturing of the mock-ups

Purposes of the tests are:

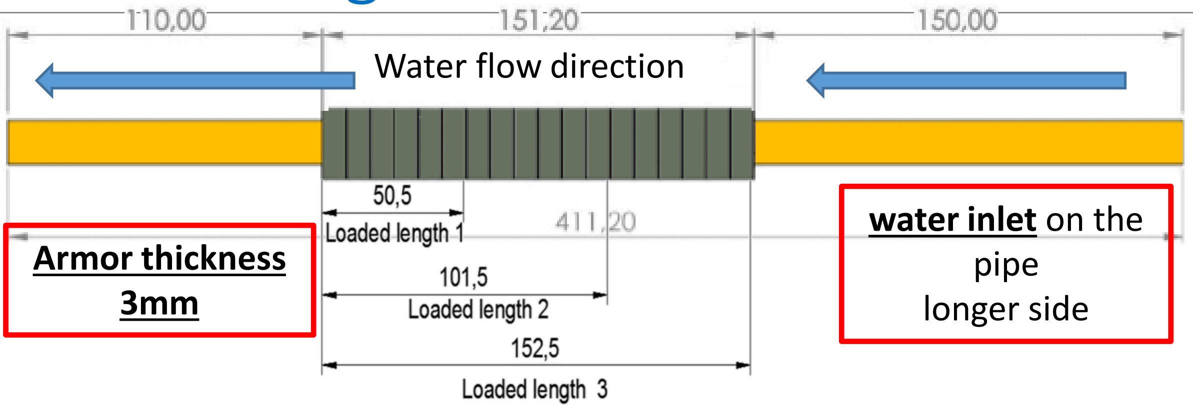
- **Assess the actual CHF at DTT standard hydraulic conditions (60°C)** for a **loaded axial** length comparable with the **plasma footprint** (SN and NT scenarios)
- **quantify the relationship between the loaded length and CHF**

Qualification activities: CHF Margin Assessment

EUROfusion

Test matrix

Max available load in HADES
~13 **[MW/m2]@**Loaded length 3
~19**[MW/m2]@** Loaded length 2
~35 **[MW/m2]@**Loaded length 1



Armor thickness 3mm

water inlet on the pipe longer side

v=11 m/s; P=3.5 bar

Without Twisted Tape (D02)							
T_w [°C]	*fp***	IHF [MW/m²]					T_{max} [°C] @35MW/m2
		CHF*	ICHF**	Loaded length 3	Loaded length 2	Loaded length 1	
60	1.78	39.2	22	-	-	from 15-to 35 or CHF	3234
140	1.8	21.4	11.8	from 5 - to CHF	from 7- to CHF	from 8- to CHF	

With Twisted Tape (D01)							
T_w [°C]	*fp***	IHF [MW/m²]					T_{max} [°C] @35MW/m2
		CHF*	ICHF**	Loaded length 3	Loaded length 2	Loaded length 1	
60	1.85	59.1	32	-	-	from 10- to 35 or CHF	3152
200	1.8	20.9	11.6	from 5 - to CHF	from 5 - to CHF	from 9- toCHF	

*by TONG$_{Dh}$-CEA correlation

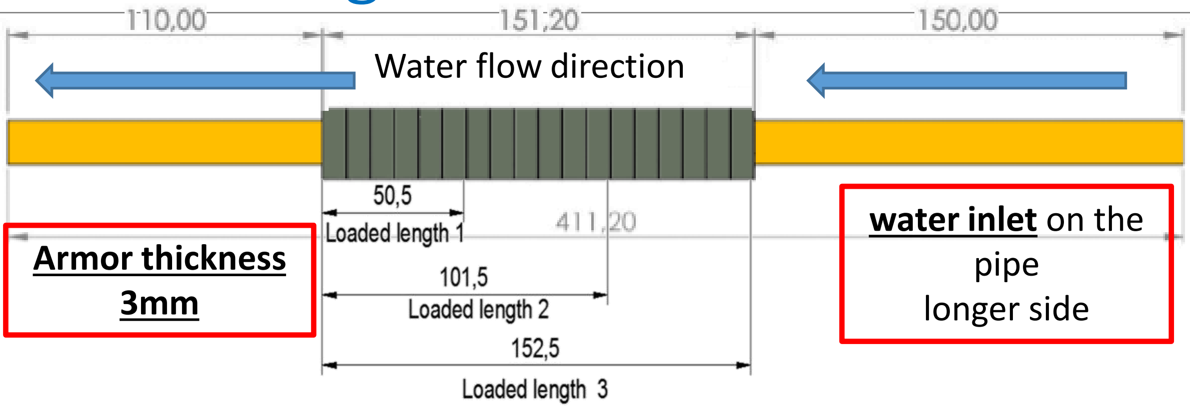
**ANSYS simulations

Qualification activities: CHF Margin Assessment

EUROfusion

Test matrix

Max available load in HADES
~13 **[MW/m2]@**Loaded length 3
~19**[MW/m2]@** Loaded length 2
~35 **[MW/m2]@**Loaded length 1



Armor thickness 3mm

water inlet on the pipe longer side

v=11 m/s; P=3.5 bar

Without Twisted Tape (D02)							
T_w [°C]	fp**	IHF [MW/m²]					T_{max} [°C] @35MW/m2
		CHF*	ICHF**	Loaded length 3	Loaded length 2	Loaded length 1	
60	1.78	39.2	22	-	-	from 15-to 35 or CHF	3234
140	1.8	21.4	11.8	from 5 - to CHF	from 7- to CHF	from 8- to CHF	

Assess the actual CHF the load is applied over a **length of 50 mm** (close to the footprint) and a water temperature of 60°C

T_w [°C]	fp**	IHF [MW/m²]					T_{max} [°C] @35MW/m2
		CHF*	ICHF**	Loaded length 3	Loaded length 2	Loaded length 1	
60	1.85	59.1	32	-	-	from 10- to 35 or CHF	3152
200	1.8	20.9	11.6	from 5 - to CHF	from 5 - to CHF	from 9- toCHF	

*by TONG$_{Dh}$-CEA correlation

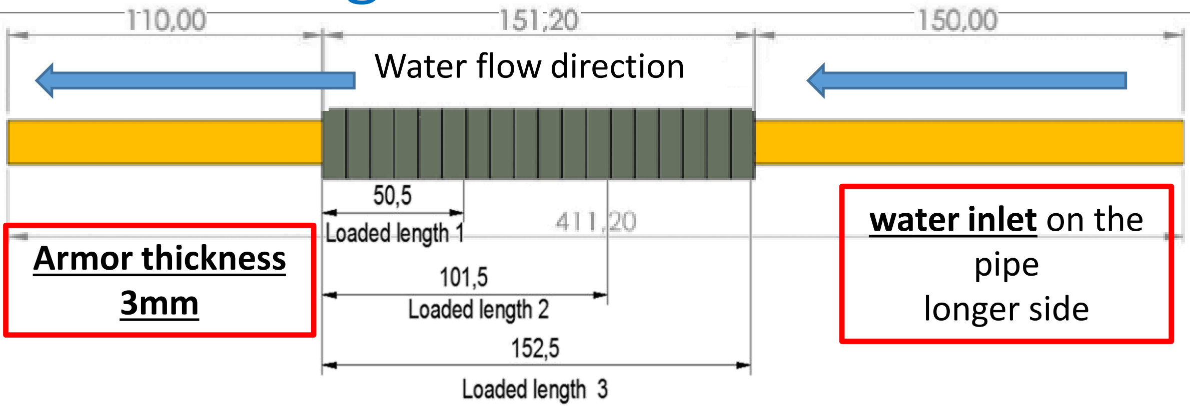
**ANSYS simulations

Qualification activities: CHF Margin Assessment

EUROfusion

Test matrix

Max available load in HADES
~13 **[MW/m2]@**Loaded length 3
~19**[MW/m2]@** Loaded length 2
~35 **[MW/m2]@**Loaded length 1



v=11 m/s; P=3.5 bar

Without Twisted Tape (D02)							
T_w *[°C]*	*fp***	IHF [MW/m²]					T_{max} [°C] @35MW/m2
		CHF*	ICHF**	Loaded length 3	Loaded length 2	Loaded length 1	
60	1.78	39.2	22	-	-	From 15-to 35 or CHF	3234
140	1.8	21.4	11.8	from 5 - to CHF	from 7- to CHF	from 8- to CHF	

To quantify the relationship between the loaded length and CHF, three axial lengths are loaded. The water temperature was increased so that the CHF could also be achieved loading the length 3

T_w *[°C]*							
		CHF*	ICHF**	Loaded length 3	Loaded length 2	Loaded length 1	@35MW/m2
60	1.85	59.1	32	-	-	from 10- to 35 or CHF	3152
200	1.8	20.9	11.6	from 5 - to CHF	from 5 - to CHF	from 9- toCHF	

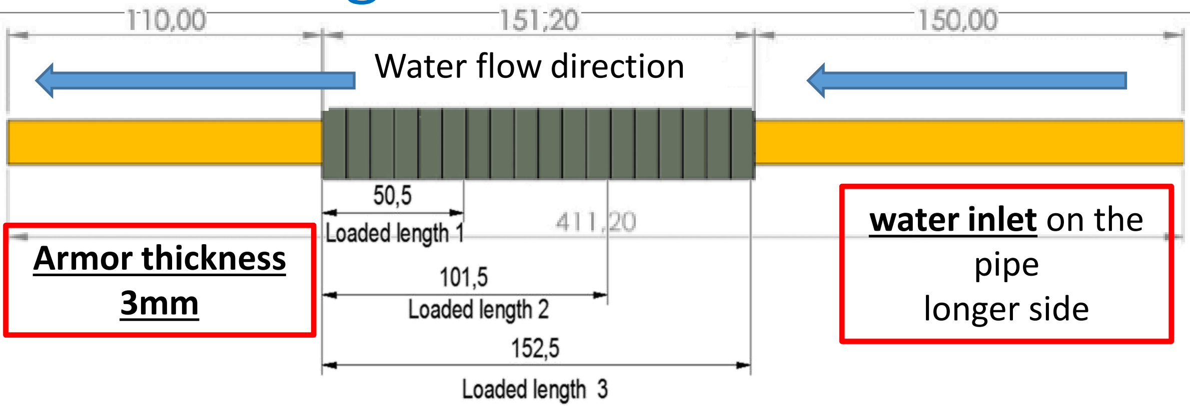
**by TONG$_{Dh}$-CEA correlation* ***ANSYS simulations*

Qualification activities: CHF Margin Assessment

EUROfusion

Test matrix

Max available load in HADES
~13 **[MW/m2]@**Loaded length 3
~19**[MW/m2]@** Loaded length 2
~35 **[MW/m2]@**Loaded length 1



Armor thickness 3mm

water inlet on the pipe longer side

v=11 m/s; P=3.5 bar

Without Twisted Tape (D02)							
T_w *[°C]*	*fp***	IHF [MW/m²]					T_{max} [°C] @35MW/m2
		CHF*	ICHF**	Loaded length 3	Loaded length 2	Loaded length 1	
60	1.78	39.2	22	-	-	From 15-to 35 or CHF	3234
140	1.8	21.4	11.8	from 5 - to CHF ✓	from 7- to CHF ✓	from 8- to CHF	

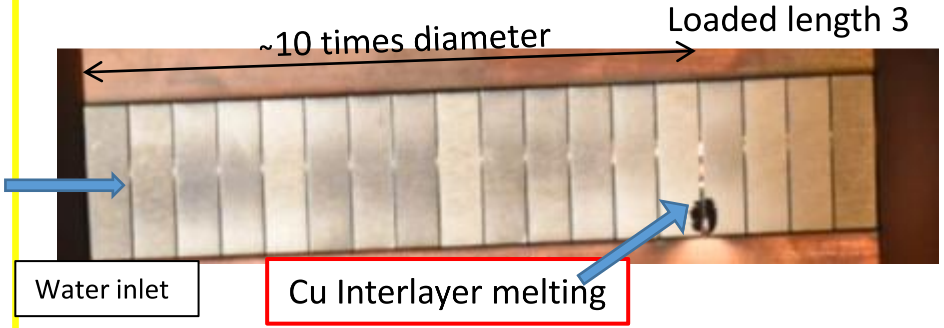
With Twisted Tape (D01)							
T_w *[°C]*	*fp***	IHF [MW/m²]					T_{max} [°C] @35MW/m2
		CHF*	ICHF**	Loaded length 3	Loaded length 2	Loaded length 1	
60	1.85	59.1	32	-	-	10-35 or CHF ✓	3152
200	1.8	20.9	11.6	from 5 - to CHF ✓	from 5 - to CHF ✓	from 9- toCHF	

**by TONG$_{Dh}$-CEA correlation* ***ANSYS simulations*

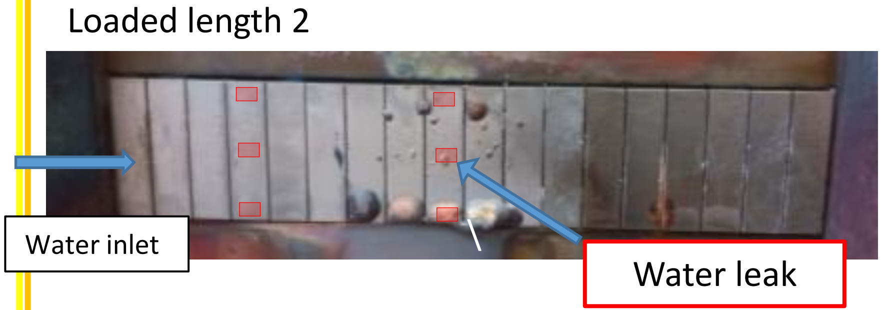
Qualification activities: CHF Margin Assessment

Preliminary results: without twisted tape

Without Twisted Tape (D02)							
T_w [°C]	*fp***	IHF [MW/m²]					T_{max} [°C] @35MW/m2
		CHF*	ICHF**	Loaded length 3	Loaded length 2	Loaded length 1	
60	1.78	39.2	22	-	13-19	15-35 or CHF	3234
140	1.8	21.4	11.8	5- CHF	7-CHF	8-CHF	



Excellent agreement with Tong-CEA correlation CHF occurred at a distance of 10 times the diameter at 12.3 MW/m² (by correlation 11.8 MW/m²)



CHF occurred at a distance of 76mm at 14 MW/m² (by correlation 11.8 MW/m²). CHF increased by 14% reducing loaded length by 1/3

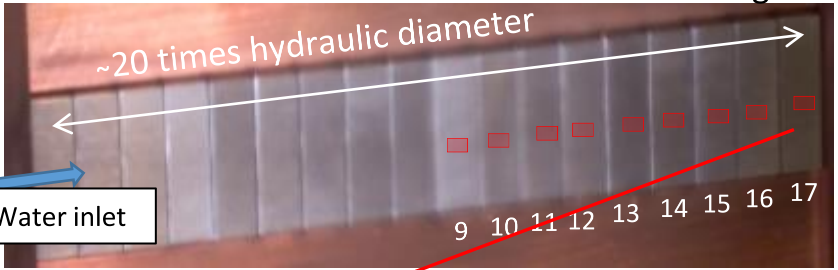
due to the breakage of the mock-up, the test was interrupted
A **mock-up of 6 monoblocks will be used to finish the tests**

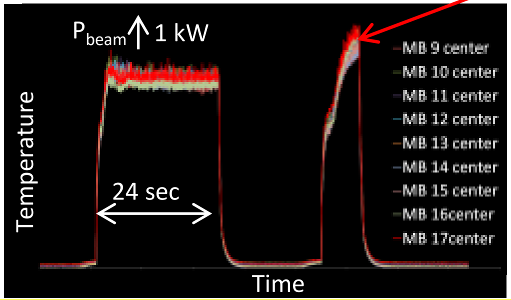
Qualification activities: CHF Margin Assessment

Preliminary results: with twisted tape

With Twisted Tape (D01)							
T_w *[°C]*	*fp***	IHF [MW/m²]					T_{max} [°C] @35MW/m2
		CHF*	ICHF**	Loaded length 3	Loaded length 2	Loaded length 1	
60	1.85	59.1	32	-	-	10-35 or CHF	3152
200	1.8	20.9	11.6	5-CHF	5-CHF	9-CHF	

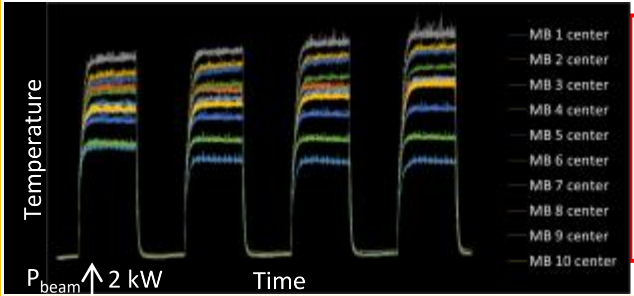
Loaded length 3





sudden temperature increase in the MBs far from the water inlet @ 12.3 MW/m²

Loaded length 2



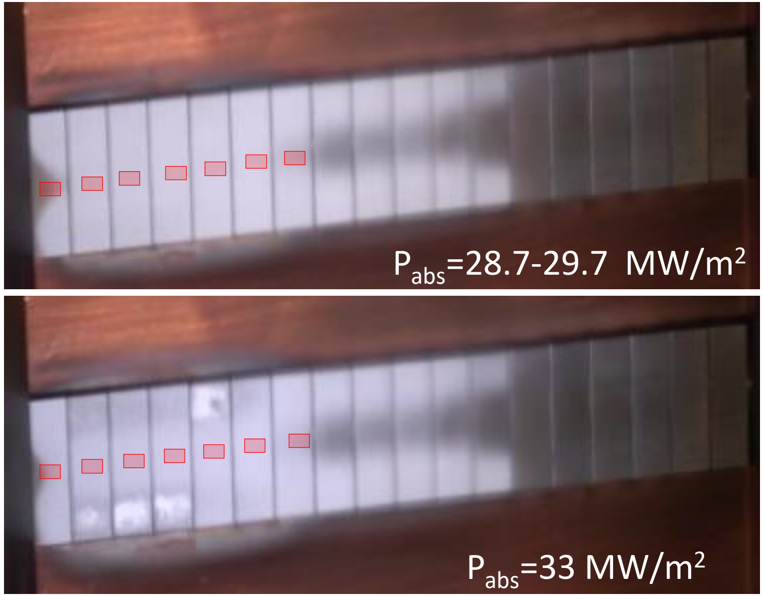
No indication until 15.5 MW/m². **To be continued**

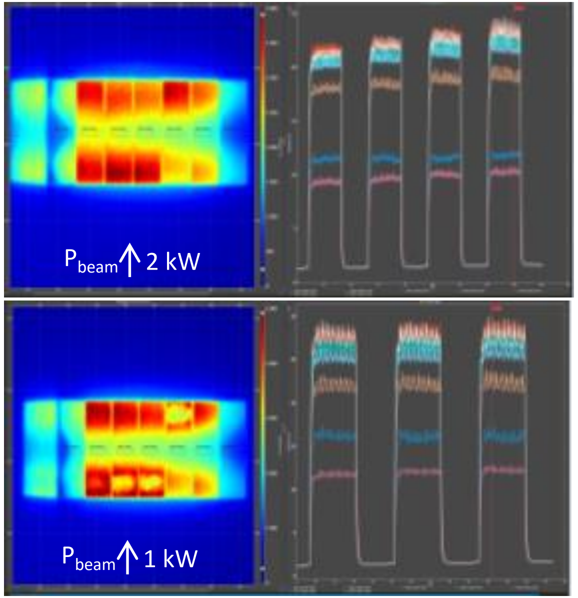
Temp. trend at the MB center during the last two shots

Qualification activities: CHF Margin Assessment

Preliminary results: with twisted tape

With Twisted Tape (D01)							
T_w [°C]	*fp***	IHF [MW/m²]					T_{max} [°C] @35MW/m2
		CHF*	ICHF**	Loaded length 3	Loaded length 2	Loaded length 1	
60	1.85	59.1	32	-	-	10-35 or CHF	3152
200	1.8	20.9	11.6	5-CHF	5-CHF	9-CHF	

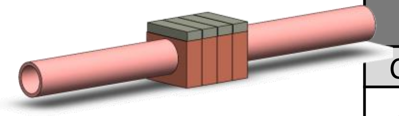




Loaded length 1 (60°C)

No indication of CHF until the Tungsten melting @33 MW/m²

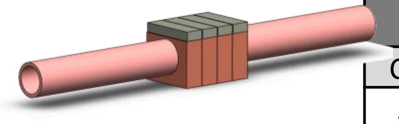
Progress in the FT mock-up manufacturing



HHF Testing parameters				
Cycles	q [MW/m^2]	T_w [°C]	p [bar]	v [m/s]
5000	5	130	40	11
300	10	130	40	11

Feasibility study of FT solution for a 90 ° curve

Progress in the FT mock-up manufacturing

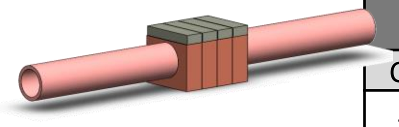


HHF Testing parameters				
Cycles	q [MW/m^2]	T_w [°C]	p [bar]	v [m/s]
5000	5	130	40	11
300	10	130	40	11

W Flat Tiles on Cu monoblocks manufactured by Cu casting (bubbles detected by UT at interface with W)

Feasibility study of FT solution for a 90 ° curve

Progress in the FT mock-up manufacturing



HHF Testing parameters				
Cycles	q [MW/m²]	T_w [°C]	p [bar]	v [m/s]
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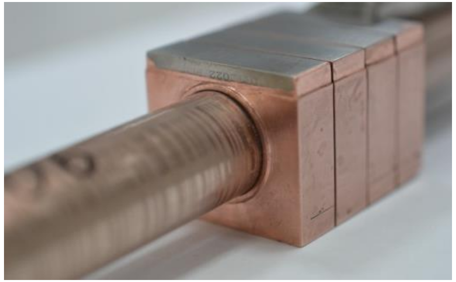
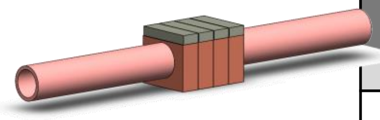
W Flat Tiles on Cu monoblocks manufactured by Cu casting (bubbles detected by UT at interface with W)



Flat tiles mock-up by HRP

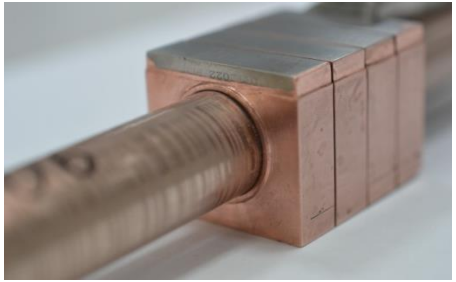
Feasibility study of FT solution for a 90 ° curve

Progress in the FT mock-up manufacturing



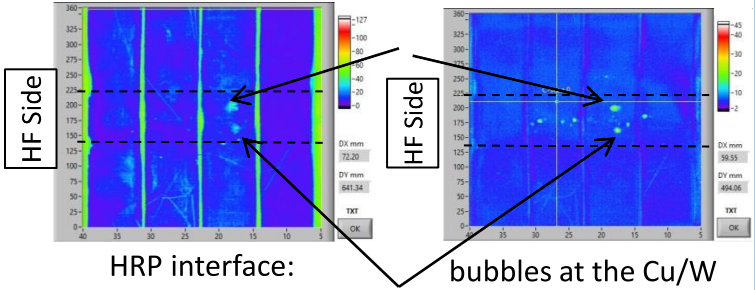
HHF Testing parameters				
Cycles	q [MW/m²]	T_w [°C]	p [bar]	v [m/s]
5000	5	130	40	11
300	10	130	40	11

W Flat Tiles on Cu monoblocks manufactured by Cu casting (bubbles detected by UT at interface with W)



Flat tiles mock-up by HRP

Ultrasonic Test results after manufacturing showed excellent joining at the HRP interface by validating the process parameters and equipment

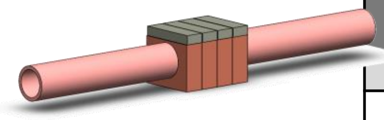


HRP interface:
2 defects in the MB #2 caused by bubbles present at the interface with the W

bubbles at the Cu/W interfaces already present in the MB

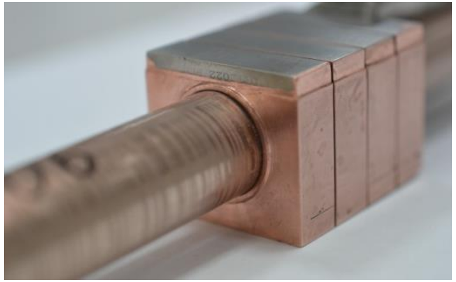
Feasibility study of FT solution for a 90 ° curve

Progress in the FT mock-up manufacturing



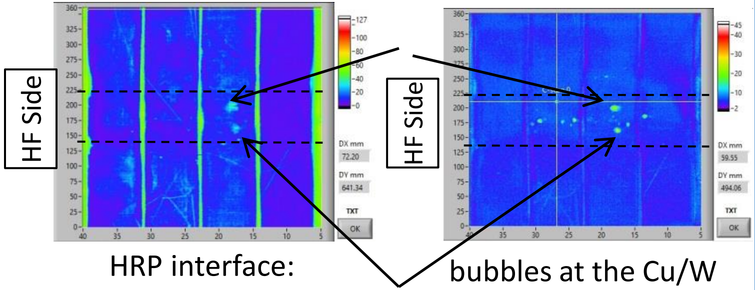
HHF Testing parameters				
Cycles	q [MW/m²]	T_w [°C]	p [bar]	v [m/s]
5000	5	130	40	11
300	10	130	40	11

W Flat Tiles on Cu monoblocks manufactured by Cu casting (bubbles detected by UT at interface with W)



Flat tiles mock-up by HRP

Ultrasonic Test results after manufacturing showed excellent joining at the HRP interface by validating the process parameters and equipment



HRP interface:
2 defects in the MB #2 caused by bubbles present at the interface with the W

bubbles at the Cu/W interfaces already present in the MB

The **parameters of the HRP process have been modified to obtain the junction between the Cu block** and CuCrZr pipe.

The **same parameters** were **used** for the fabrication of **the W monoblock small mock-ups** under testing HADES and GLADIS with positive results.

FT at the Dome extremity and W monoblocks can be joined to CuCrZr tubes during the same HRP cycle

Final Remarks

- The purpose of this **first** divertor is
  - to be **flexible to test different magnetic configurations** and **scenarios** thanks to **large private region room** and
  - to be **reliable** thanks to the **high allowable thermal loads**.
- Its design was born taking into account the manufacturing constraints, **speeding up and simplifying the qualification phase**
- The design is in the engineering phase.
- The **qualification** of the components is ongoing with positive **results**.
- **Full scale prototype** planned for late next year.

Thanks for your attention

and thanks to the
In-Vessel Component team

DTT:

IVC WBS Coor.: B.Riccardi, DIV RO: F. Giorgetti, FW RO: M. Furno Palumbo

ENEA Labs:

M. Angelucci, E. Cacciotti, F. Crea, F. Crescenzi, R. De Luca, G. De Sano (Tor Vergata phd student), G. Dose, P. Frosi, M. Iafrati, P. Lorusso, A. Mancini, E. Martelli, A. Moriani, A. Satriano, A. Tatì, L. Verdini and S. Roccella

RFX:

P. Innocente, L. Balbinot (UniTus phd student)

PoliMi:

M. Passoni

CREATE:

D. Marzullo, N. Massanova

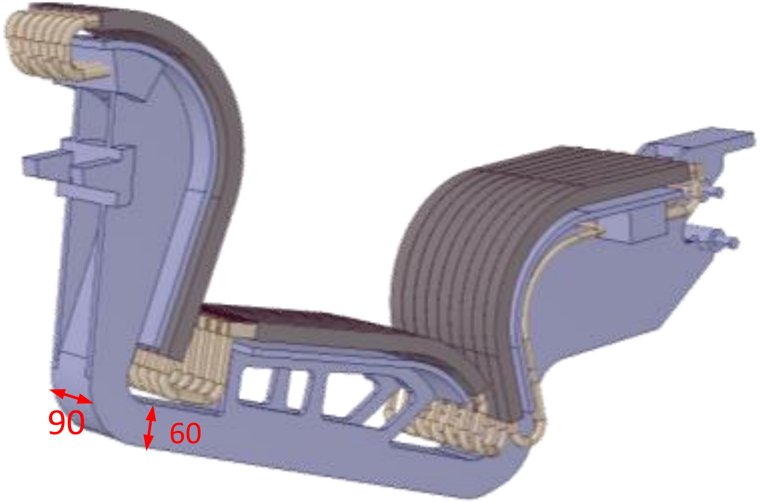
JSI:

B. Končar , O.Costa and P. Tarfila

Conceptual design: divertor module

The design

The **PFUs connected in series externally to the cassette** to reduce the **size of the cassette body**



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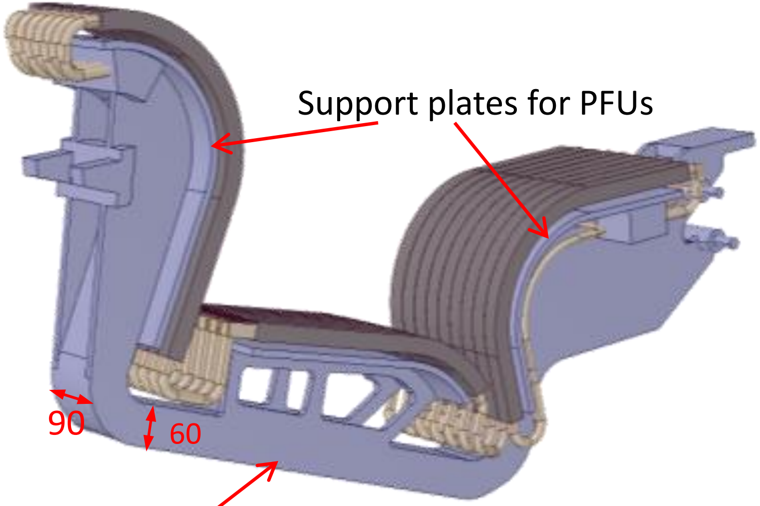

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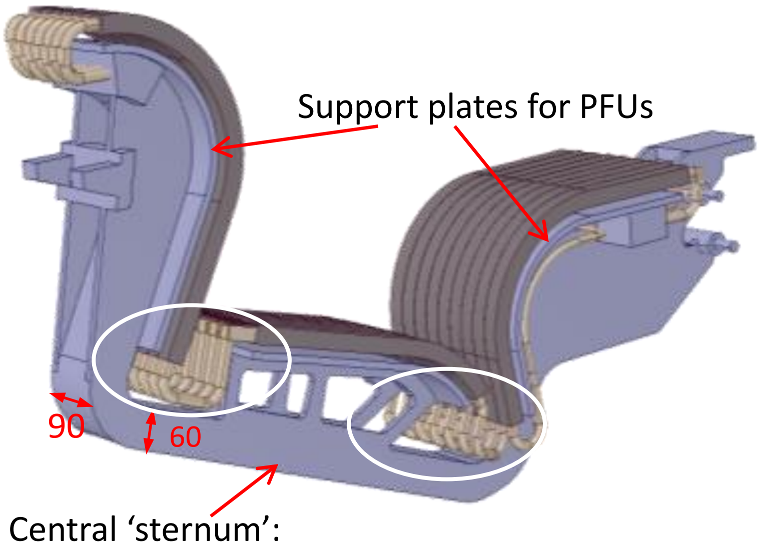
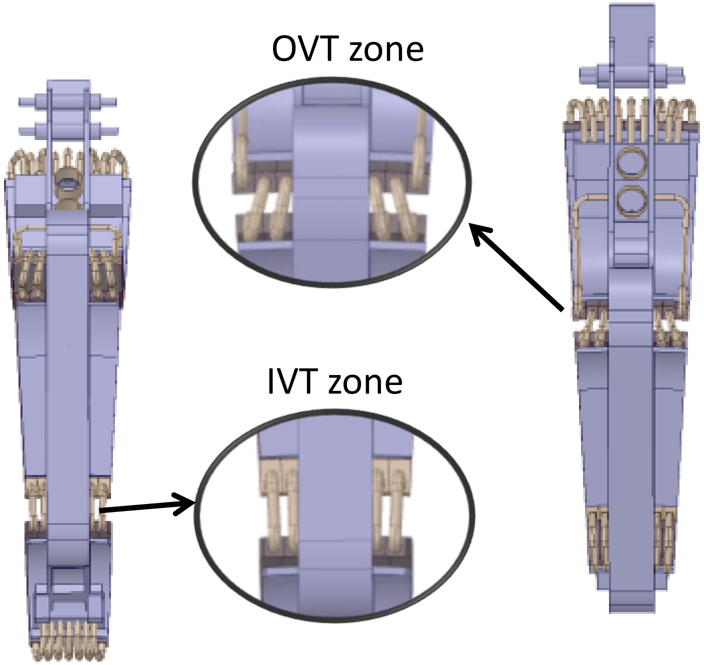


Slots for the pumping



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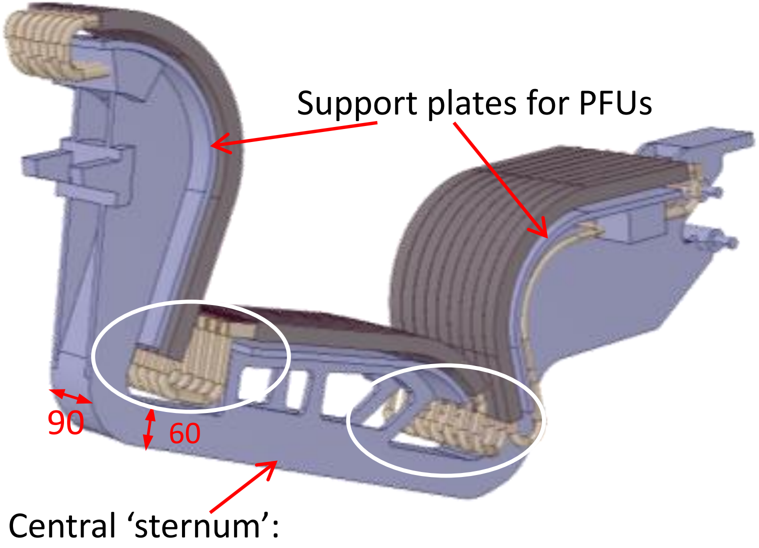
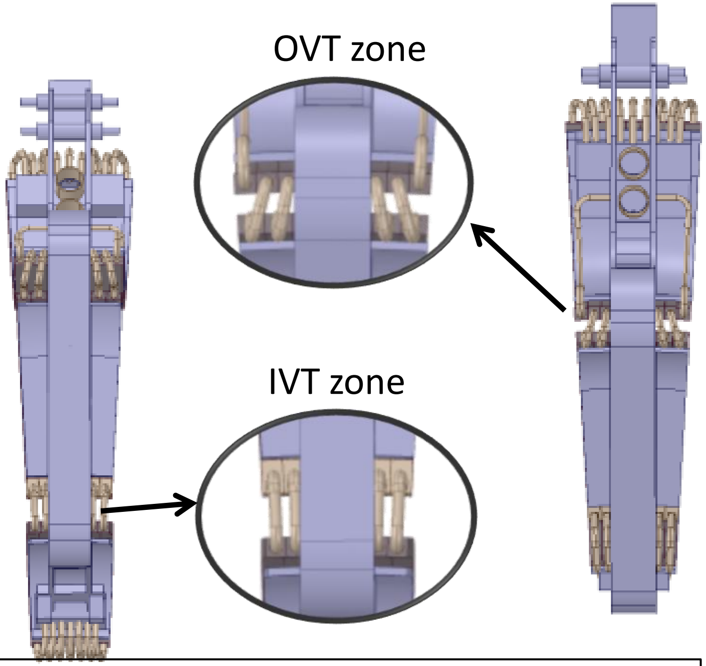


Slots for the pumping



3D simulations have demonstrated that the slots are adequate for SN configuration.

Conceptual design: divertor module

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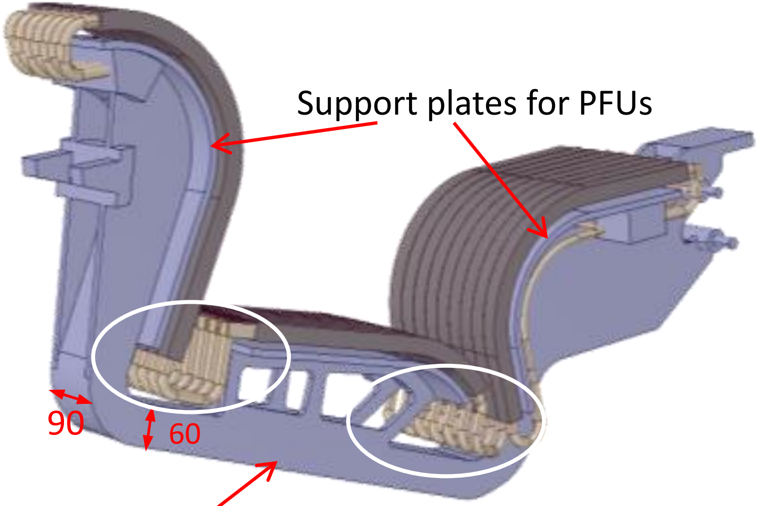
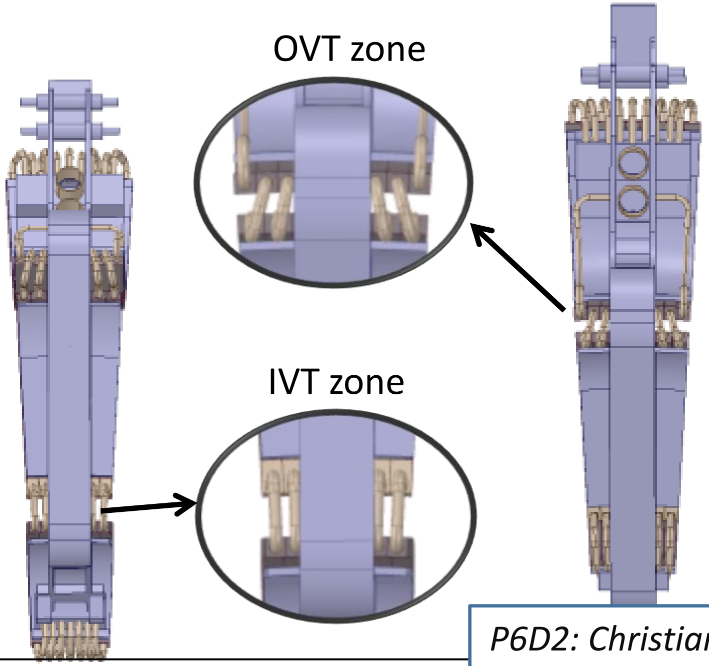
The **PFUs connected in series externally to the cassette** to reduce the **size of the cassette body**



Slots for the pumping



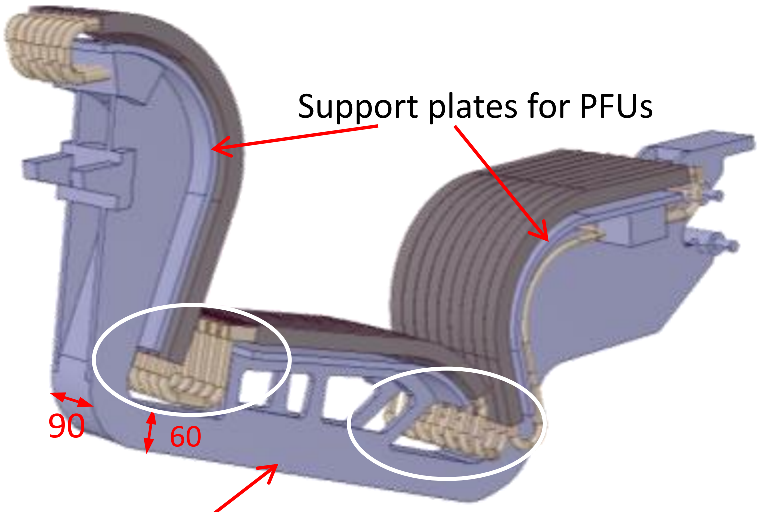
3D simulations have demonstrated that the slots are adequate for SN configuration.

P6D2: Christian Day (on Thursday)

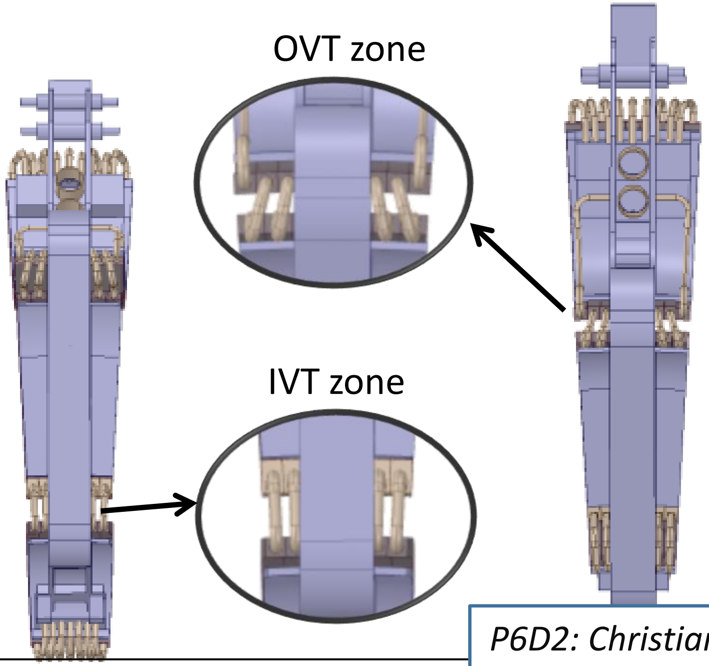
Conceptual design: divertor module

The design

The **PFUs connected in series externally to the cassette** to reduce the **size of the cassette body**



Slots for the pumping



3D simulations have demonstrated that the slots are adequate for SN configuration.
Design modifications are being studied to improve the pumping capacity and neutral compression for configurations with strike point on the Dome

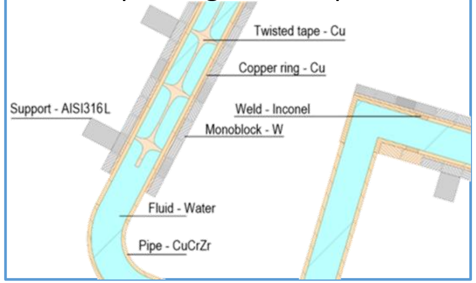
P6D2: Christian Day (on Thursday)

Conceptual design: poloidal shaping

Thermo-fluid dynamics&mechanical analysis

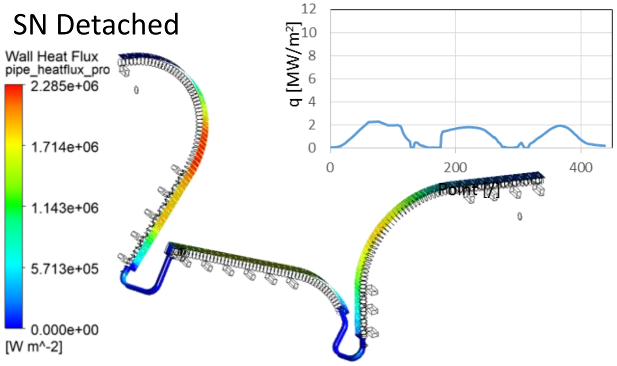
CFD Model:

- Single-phase fluid model
- Conjugate heat transfer
- k-w SST turbulence model
- Pipe roughness: 5 µm

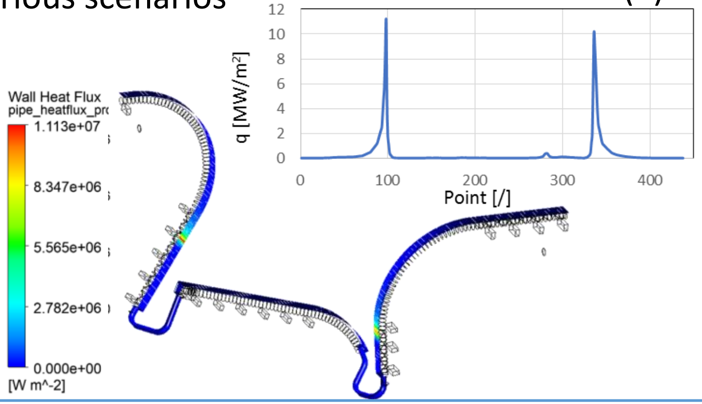


Thermal load from edge simulations for various scenarios

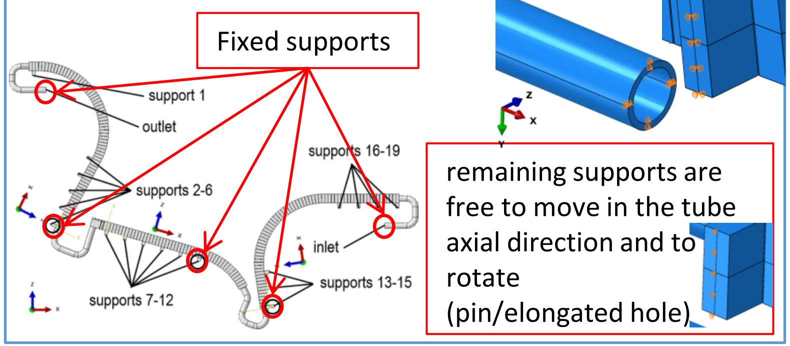
SN Detached



SN Attached (2)



Mechanical boundary conditions



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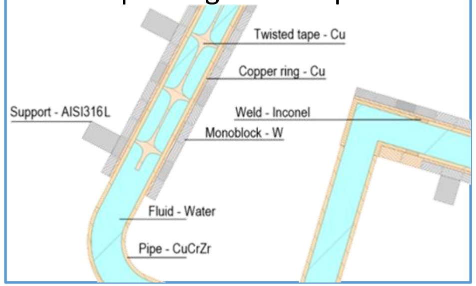

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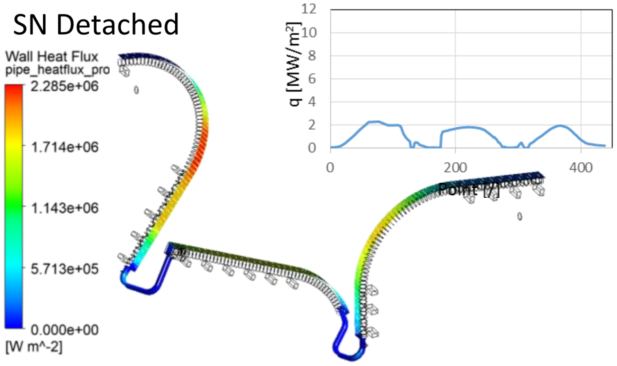

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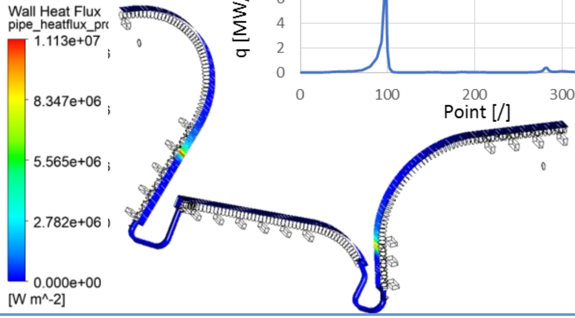
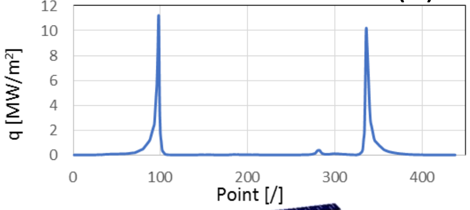
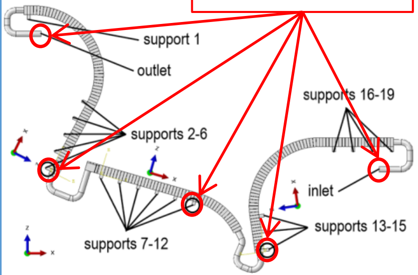
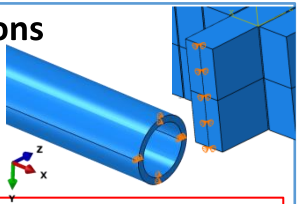




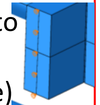
Mechanical boundary conditions

Fixed supports





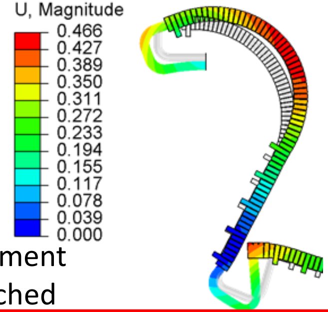
remaining supports are free to move in the tube axial direction and to rotate (pin/elongated hole)



Results

	PIPE (CuCrZr)		WELD (inconel)		SUPPORTS (AISI 316)	
SN Detached						
MISES [MPa]	**MAX**	**AVG**	**MAX**	**AVG**	**MAX**	**AVG**
	171.32	67.45	130.20	67.31	175.75	23.36
T [°C]	**MAX**	**AVG**	**MAX**	**AVG**	**MAX**	**AVG**
	126.29	74.79	131.08	90.73	84.00	70.13
SN Attached (2)						
MISES [MPa]	**MAX**	**AVG**	**MAX**	**AVG**	**MAX**	**AVG**
	215.77	50.71	71.84	41.85	149.45	20.26
T [°C]	**MAX**	**AVG**	**MAX**	**AVG**	**MAX**	**AVG**
	222.54	63.53	63.08	62.17	89.39	63.68

CuCrZr @250°C
Sy=331Mpa (Treat. A)



Displacement
SN Detached

Conceptual design: poloidal shaping

Thermo-fluid dynamics&mechanical analysis

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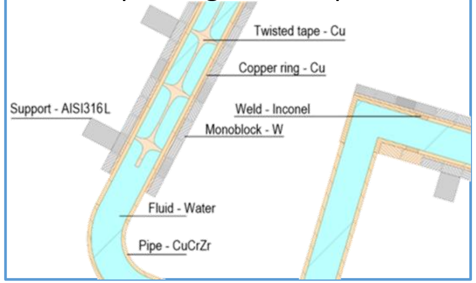

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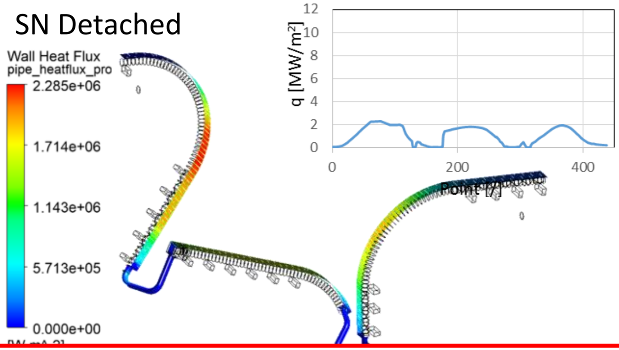
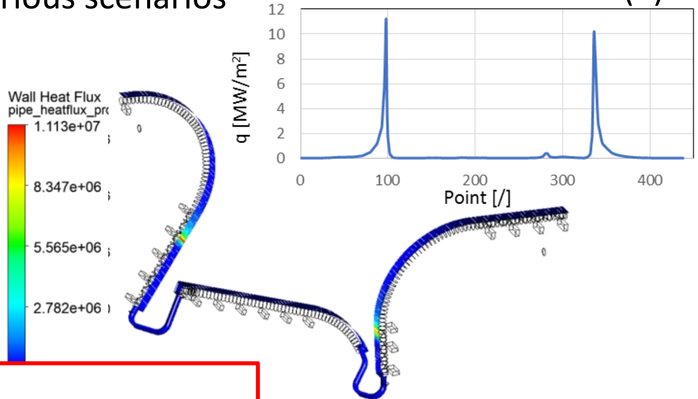
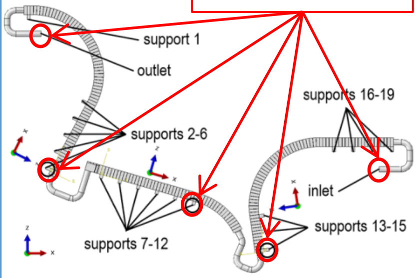


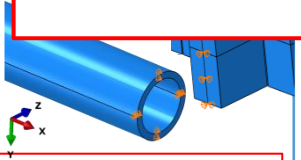
SN Attached (2)



Verification under Electro-Magnetic loads is ongoing

Mechanical boundary condition





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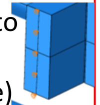

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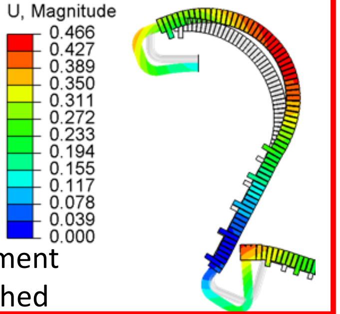

Displacement
SN Detached