Italian National Agency for New Technologies,
Energy and Sustainable Economic Development

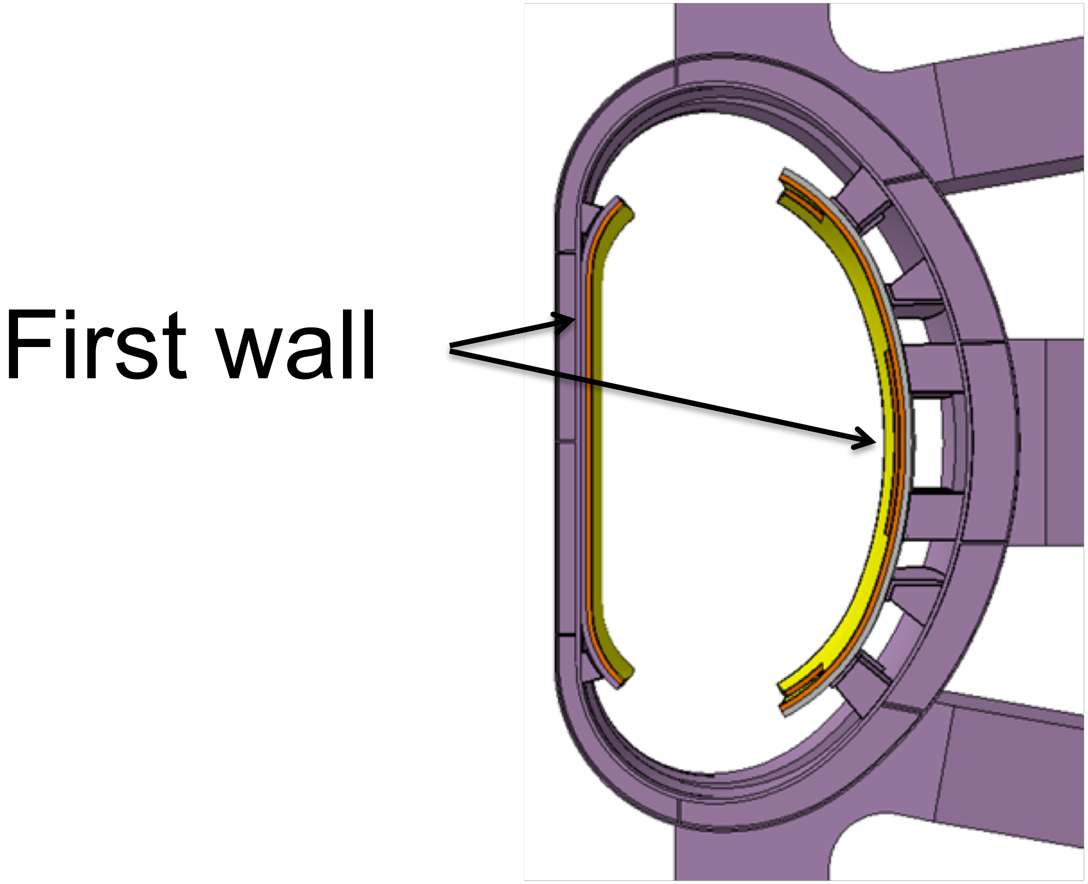
First wall & Divertor

Villa Mondragone, Monte Porzio Catone (Rome), Italy – 14/12/2018

G. Mazzitelli, M. Iafrati, A. Mancini S. Roccella, P. Rossi, E. Visca,
FSN-FUSTEC

Introduction

Two of the most important components inside the vacuum vessel are :



Introduction

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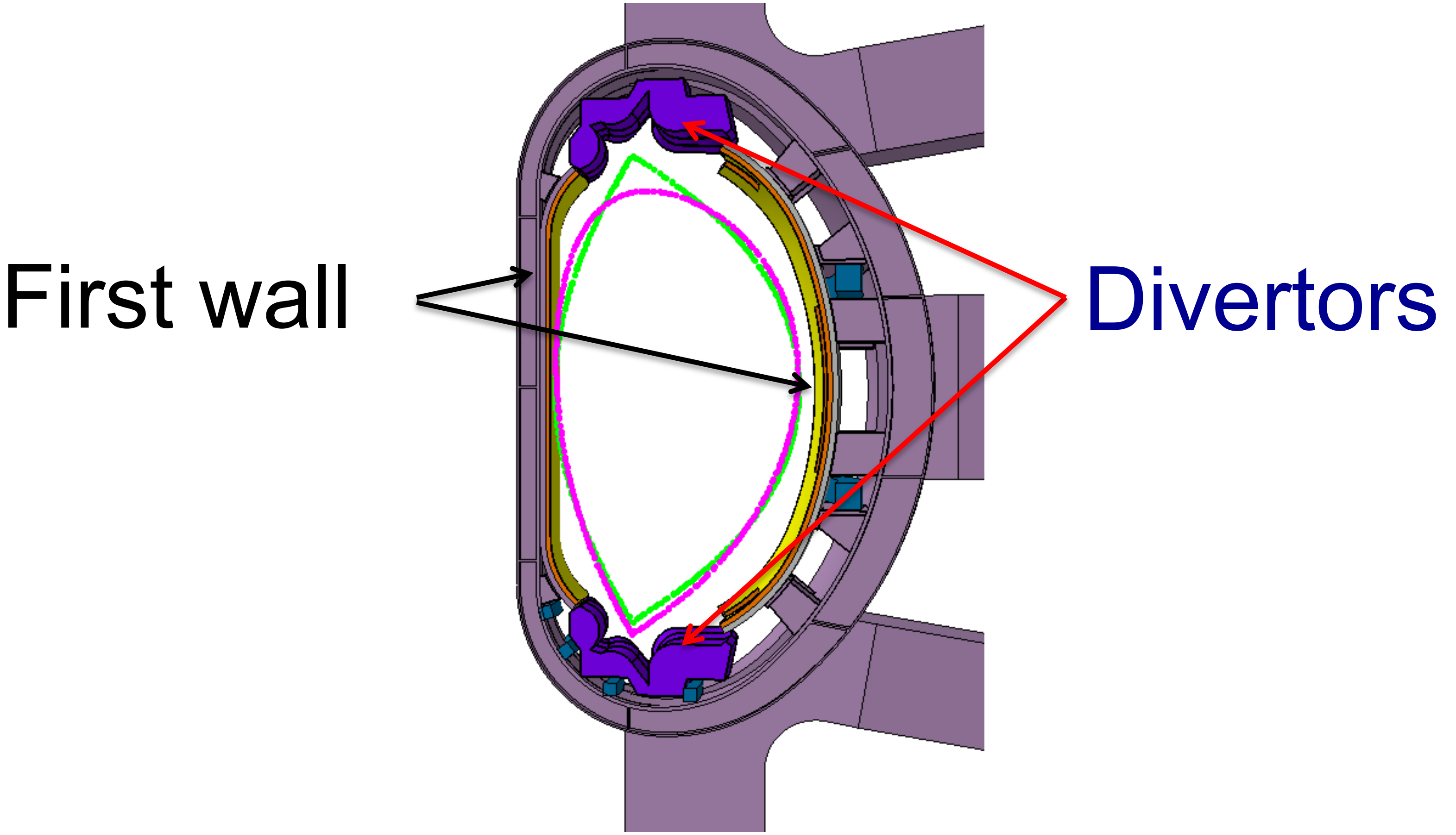
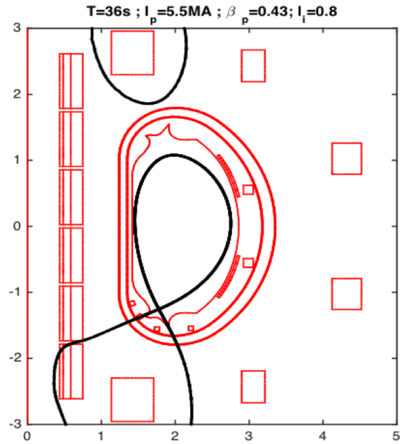
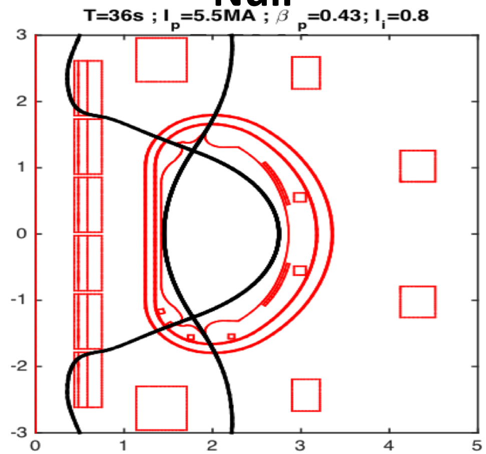


Divertor:magnetic flexibility

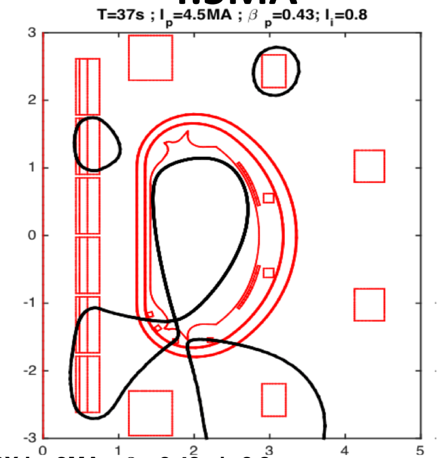
Single Null 5.5MA

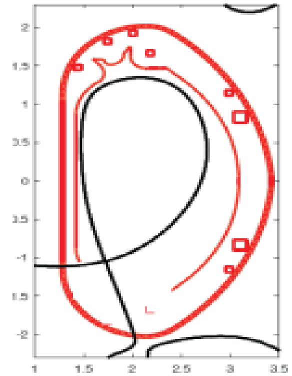


Double Null

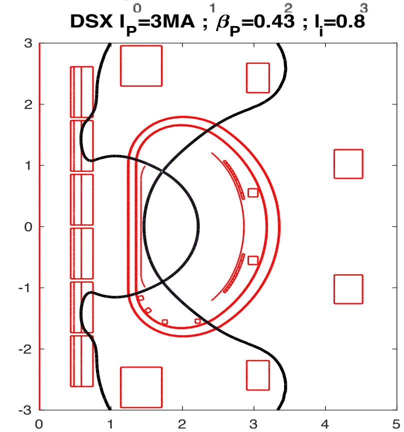


Snowflake 4.5MA





X-Divertor 5MA



Super-X 3MA

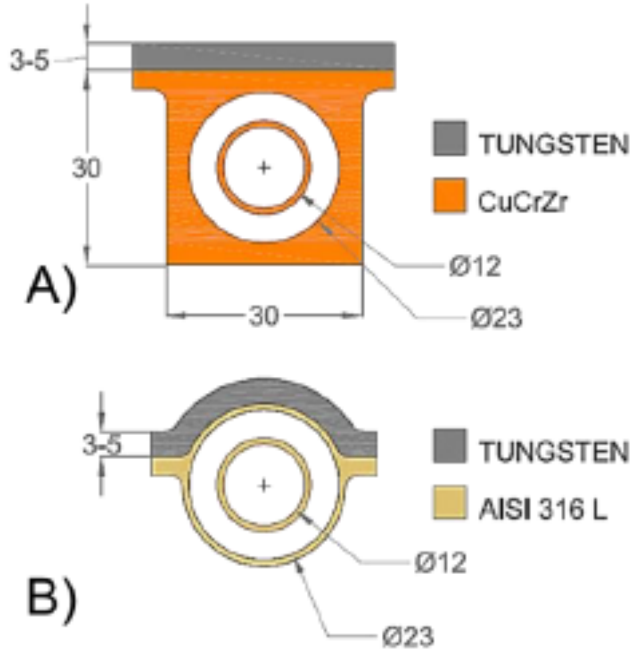
Different magnetic configurations require different divertors

First Wall

FW CONCEPT

Concept geometrical parameters (width 30 mm, total height 55 mm, gap 0,5 mm)

- Coaxial cooling channels
- Lateral wings
- Swirl
- Plasma spray W with FGM interlayers



FW Total surface: 55 m^2

W 3mm thick (3.2 ton)

Concept A

Material: CuCrZr heat sink (10 tons)

Concept B

Material: AISI 316 L heat sink

First Wall

FW heat loads

Ptot (MW)	%FW (%)	%DIV (%)	Wall Power Density (MW/m²)		
			min	max	average
25	30	70	0.075	0.135	0.100
25	70	30	0.175	0.307	0.233
45	30	70	0.135	0.237	0.180
45	70	30	0.315	0.553	0.420
Ramp-up					1.5

The following relevant scenarios have been selected:

1. 100s long steady state at 0.55 MW/m2
2. 15s long ramp-up (1.5 MW/m2), followed by a steady state operation at 0.135 MW/m2

- Water coolant parameters:
  - temp. 100°C (normal operation)
  - Temp. 185 C° (liquid metal divertors)
  - 2-3 MPa, 5-6 m/s

FW COOLING SYSTEM	
Temperature (inlet)	185 °C
ΔT	10 °C
Total water flow	1-2 m^3/s
Pressure drop	4-5 bar

First Wall

Temperature distribution

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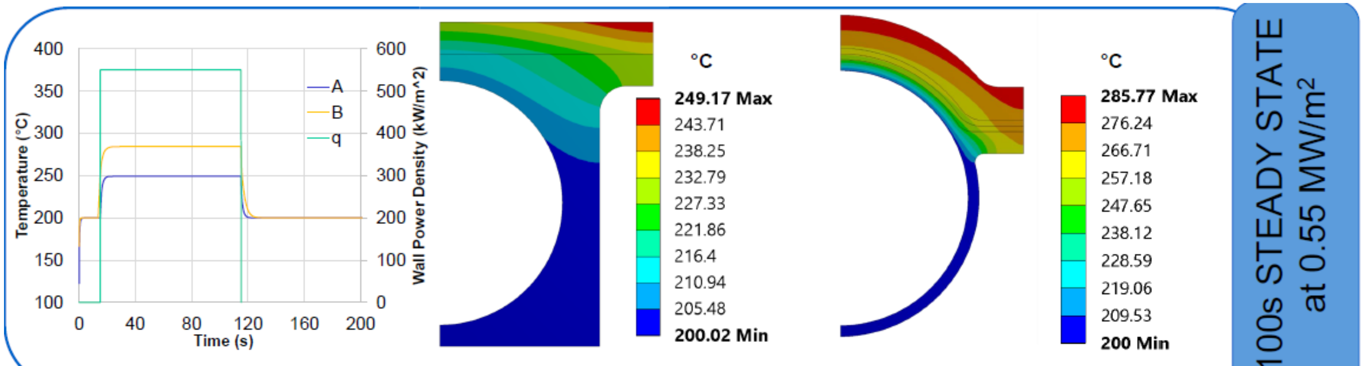
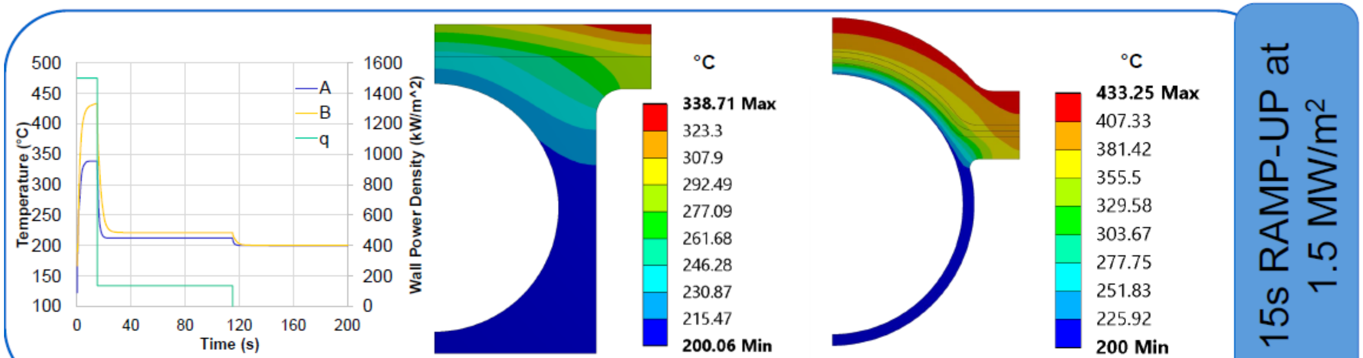


Temperature distribution with detail @115s



Temperature distribution with detail @15s

First Wall

Stress distribution

The following relevant scenarios have been selected:

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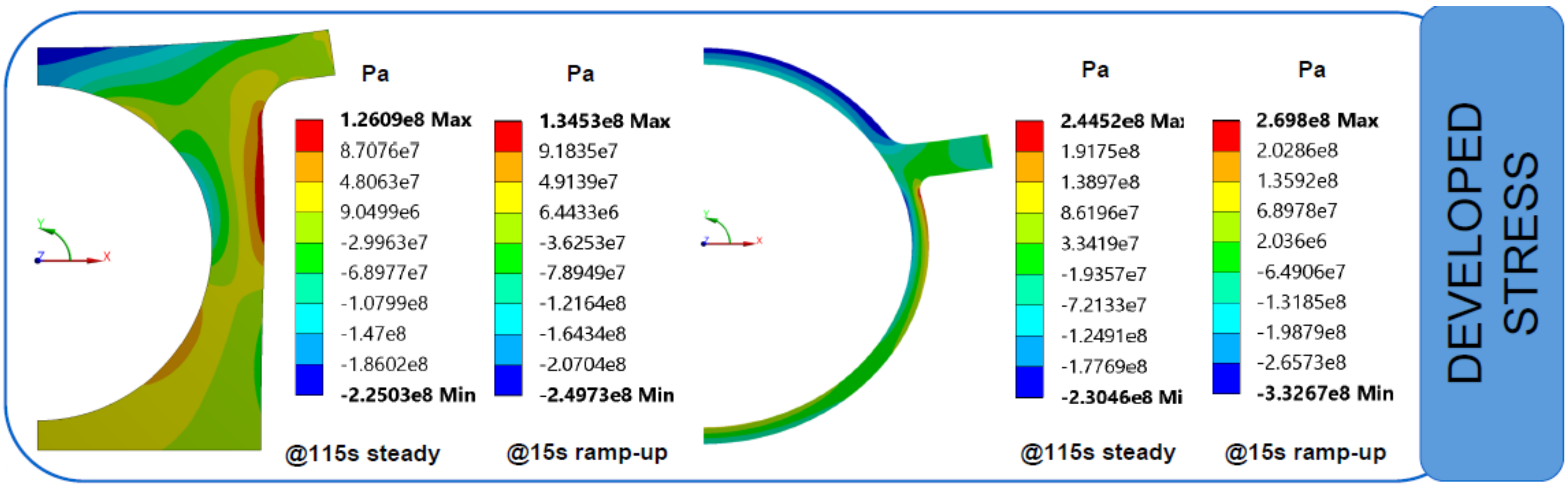


Milestones/Planning

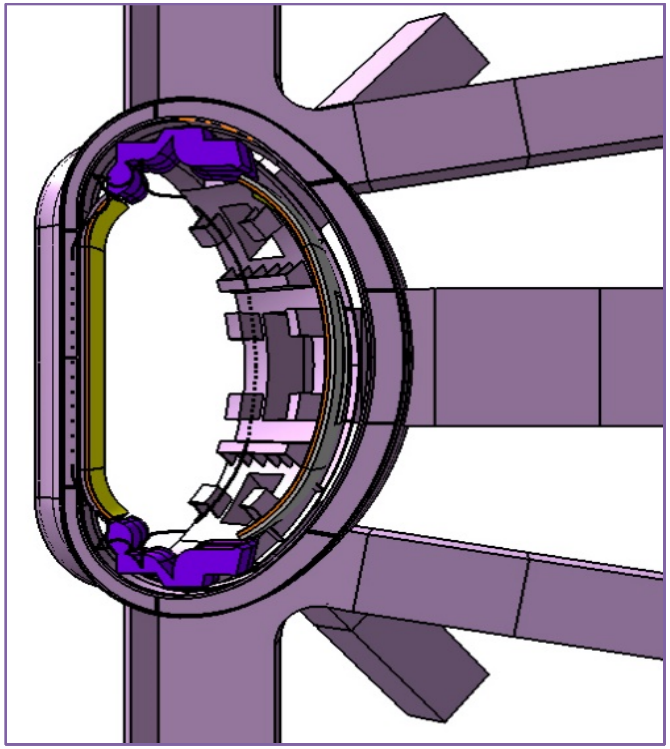
- **Design completion**
  - Concept definition (coaxial pipe, wings, swirl, CuCrZr or SS or..)
  - Manufacturing aspects (pipe bending, W deposition, FGM interlayers…)
  - Segmentation (RH compatibility)
  - Manifolds
  - Cooling
  - Supporting system
  - Mock-up testing
- Design review
- Technical specification
- Call for Tender
- Contract signature
- Completion

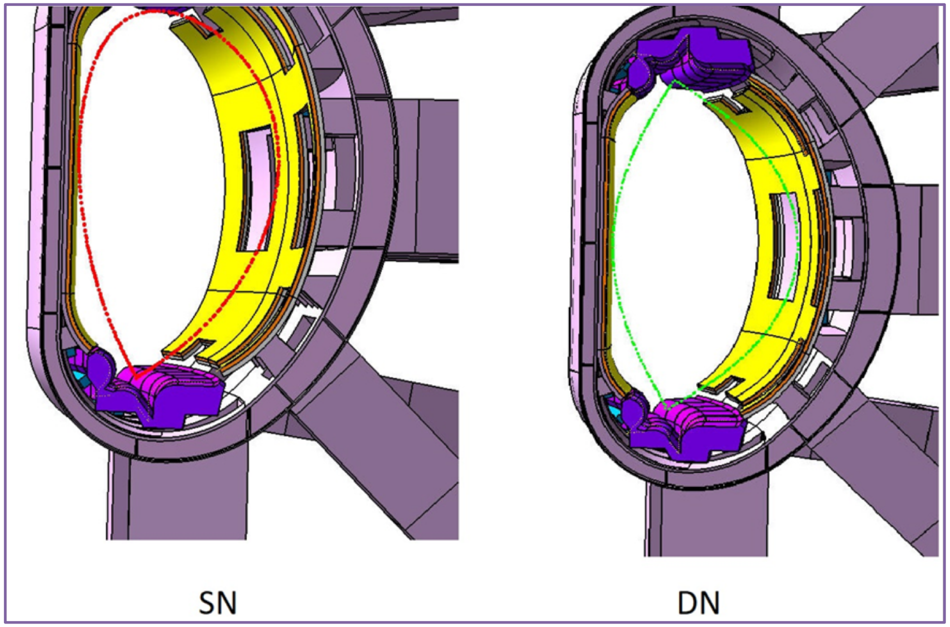
		0.5				1.5				2.5				3.5				4.5				5.5				6.5				7.5
	2018		2019				2020				2021				2022				2023				2024				2025			
	III	IV	I	II	III	IV	I	II	III	IV	I	II	III	IV	I	II	III	IV	I	II	III	IV	I	II	III	IV	I	II	III	IV
FW	DA						CFT	CAE			manufacturing																			

DA = Design Activity
CFT = Call For Tender
CAE = Contract Award & Engineering

Divertor

DTT divertor is segmented in 54 toroidal cassettes (symmetric wrt the equatorial plane in the upper part for the DN configuration).
Each divertor cassette comprises a cassette body, which supports the plasma facing components (PFCs), an inner (IVT) and outer vertical target (OVT) and a dome.



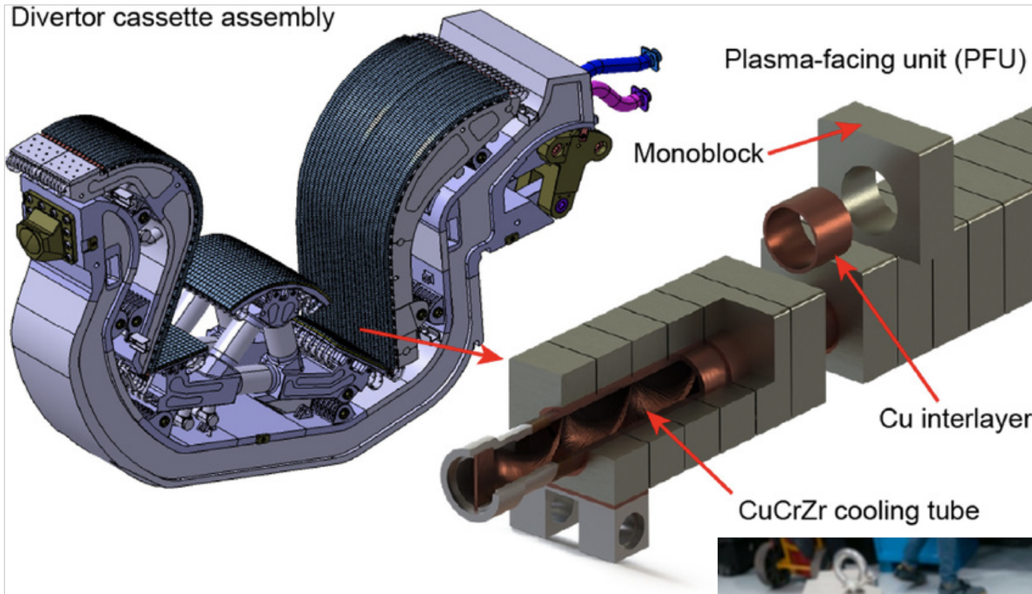


The divertor configuration will be identified on the basis of the outcome of the PEX studies (around 2022-23)

but……

Divertor

We are ready to build a ITER-like divertor for the first plasma

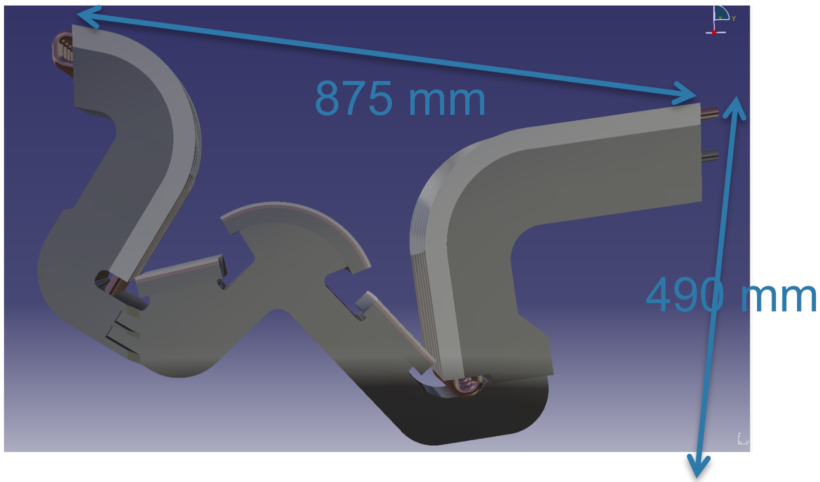


Materials
Armor: tungsten
Heat Sink pipe: copper alloy
Cassette body: stainless steel

Divertor

Some numbers

3 cassettes per sector: 8 PFU per OVT per cassette, 7 PFUs per IVT per cassette



Cassette masses
- Cassette-body:
  - AISI 111kg
- PFU:
  - Cu 9 kg
  - W 64 kg

Total cassette mass
- 184 kg

Divertor mass:
- AISI 6 ton
- Cu 0.5 ton
- W 3.5 ton

Total Divertor mass: 10 ton (like 1 ITER cassette)

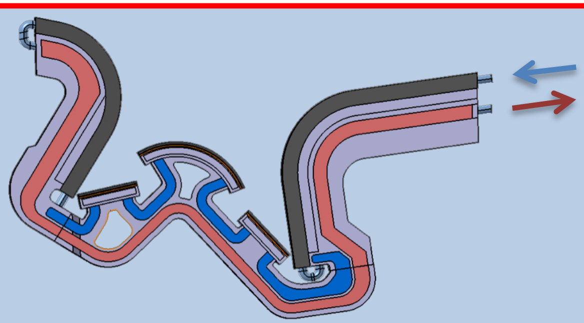
Hydraulic conditions:

Tin= 100°C

V= 12 m/s

G= 0.6 m^3/s

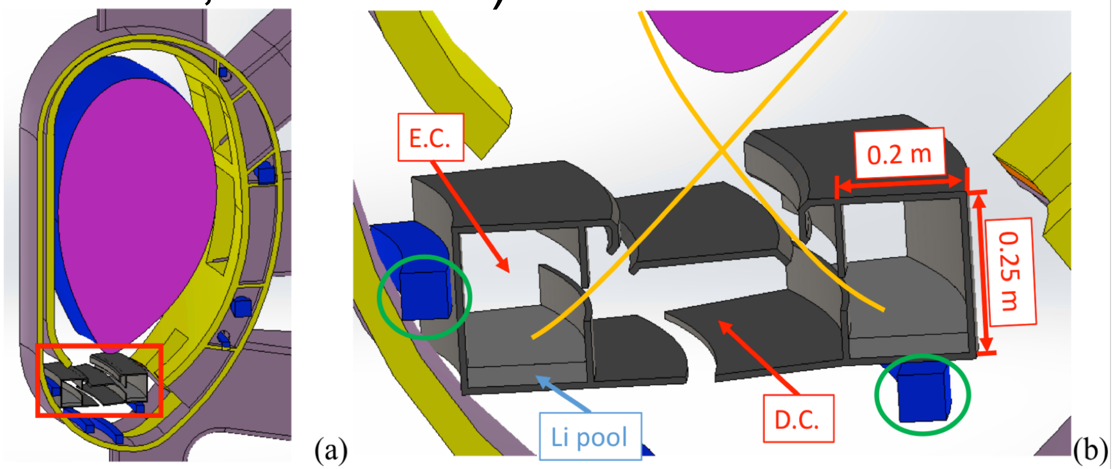
DT=10 °C

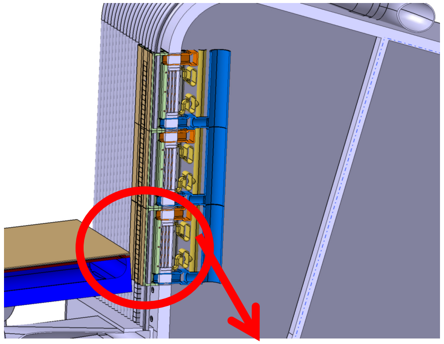


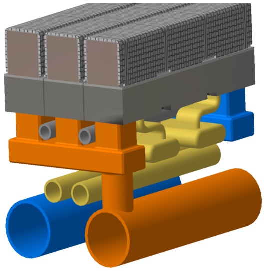
Flexible liquid divertor geometry

As regarding liquid metals divertor, we are in the framework of EUROfusion workpackage on liquid metal we are involved in the capillary porous system conceptual design of a divertor for DEMO and DTT but We are even thinking a quite different solutions like the possibilities to have “boxes/pools” of liquid metal specially for Li for which evaporation is very important.

(Zanino[1], Goldston[2])





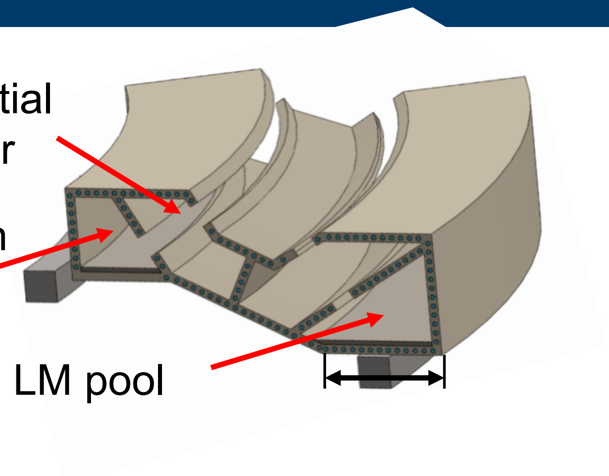


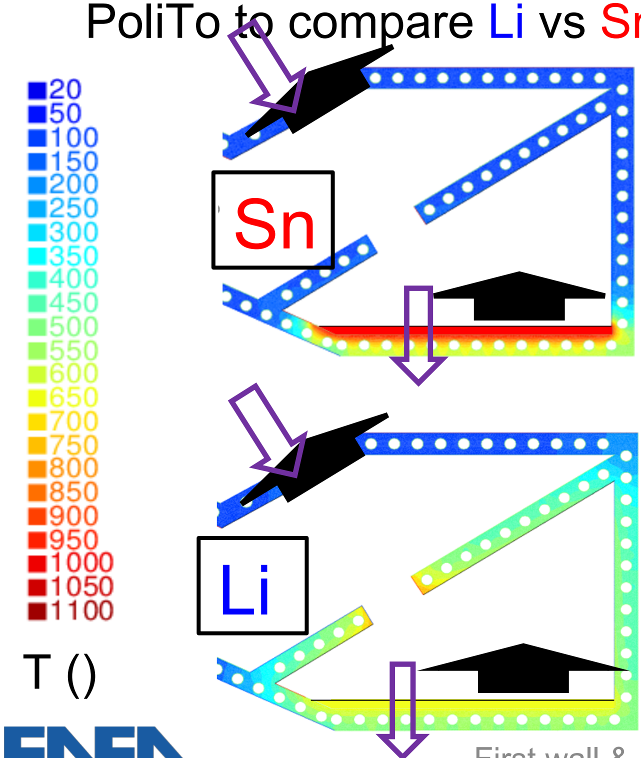
1) R. Zanino IAEA (2016) Kyoto

2) R. Goldston , IAEA P.E. WS-Wien 2015

Vapor-box divertor for DTT

- Proposed geometry of vapor-box divertor to fit the DTT chamber;
- Plasma contamination by evaporated LM reduced by condensation on the box walls;
- Self-consistent model developed at PoliTo to compare Li vs Sn as LMs.





- Relatively low source
- → low vapor density
- → low radiation, low condensation
- → heat load concentrated on pool
- Relatively high source
- → high vapor density
- → high radiation, high condensation
- → effective heat load spreading on walls

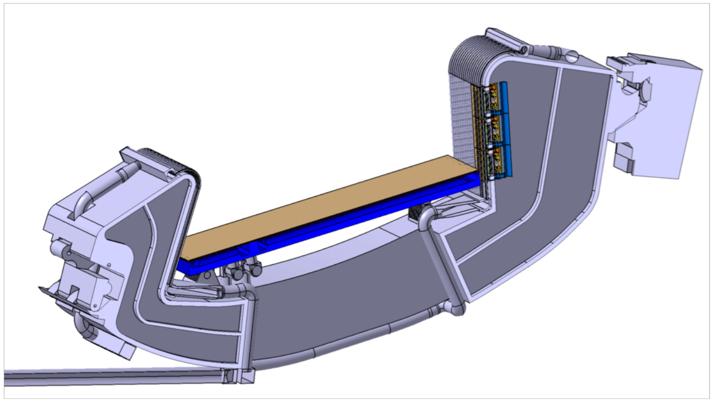
- For both Li and Sn impurity flux towards MC drastically reduced
- Effect of impurity influx on core plasma contamination/dilution to be assessed

Project of the Liquid Divertor module

- The surface exposed to the plasma will be a Capillary Porous System made by tungsten wires or felt filled with liquid metal

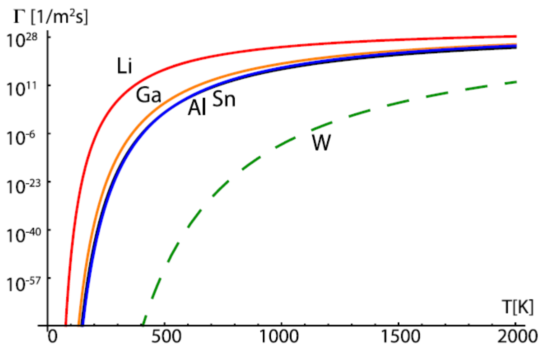
- Heat load 10 MW/m^2 steady state - 20MW/m^2 transient

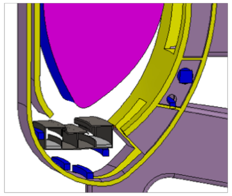
- The choice of the materials should be compatible with DEMO
  - Max temperature of CuCrZr 350 °C
  - Structural material AISI 316IG/EUROFER

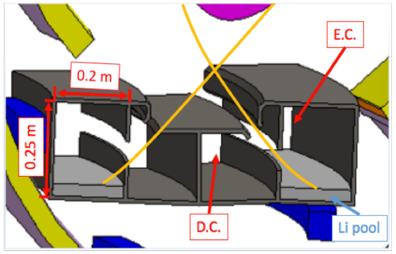


Project of the Liquid Divertor module

Choice of the liquid material







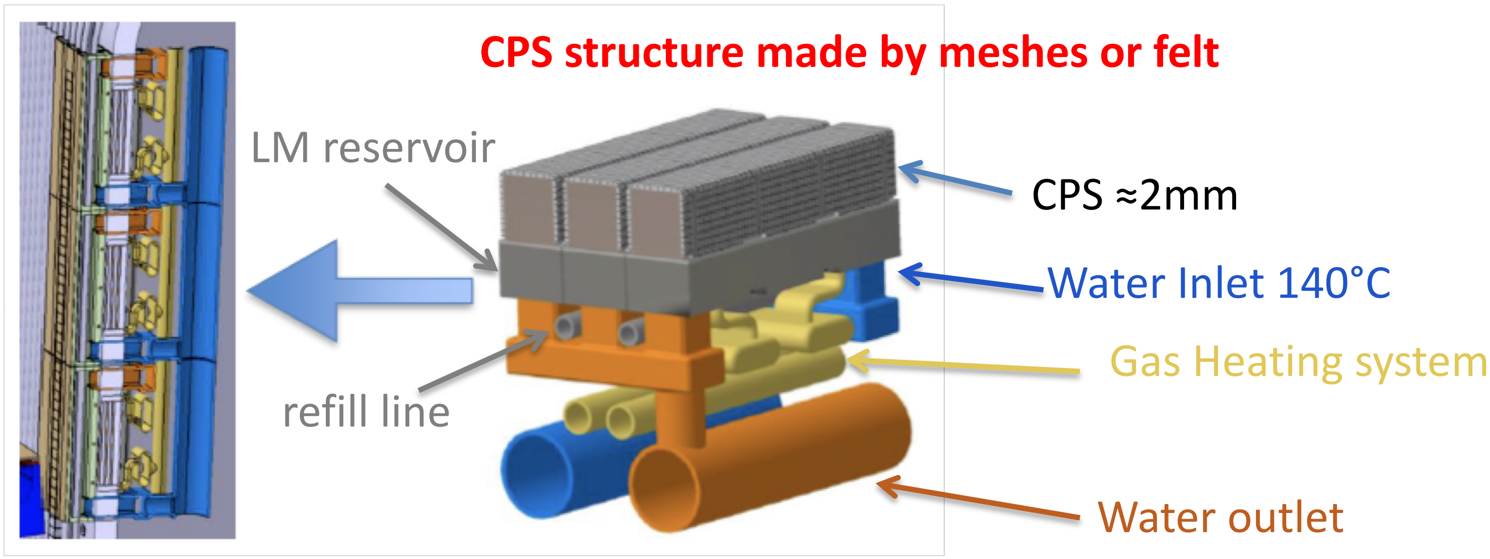
The operational window of Tin is much wider than Li

Evaporation for Li at surface temperature greater than 550° is very high. The concept of a vapor box seems more viable.

Without changing the DEMO divertor module design we have chosen to start with tin as liquid material

Project of the Liquid Divertor module

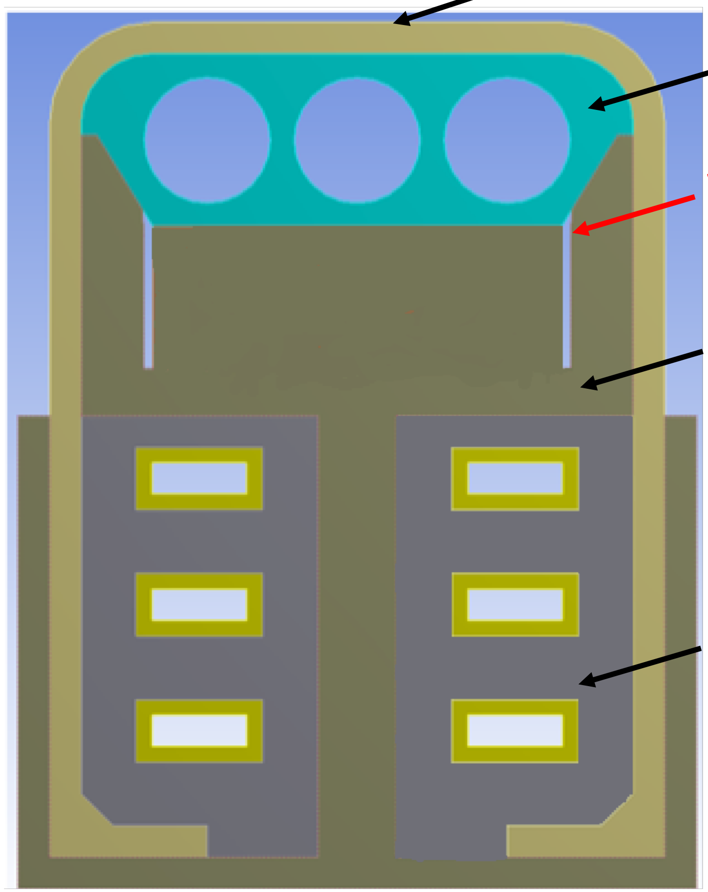
Starting point - Definition of the basic requirements for the liquid module

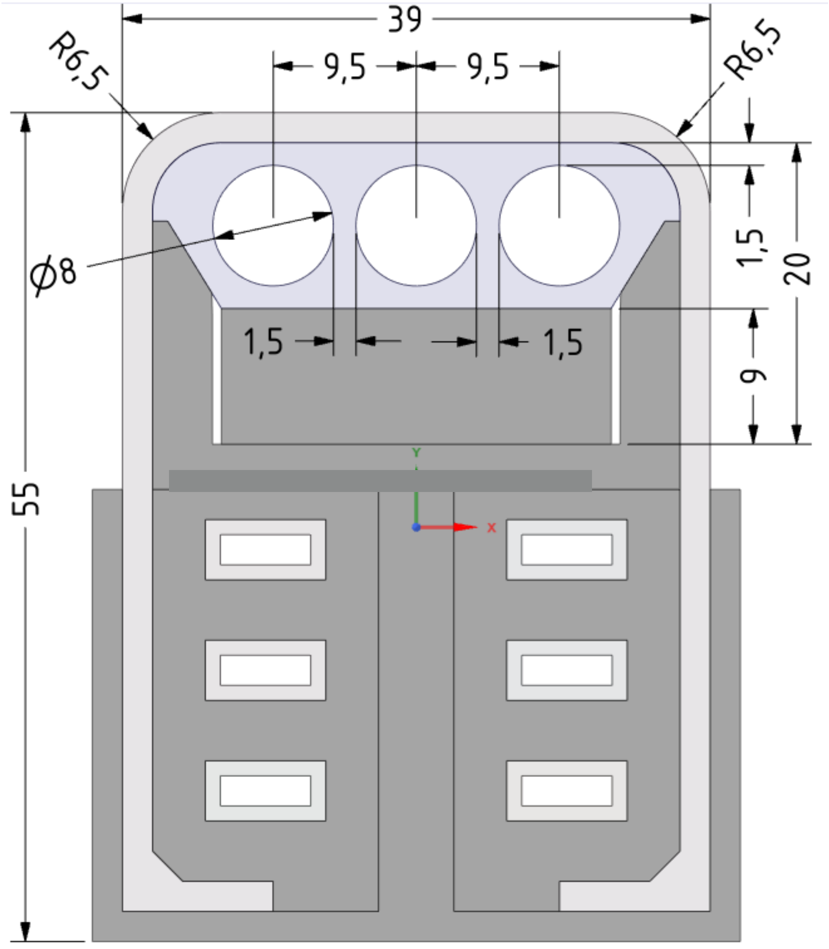


Each liquid metal elementary unit should be provided by:

- Coolant
- LM reservoir and refill line
- Heating system
- Anti-corrosion layer

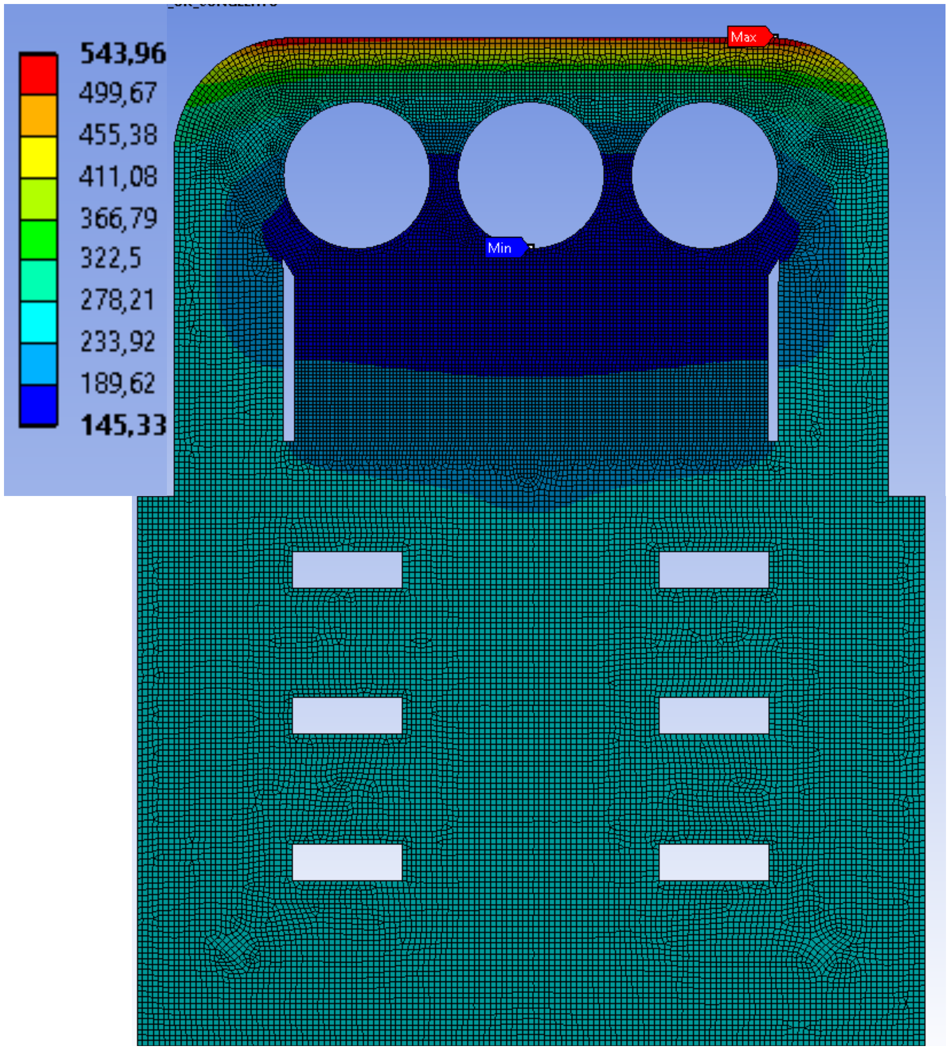
Project of the Liquid Divertor module

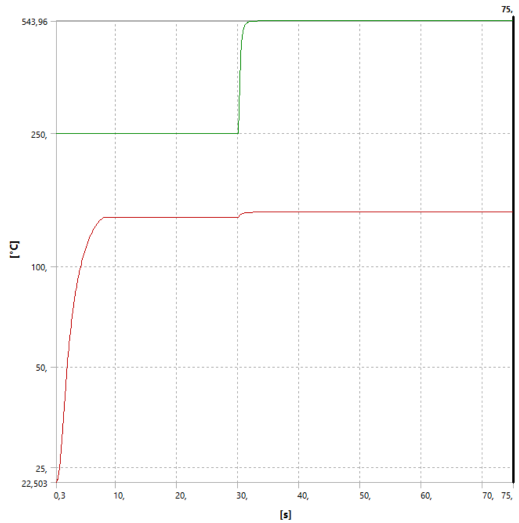




The length of the module can be adapted to fit the divertor cassette

Project of the Liquid Divertor module





Step1
Gas heating T=250°
Δt_1 = 30s
Step2
Heat flux applied
Δt_2 = 45s

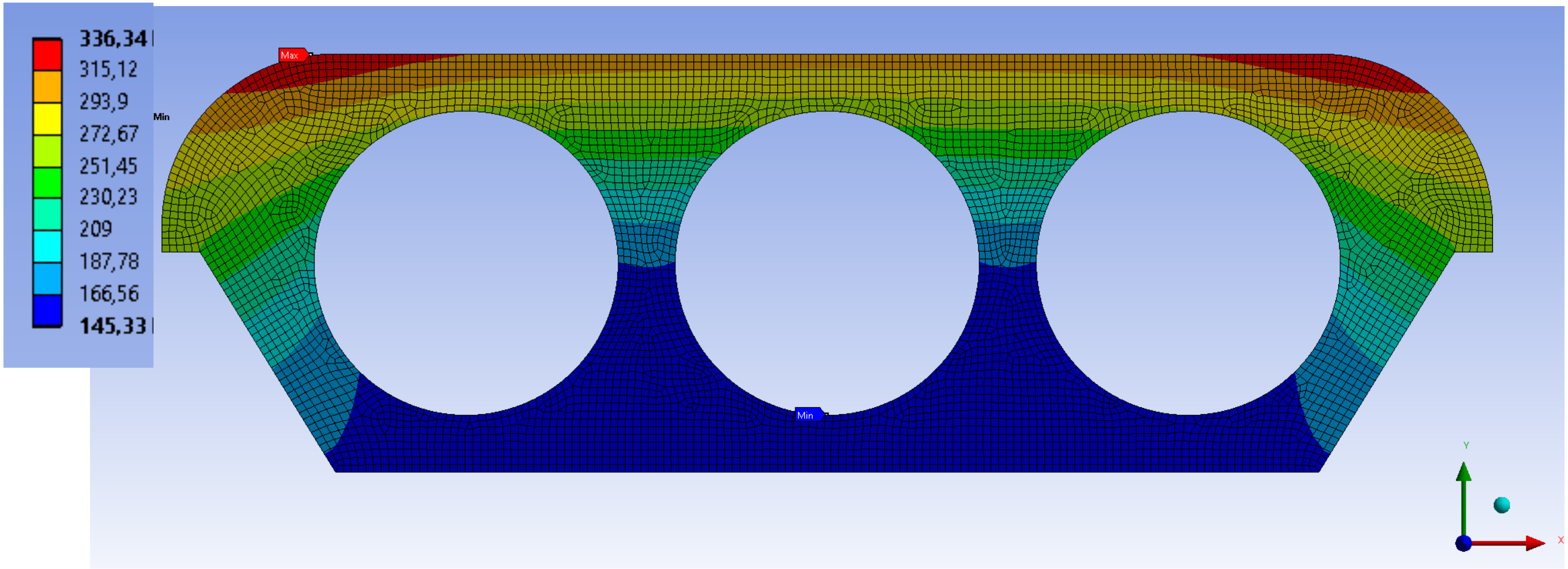
T_{water} = 140°
P_{water} = 50bar
V_{water} = 12m/s

Heat flux = 10MW/m^2

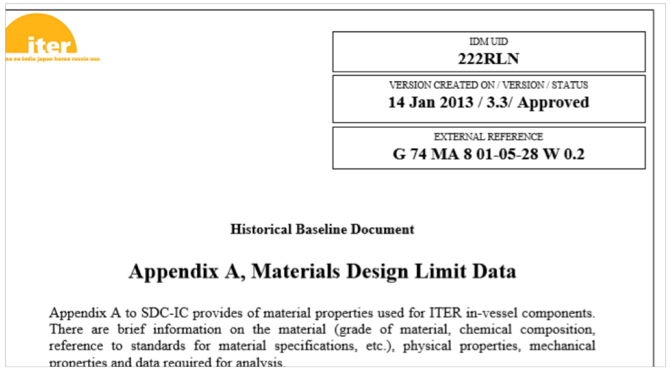
Project of the Divertor module

The temperature of the CuCrZr is always below 350 °C

Heat flux = 10MW/m^2



Project of the Liquid Divertor module



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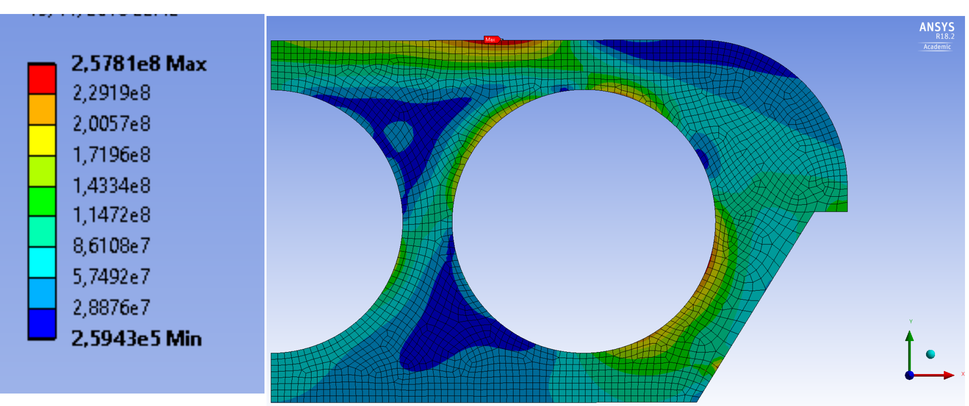
Historical Baseline Document

Appendix A, Materials Design Limit Data

Appendix A to SDC-IC provides of material properties used for ITER in-vessel components. There are brief information on the material (grade of material, chemical composition, reference to standards for material specifications, etc.), physical properties, mechanical properties and data required for analysis.



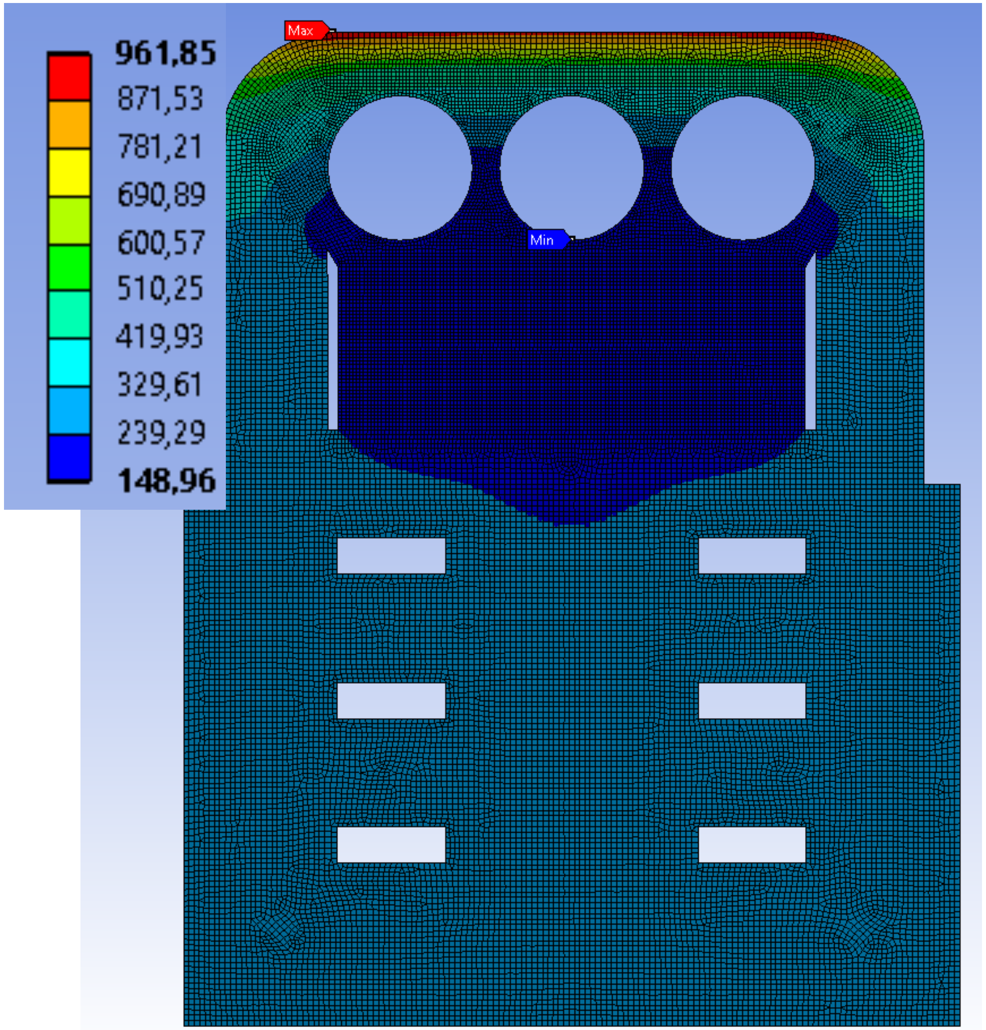
T, °C	$S_{y,min}$	$S_{y, irr. min}$
	MPa	
20	407	-
50	397	-
100	381	-
150	365	485
200	348	347
250	331	375
300	313	259
350	294	194
400	275	20
450	254	-
500	233	-

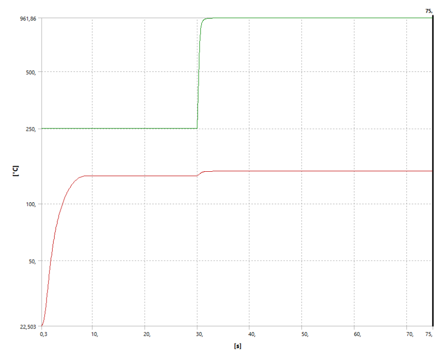
Table A.S31.3.2-1: Minimum Yield Strength for the treatment A (solution annealing + cold work + ageing) CuCrZr-IG before and after irradiation (0.3 dpa ≤ displacement dose ≤ 5 dpa and $T_{test} = T_{irr}$)

Max stress 257MPa of CuCrZr at 309 °C

Heat flux = 10MW/m^2

Project of the Liquid Divertor module





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Heat flux applied
Δt_2 = 45s

T_{water} = 140°
P_{water} = 50bar
V_{water} = 12m/s

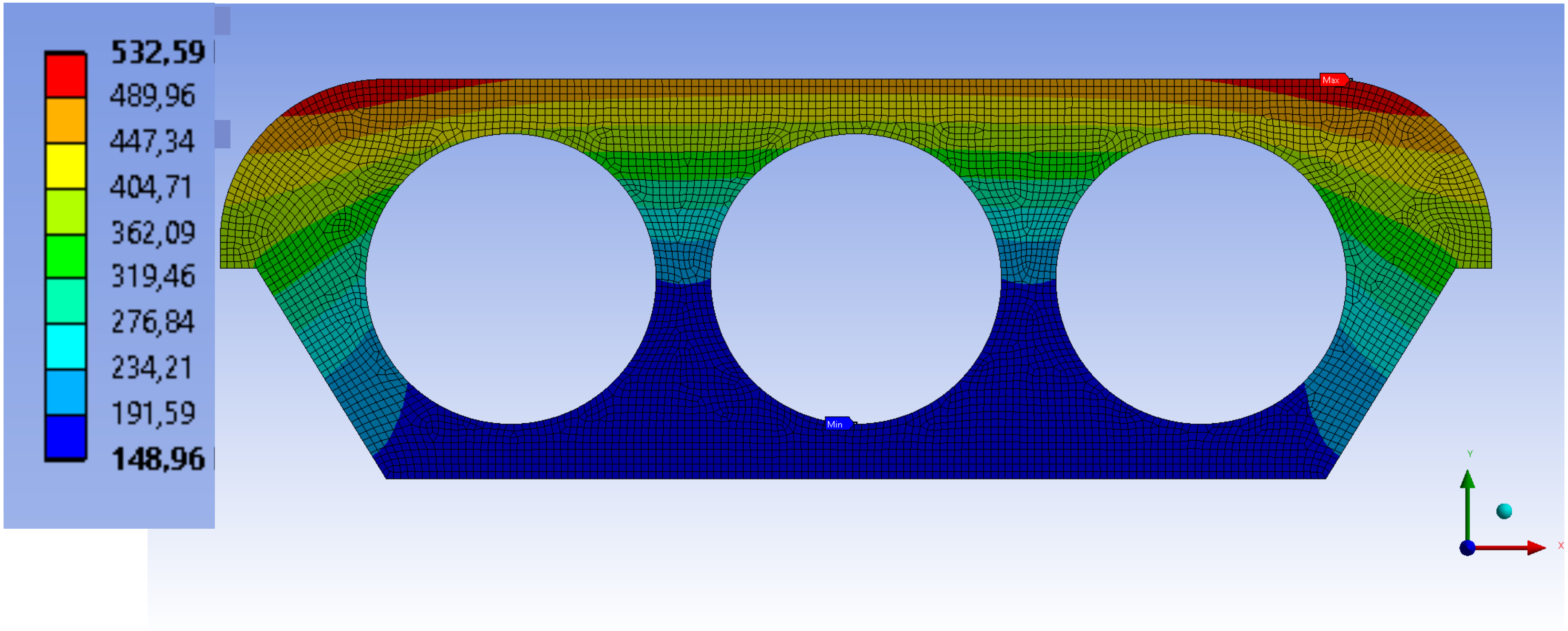
Heat flux = 20MW/m^2

The surface temperature of the CPS is still below the high evaporation rate

Project of the Liquid Divertor module

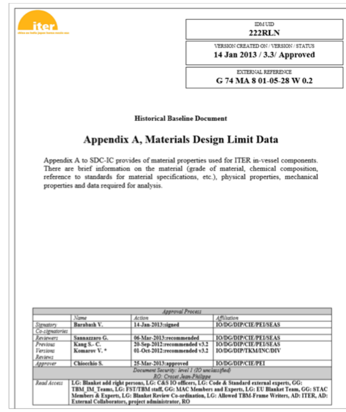
The temperature of the CuCrZr is NOT always below350 °C

Heat flux = 20MW/m^2



Project of the Liquid Divertor module

Heat flux = $20 MW/m^2$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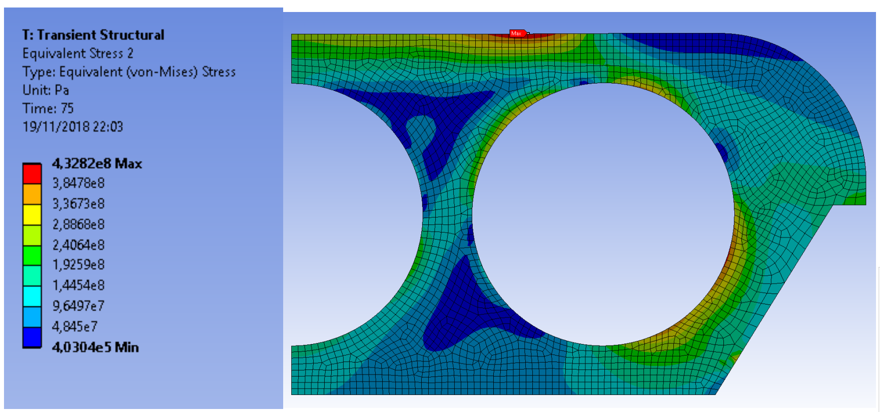

Max stress 434 MPa of CuCrZr at 480 °C

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