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Synergies in the technological developments of the W7-X and JT-60SA metallic divertor plasma facing components

8th of November 2022 – 4th technical workshop on Divertor concept - Vienna

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1. W7-X and JT-60SA water-cooled divertor – Divertor targets

1. Divertor target with W armor material
   - Requirements
   - Curent design
   - Thermal analysis

1. W7-X and JT-60SA water cooled divertor – Divertor targets

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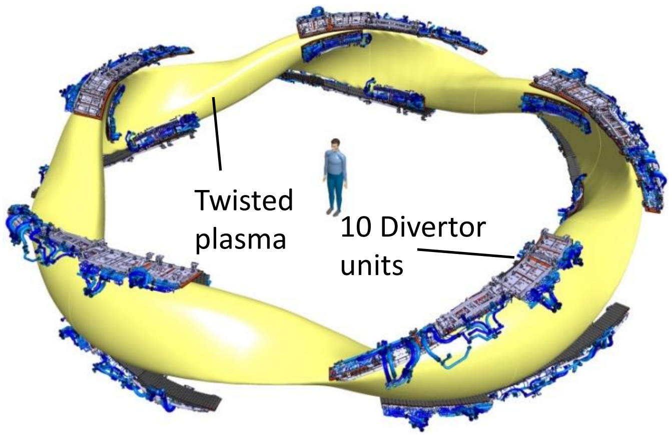
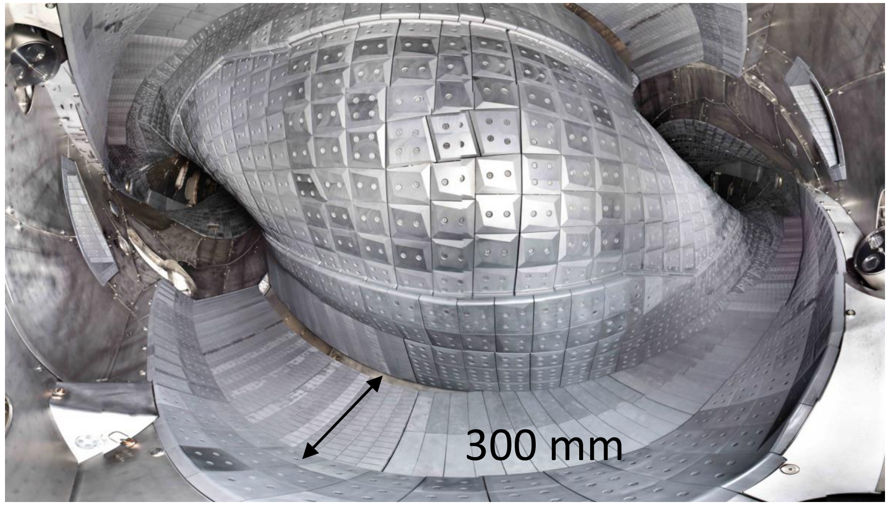
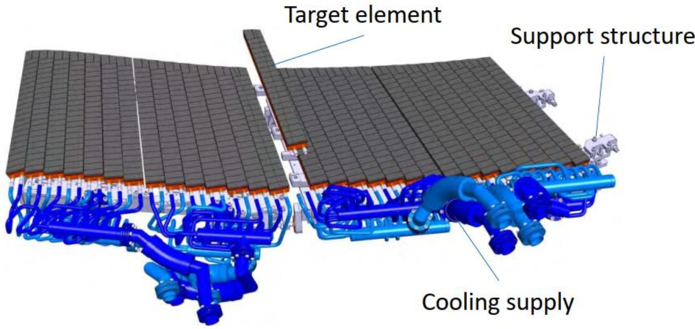
Stellarator



W7-X



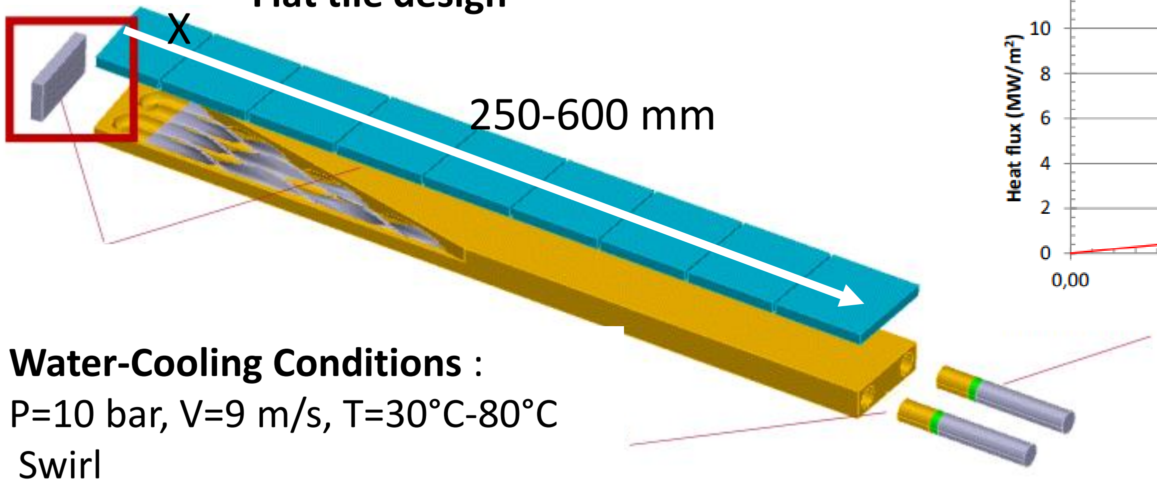
Target modules



Smoothly shaped divertor surface
(field line angle < 2 deg.)

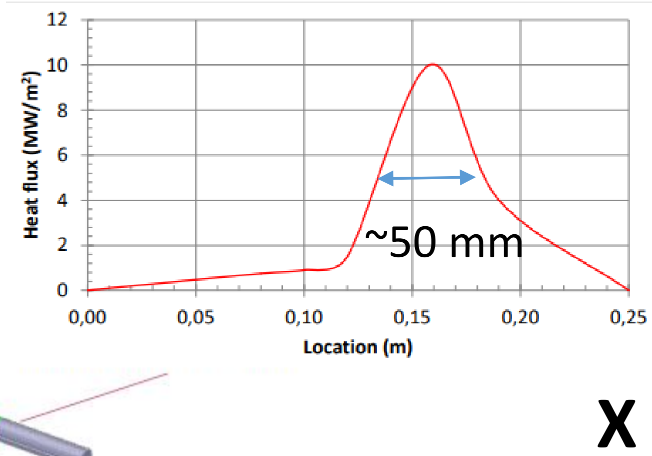
Target element:

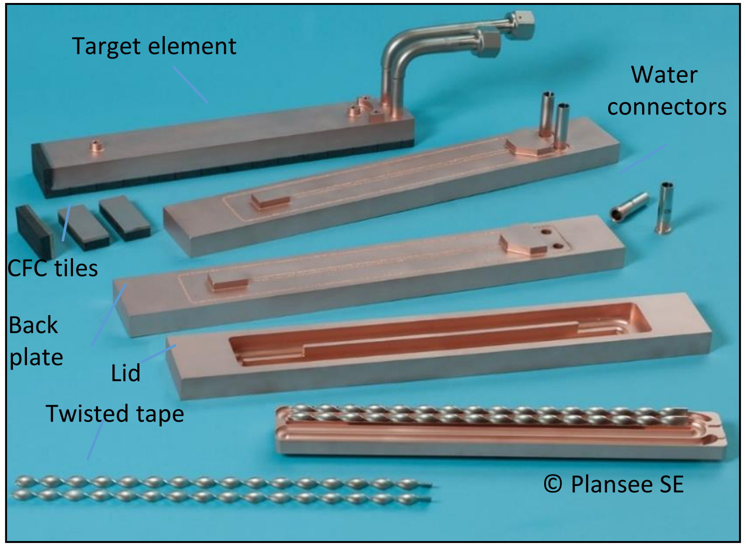
Flat tile design



Water-Cooling Conditions :
P=10 bar, V=9 m/s, T=30°C-80°C
Swirl

Steady state heat loads





1. W7-X and JT-60SA water cooled divertor – Divertor targets

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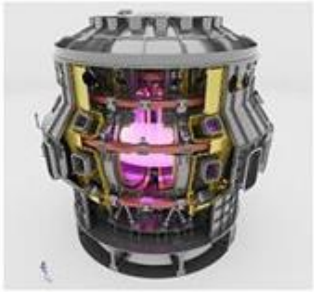
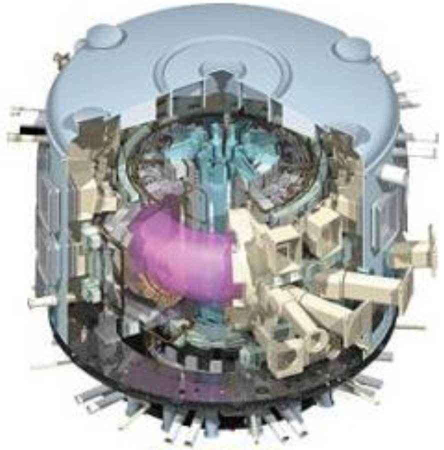


JT-60SA

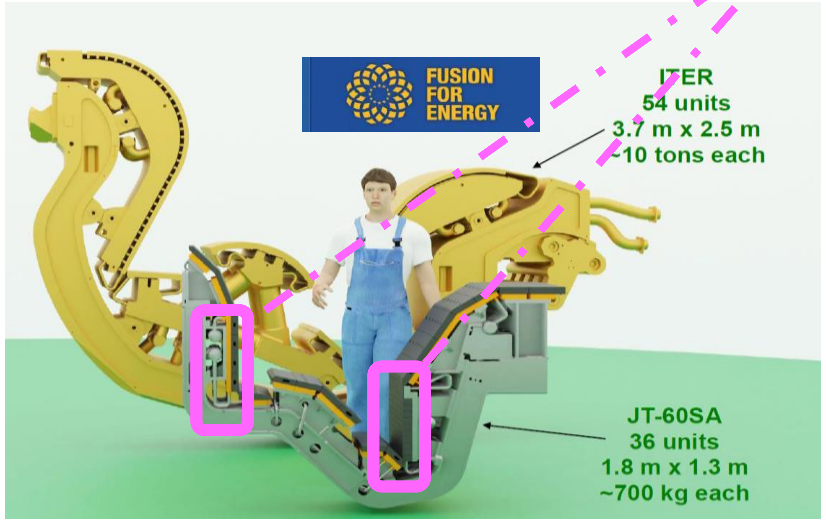
135 m^3



ITER

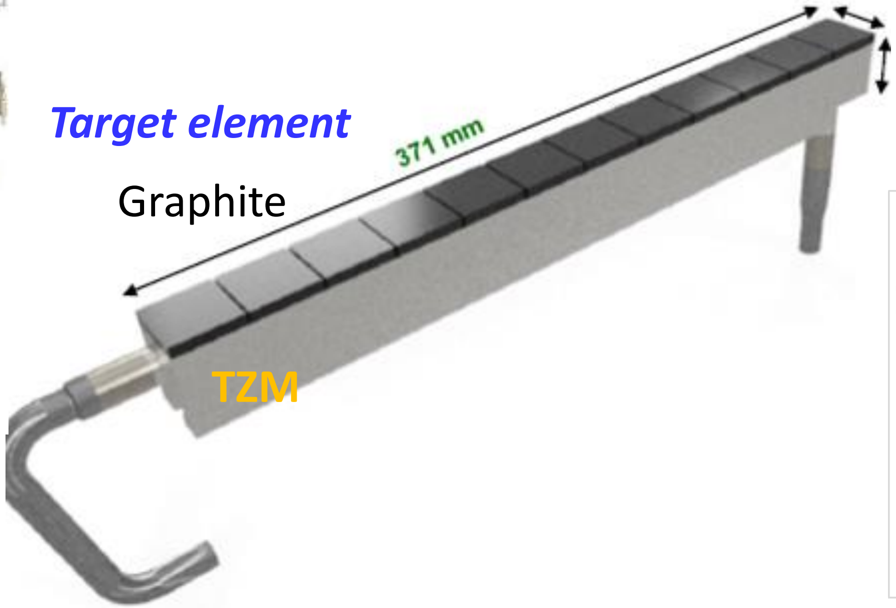
800 m^3

Divertor cassette and plasma facing components

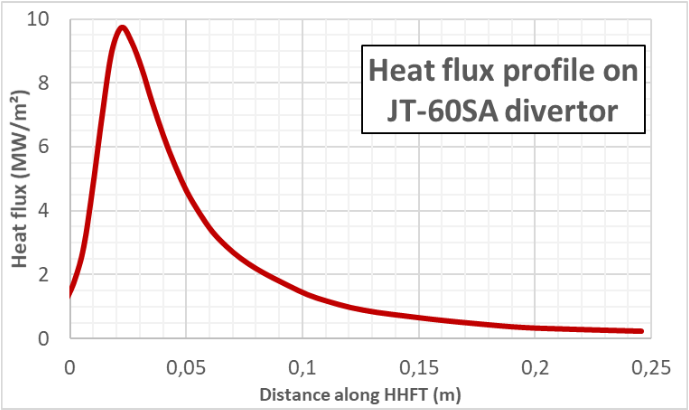


→High-beta, inductive and non-inductive operation

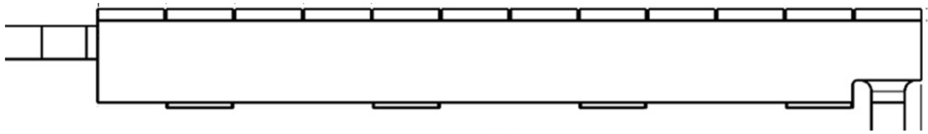
Target element



Steady state heat loads



Cooling conditions :
20 bar, 7m/s, 40°C, swirl



→ Operation of actively cooled graphite divertor in **2029**

→ Target tender (samples, prototypes, series) started in **07/22**

2.1 Divertor target with W armor material – Requirements

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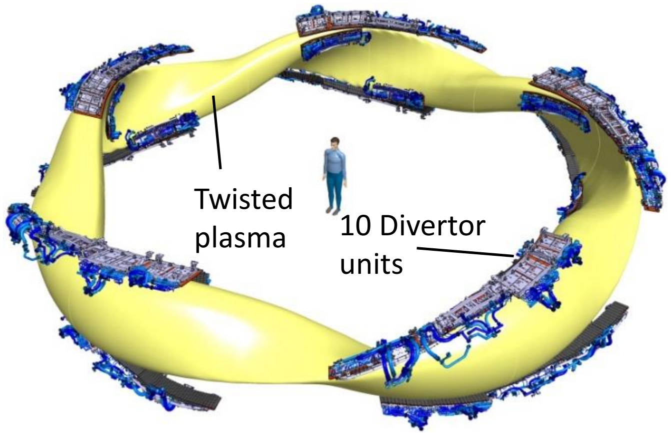
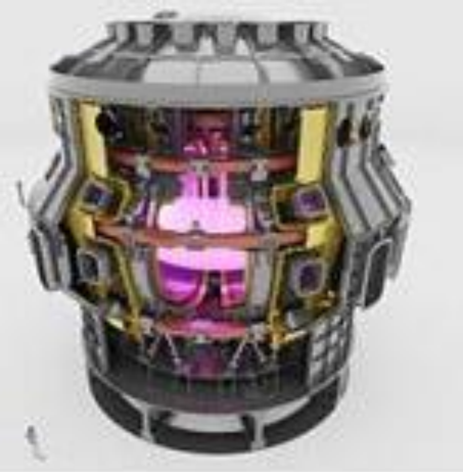
W7-X



- W armor material (to be relevant with European fusion power plant)
- Activities started in 2021
- Keep the present cooling system
- Optimize the interfaces changes between the target and the divertor support structure
- Minimize the weight increase
- Qualify the integrity of materials and component under thermo-mechanical loads (CuCrZr < 450 °C; W,TZM<1200°C)

JT-60SA



- **Heat loads (same as W7-X CFC-target)**

10 MW/m² (Steady state)
+ 15 MW/m² (Transient)
No VDE, ELMs…

- **Schedule**

  Geometry defined: 2025
  Technology qualified: 2026
  Installation: ~2032

- **Heat loads (higher than JT-60SA C-target)**

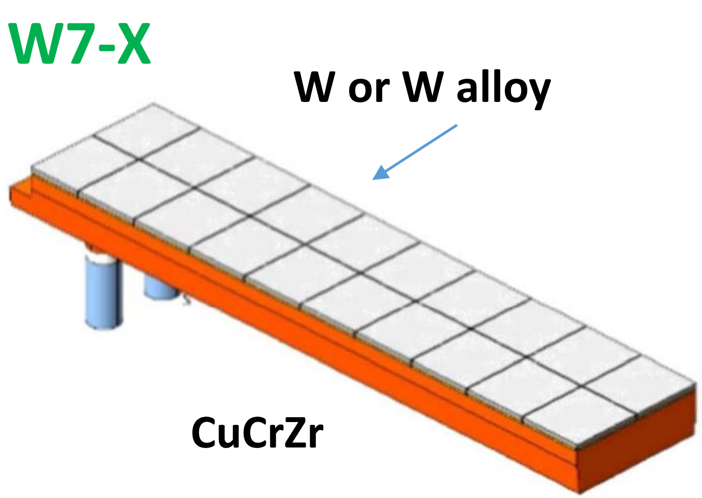
15 MW/m² (Steady state)
ELMs : 10 MJ/m² - 0.2 ms

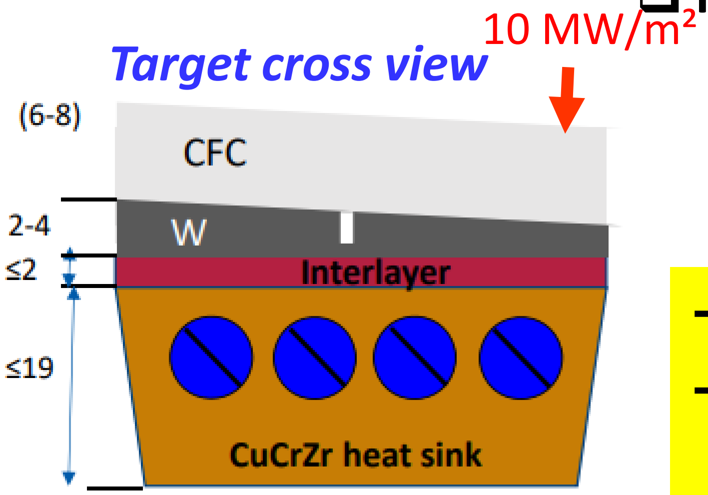
- **Schedule**

  Geometry defined: 2025
  Technology qualified: 2026
  Installation: ~2033

→ Divertor target with W armor material for W7-X and JT-60SA:
Similar requirements and component size

2.1 Divertor target with W armor material – Flat tile design

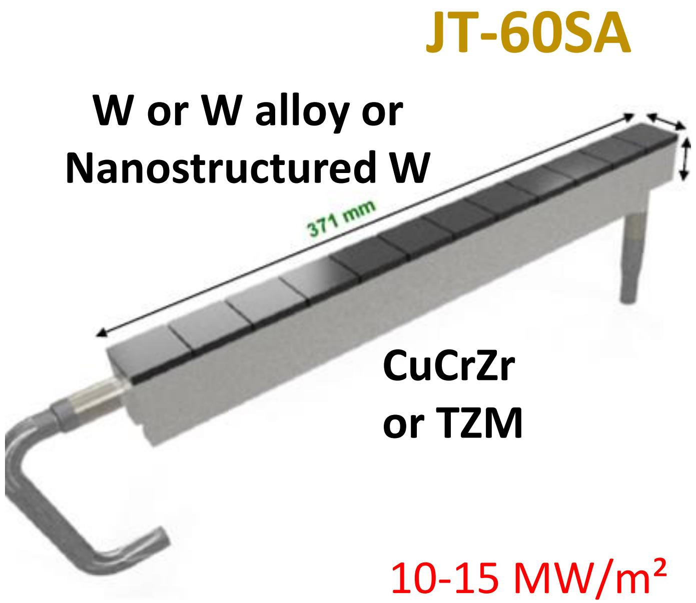


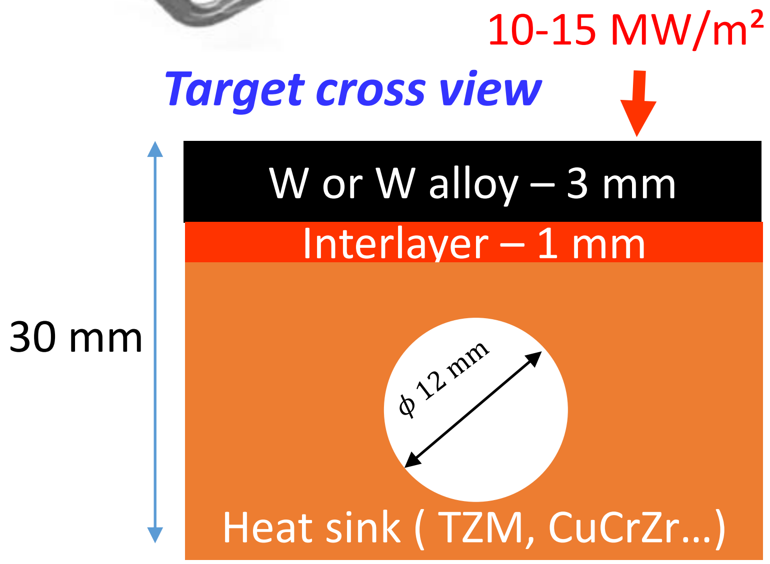


- **Material choice:**
  - W/W alloy/nanostructured W: ductility at RT (alloy/nano), transient resistance
  - CuCrZr ("ITER grade") : good thermomechanical properties, existing feedback from **joining** feasibility (used for series manufacturing)
  - TZM (JT60SA): good thermomechanical properties, material used for series manufacturing but not reactor relevant (activation)

- **Rationales for the material thickness choice:**
  - W: erosion (> 2 mm), recrystallization
  - CuCrZr, TZM: structural resistance
  - Interlayer: joining feasibility feedback

→ Similar solutions: design, materials
→ Similar technological developments needed





2.2 Divertor target with W armor material – Thermal analysis

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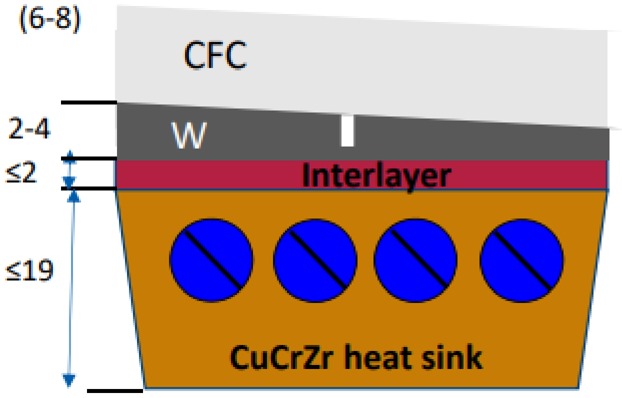
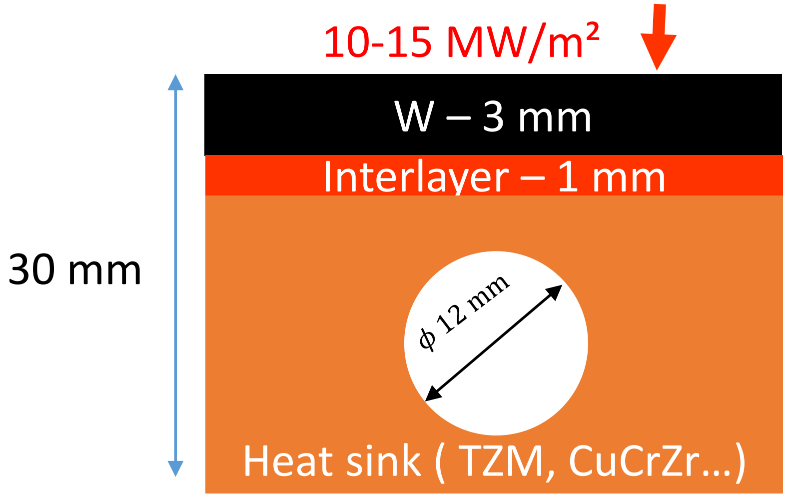
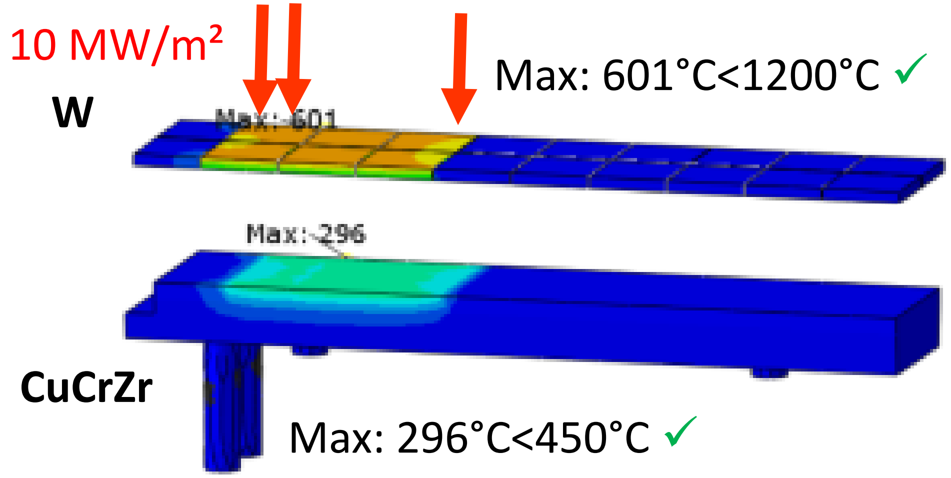
W7-X



JT-60SA



Results of thermal analysis (FEM)[1] :



→ Proposed geometry is able to sustain 10 MW/m² in steady state ✓

Results of thermal analysis (FEM)

Heat sink	CuCrZr		TZM	
Incident heat flux (MW/m²)	10	15	10	15
Heat sink Max Temp. (C)	452	603	963	1435
W Max Temp. (C)	704	1015	1221	1832

→ Proposed geometry may be able to sustain 10 MW/m² in steady state ✓

→ What are the technological solutions able to sustain 15 MW/m² in steady state ?

1: J. Boscary et al, SOFT conference, 2022, submitted

2.3 Divertor target with W armor material –15 MW/m² in steady state

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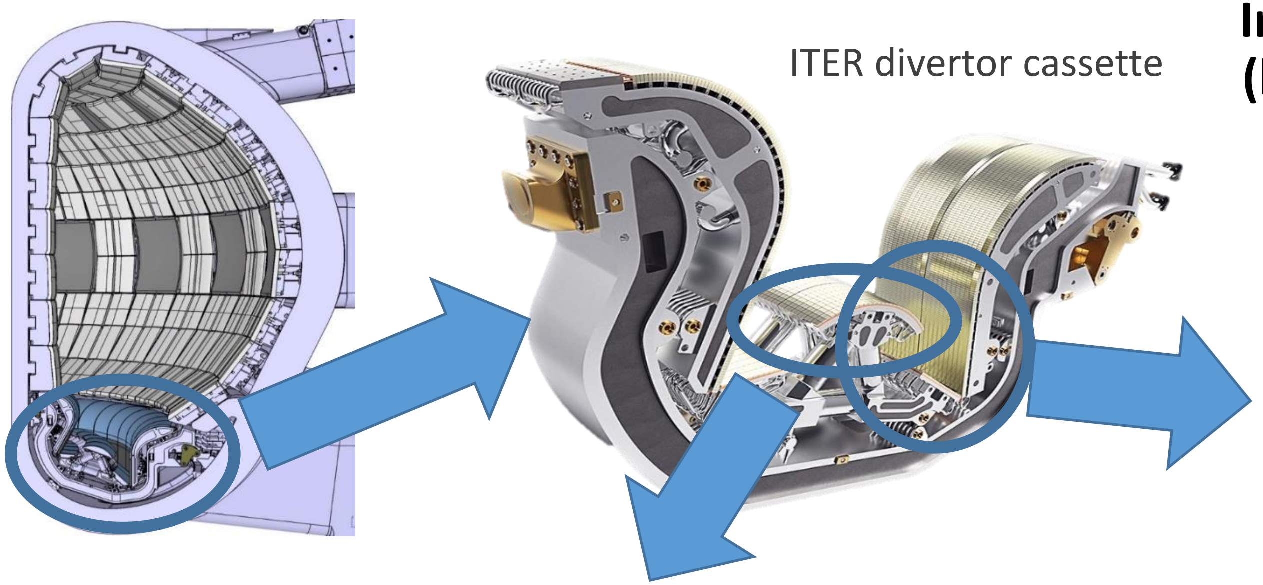
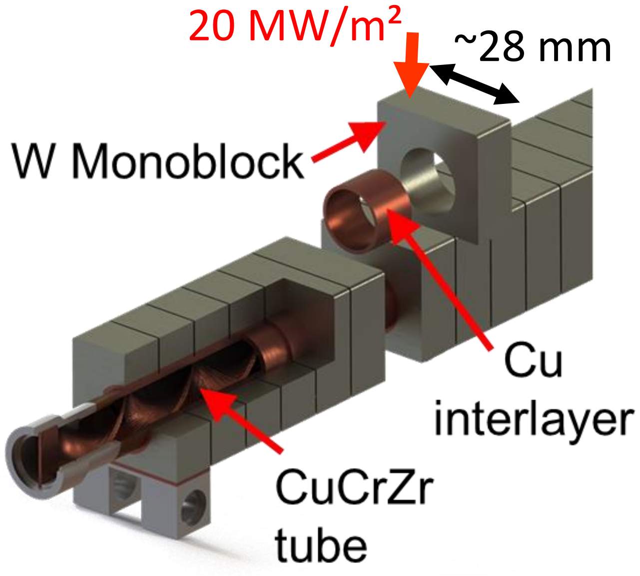
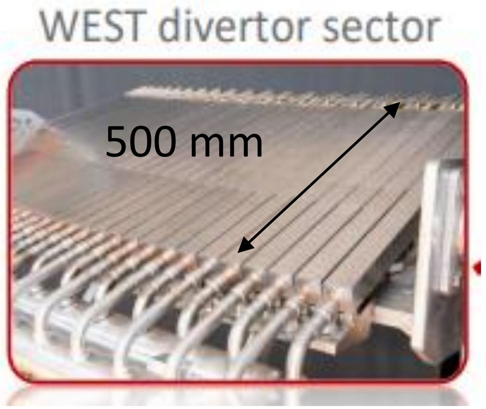


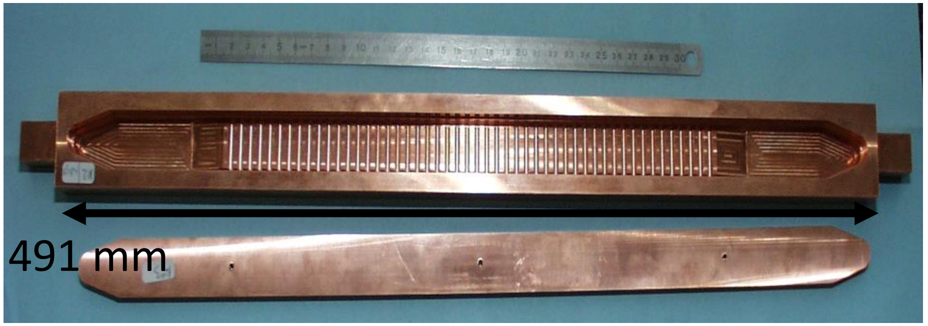
Inner and outer vertical targets (based on monoblock concept)



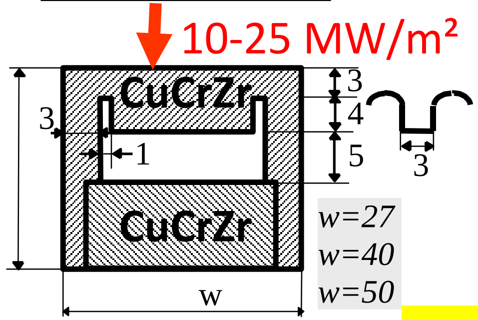


Dome PFC based on hypervapotron cooling concept

Example of Hypervapotron mock-up (2000)



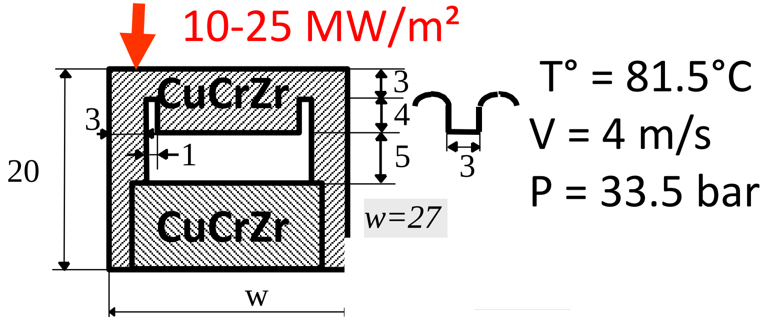
Schematic cut view



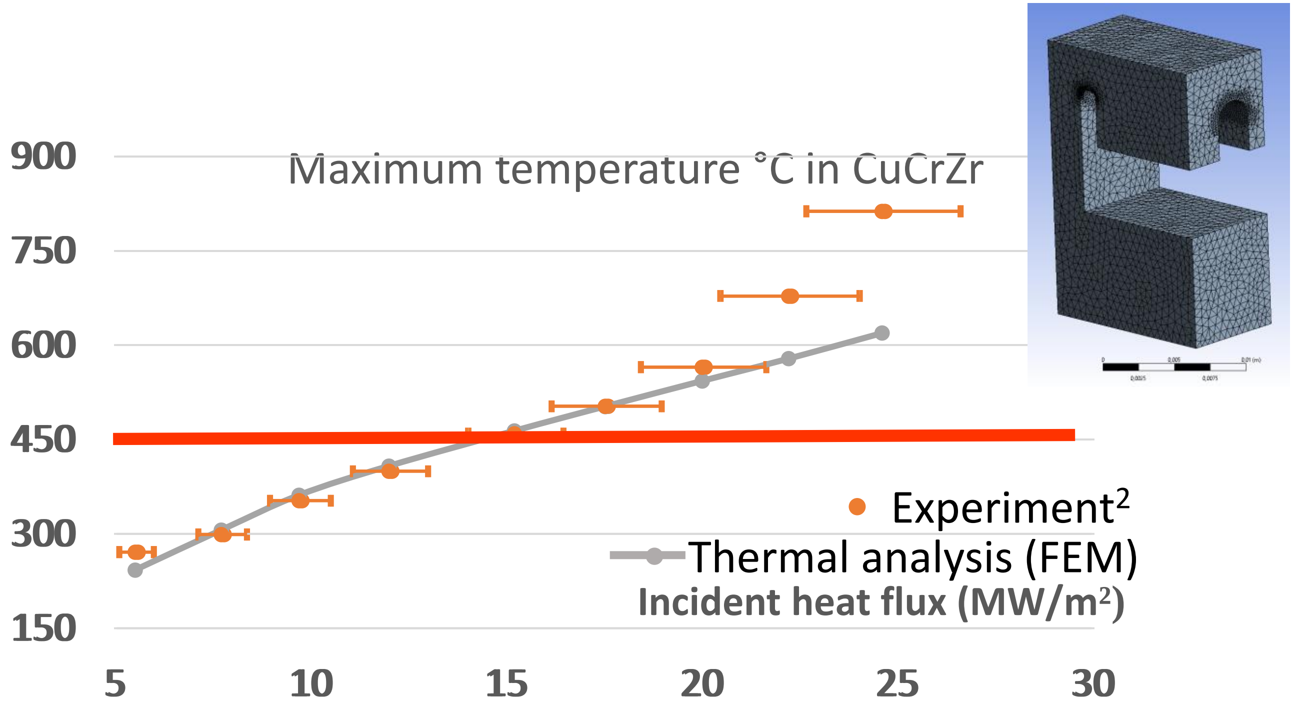
☺ Able to sustain 20 MW/m² in quasi- steady state feedback from series manufacturing

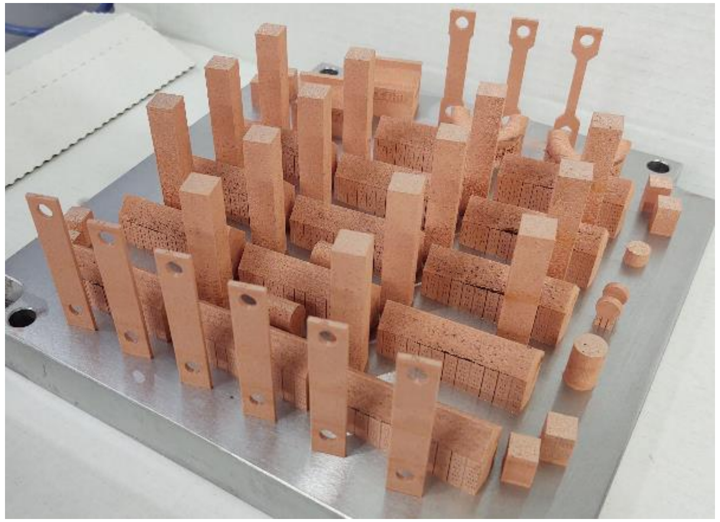
☹ Cost, multiple cylindrical joining

2.3 Divertor target with W armor material – 15 MW/m² in steady state



- → Proposed geometry is able to sustain 15 MW/m² in steady state ✓
- → The use of FEM is promising to define the most adapted W target hypervapotron geometry
- → Need of mock-up manufacturing/high heat flux testing (use of CuCrZr additive manufacturing[3] for rapid manufacturing)





2: F. Escourbiac et al, Fus. Eng. and Des., 2003
3. Salvan, 2021

Conclusions

- Divertor water cooled targets with C armor material : for W7-X it was commissioned in 2022 and for JT-60SA it will be commissioned in 2029

- Divertor water cooled target with W armor material for W7-X and JT-60SA
  - Installations planned in 2032-2033
  - Steady state heat loads requirement : 10 MW/m² (W7-X) to 15 MW/m²(JT-60SA)
  - Lower loads (heat, neutrons…) compared to the ITER and DEMO divertor targets
  - Curent designs: **Flat tile design**
  - Similar design and material choices lead to the sharing of knowledge between the two developments (joining/new materials/manufacturing)
  - Technological developments are run with **industries**
  - Future plans: **surface shaping** may be studied to propose surface shapes consistent with manufacturing feasibility and plasma shapes

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