Divertor Design Considerations for CFETR

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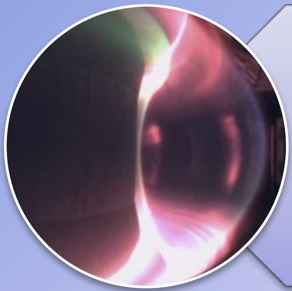
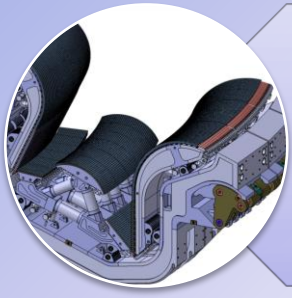
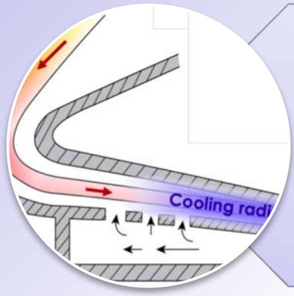
OUTLINE



Key PSI issues for CFETR

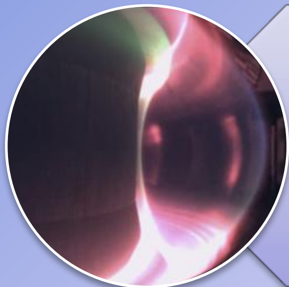


CFETR Divertor options



Alternative target concepts

OUTLINE



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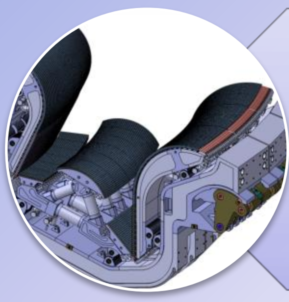

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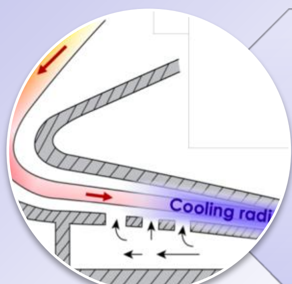
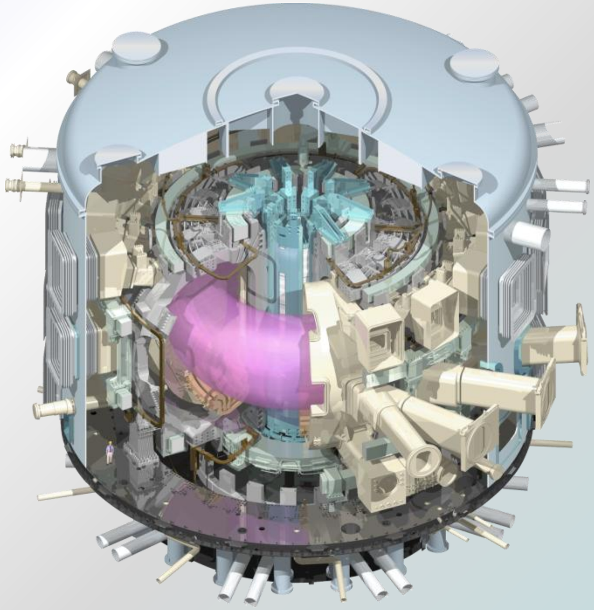


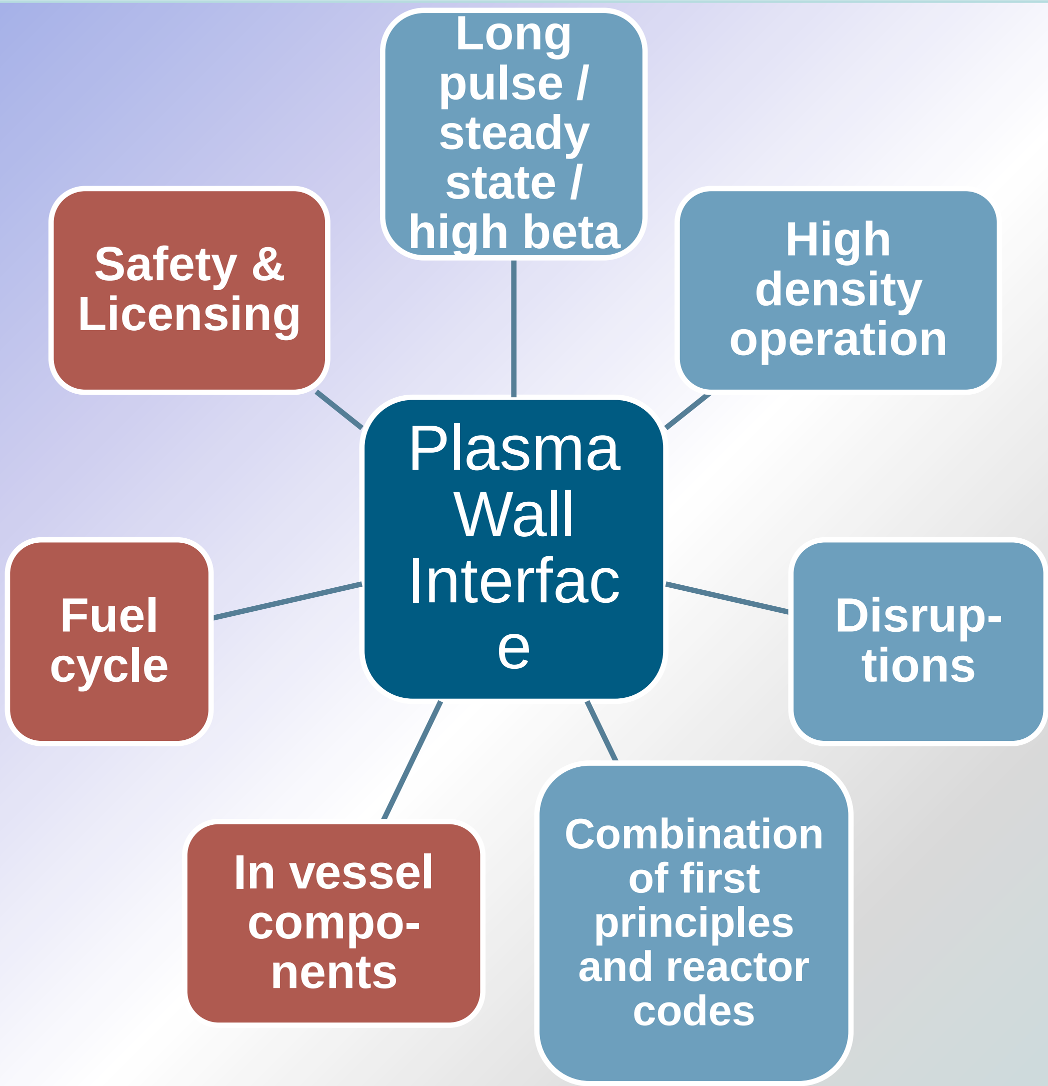
Alternative target concepts

CFETR-main parameters (CFETR-00-00-03)

	CFETR	ITER
Major radius (m)	**5.5**	6.2
Minor radius (m)	**1.6**	2.0
Elongation	**1.8**	1.85
Plasma current (MA)	**12/10/7**	15 (17)
Toroidal field (T)	**5.3/4.5**	5.3
Central density ($10^{20}/m^3$)	(1.0)	1.0
Central temperature (keV)	(15)	20
Confinement time (s)	(1.5)	3.7
Heating Power (MW)	**50/80**	73
Fusion power (MW)	**50~200**	500 (700)
Plasma volume (m^3)	**500**	830
Operation time (s/ yr)	**$1\text{-}1.6\cdot10^7$**	$4.0\cdot10^5$



Integral Approach Is Mandatory for the Design of Plasma-Wall Interface



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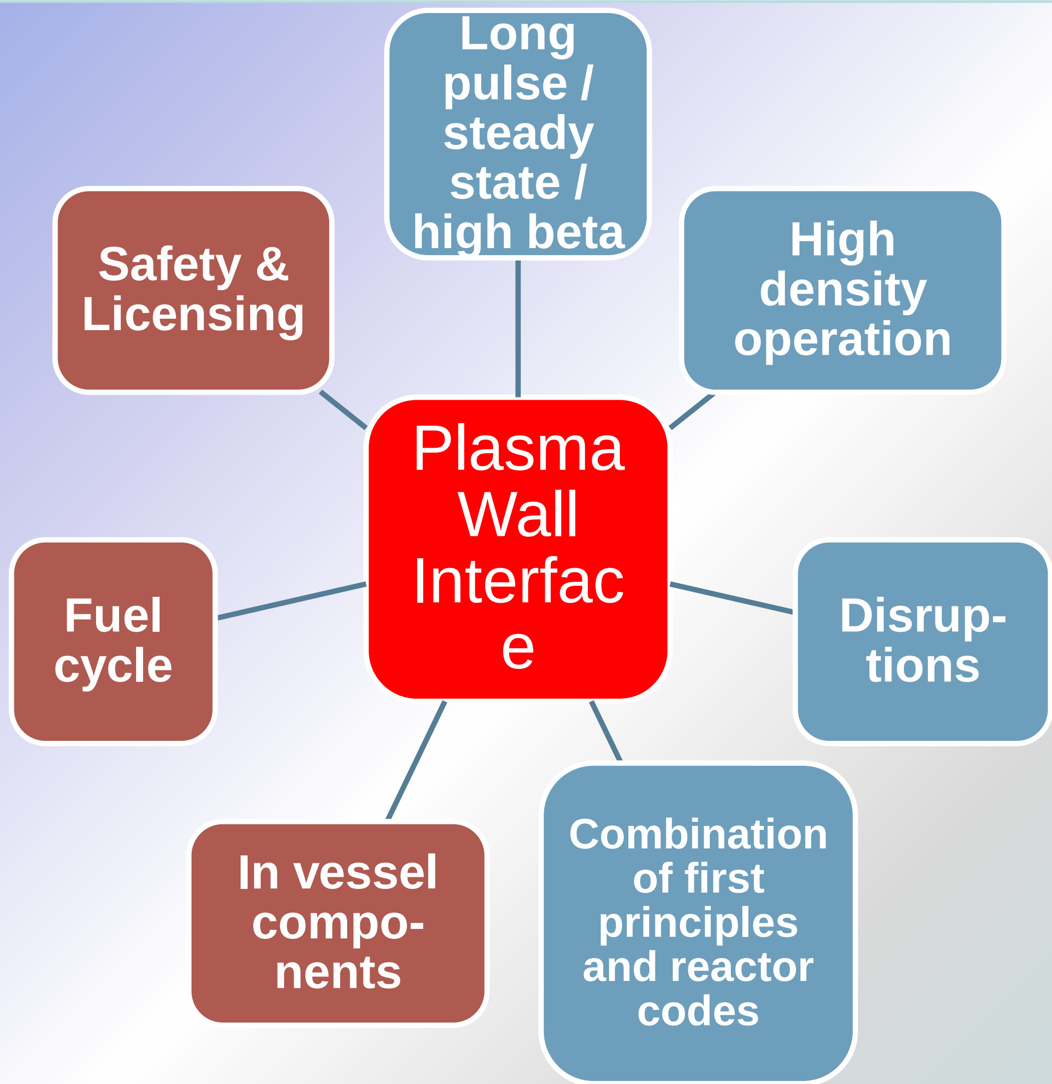
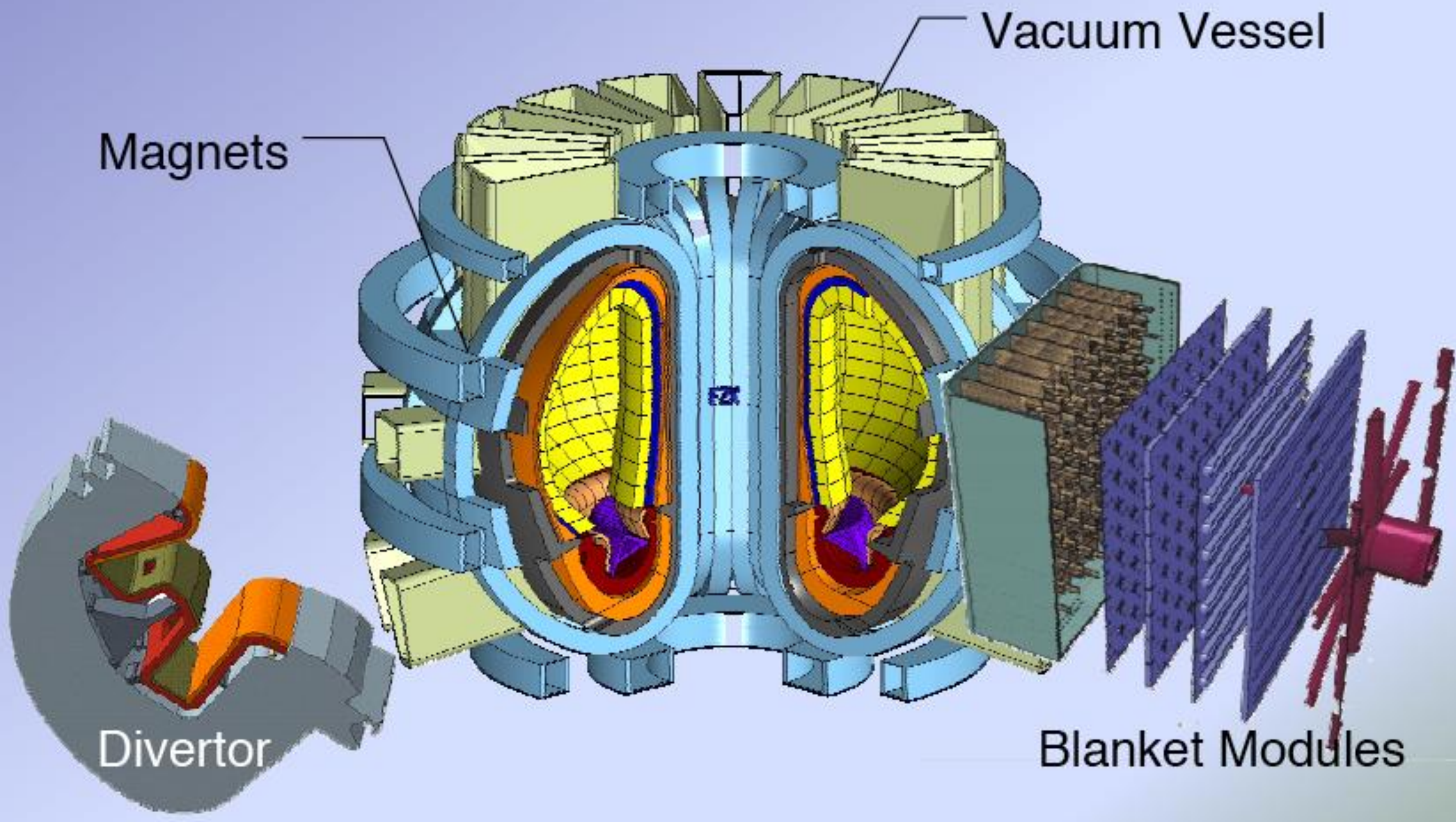


Divertor Is a Key Component for CFETR

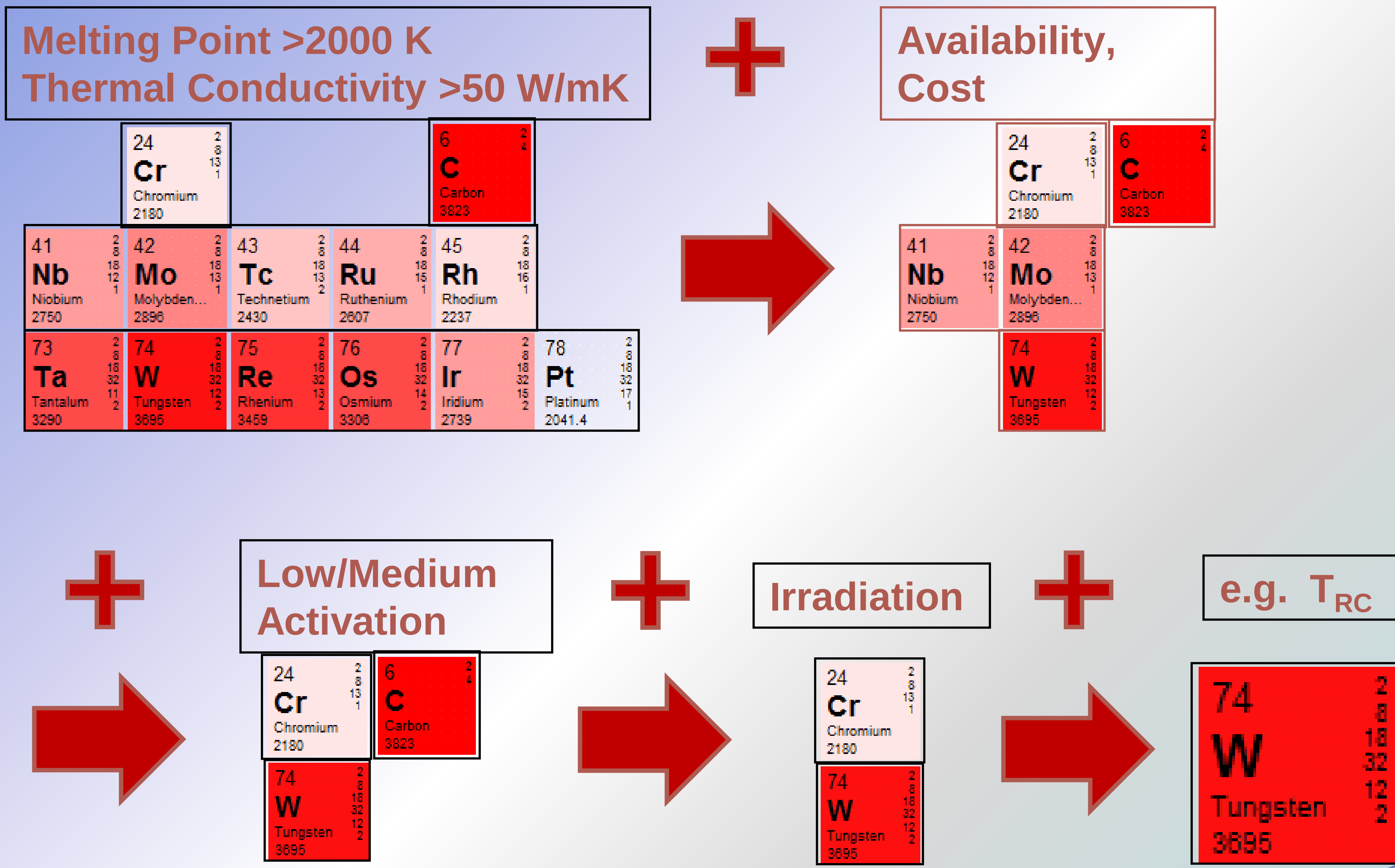


Main Challenges for Divertor

- Exhaust the major part of the plasma thermal power, reducing heat flux below limitation of target materials.
- Remove fusion helium ash from core plasma while providing sufficient screening for impurities from wall.
- Maintain acceptable erosion rate in terms of reactor lifetime.

Selection of High Heat Flux Materials for DEMO Divertor Target

B. Unterberg, 20th PSI Conf. 2012, Germany



Major Problem for W is Melting under Transient Heat Load

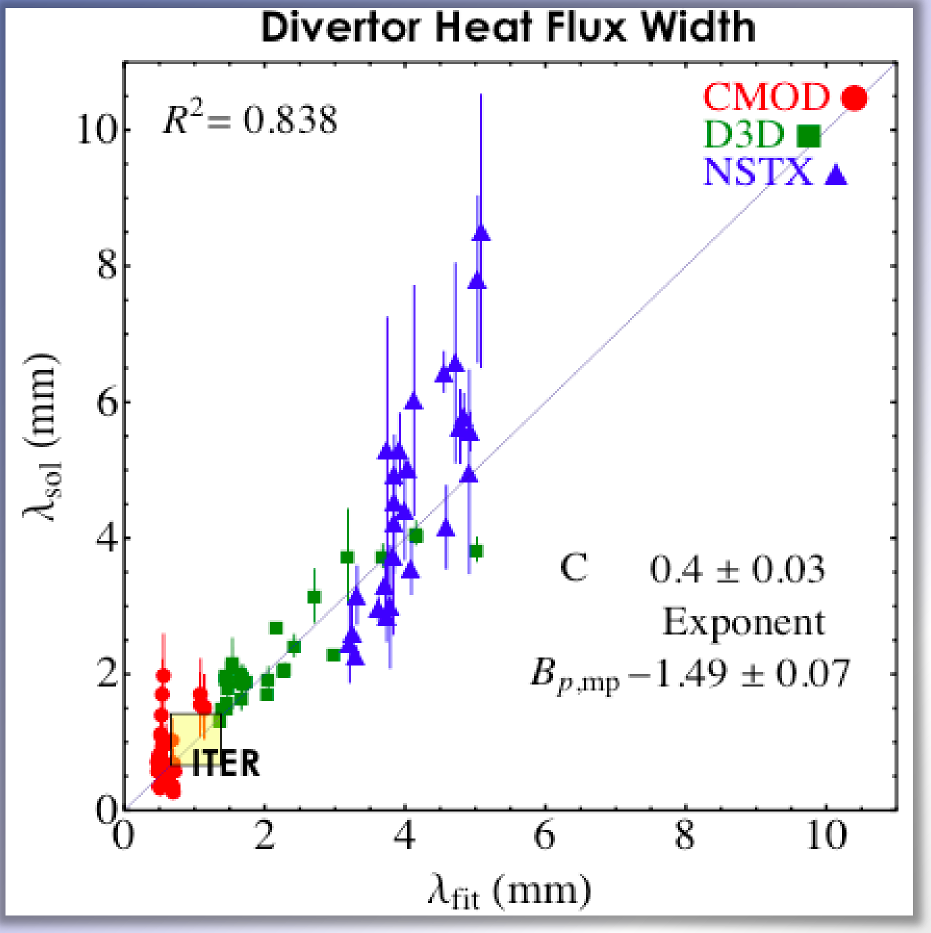
R. Haange, ITER STAC-12,/2012, Cadarache

W melting parameter: $\varepsilon_{melt} \geq 50\ MJm^{-2}s^{-1/2}$

I_p (MA)	P_{IN} (MW)	Stored energy (MJ)	$E_{transient}$ (MJ)	$\lambda_{q\|\|omp}$ (m)	q_{target} ($MJ\ m^{-2}$)	ε ($MJ\ m^{-2}s^{-1/2}$)	Type
7.5	40	75	25 → 38	0.01	0.83 → 8.3	15.2 → **213**	**Disruption**
15	50	350	88 →175	0.005	5.78 → 76.9	**105 → 1984**	**Disruption**
7.5	40	75	6.4 → 8.0	0.01	1.39 → 1.74	**77 → 123**	**Type I ELM**

- **Disruptions and unmitigated ELMs are predicted to melt W target for ITER (above).**
- **This will also apply to CFTER → Disruption & ELM mitigation are mandatory.**
- **W Melting detection and RH are required to repair W damage.**

SS Heat Exhaust Is Also Challenging due to Very Narrow Power Deposition Width



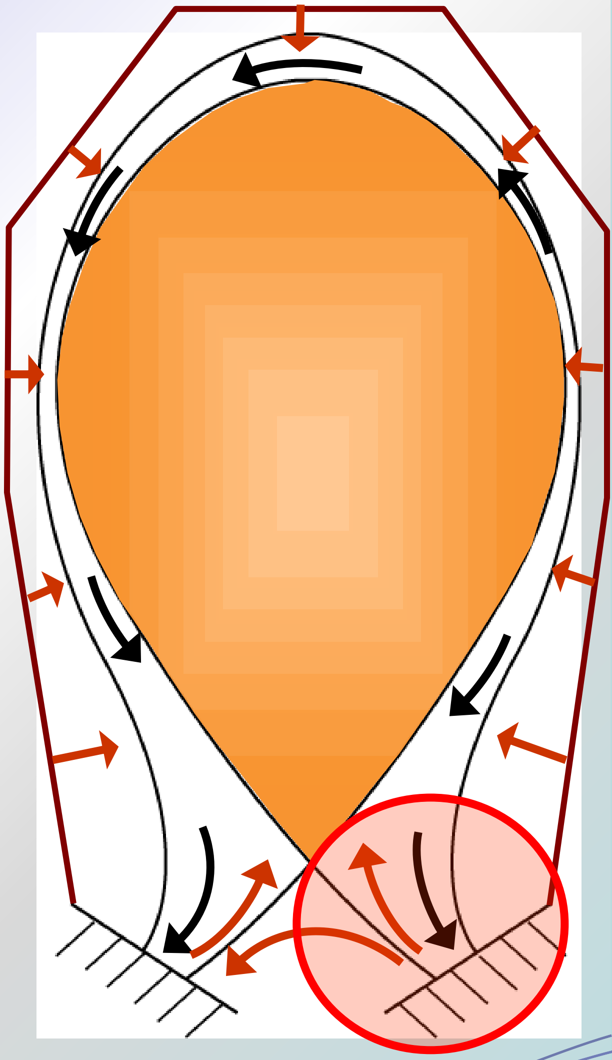
Detachment is required.

CFETR Faces Much Greater Challenges than ITER due to Larger Duty Cycle ≥ 0.3 ~ 0.5

General migration pattern seen in today's devices: main wall erosion, convection into divertor ➔ deposition

R. Pitts, 2012 KSTAR Meeting

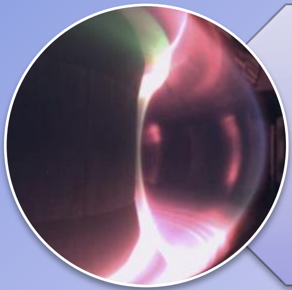
	No. Pulses (Y2000-2008)	Time in diverted Phase (hr)	Outer divertor ion fluence
JET	13466	40.5	$\sim 5 \times 10^{27}$
ITER	1	0.15	$\sim 1.5 \times 10^{27}$



➔9 years JET operation ~ 3 ITER Q_{DT} = 10 pulses in terms of divertor fluence, important for target erosion and T-retention

➔ Much more serious for CFETR

OUTLINE



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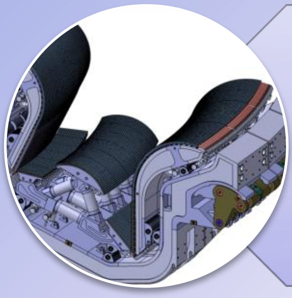
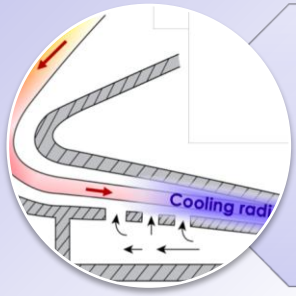
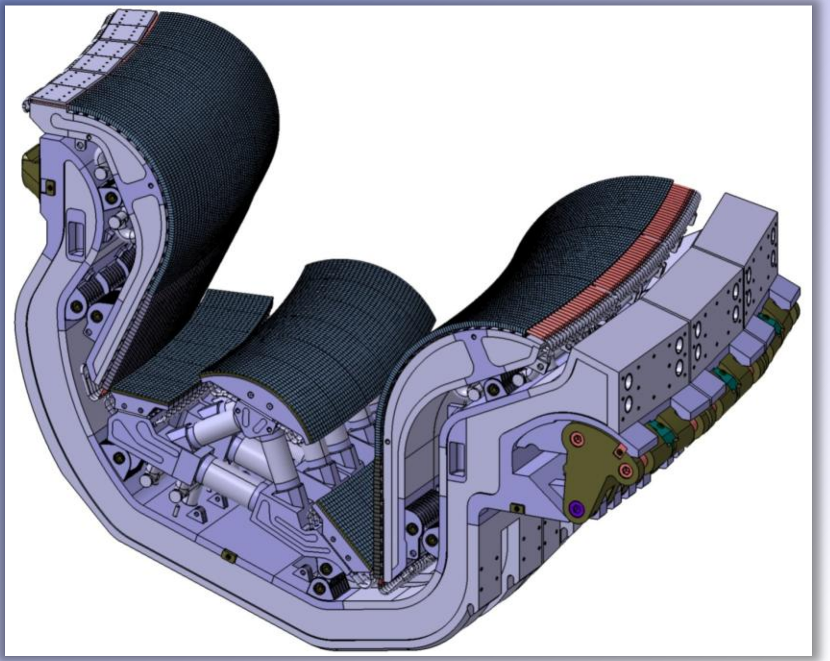


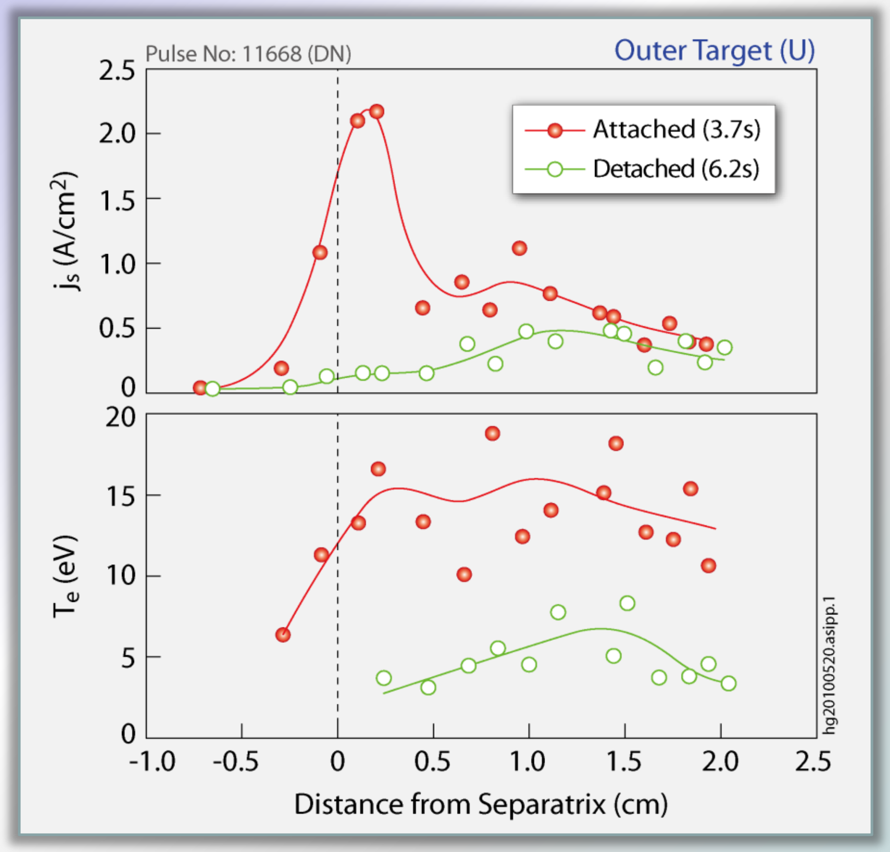
CFETR Divertor options



Alternative target concepts

ITER-Like Vertical Target Structure





- **Promote detachment near strike point due to preferential ionization near strike points.**
- **Provide sufficient He ash removal.**

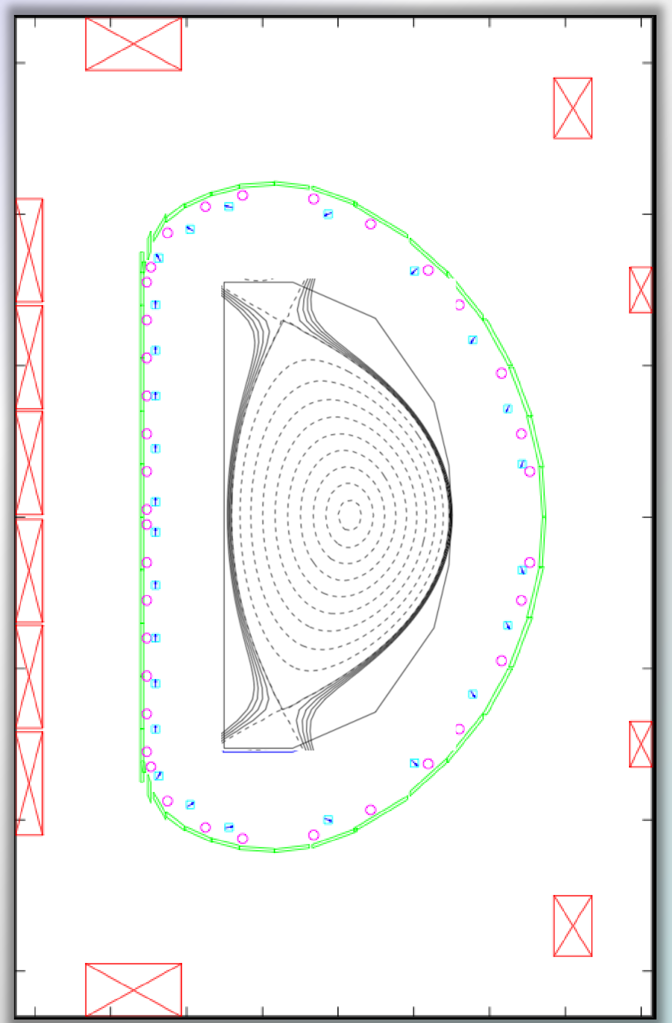
System Design & Integration

- Divertor cassettes with plasma facing components
- Cooling system to exhaust plasma and neutronic heat deposition
- Cryopumps to exhaust neutralized gas
- Fuelling system to promote plasma detachment / mitigate re-attachment
- Divertor view system and RH to monitor and repair divertor components…

SD or DN ?

Advantages of DN:

- **Larger plasma-wetted area, facilitating power exhaust**
- **Allowing pumping via both top and bottom, facilitating particle exhaust**
- **Naturally large triangularity, facilitating advanced tokamak operation**
- **Accommodate Advanced divertor configuration, e,g., SXD**



Advantages of SN:

- **Accommodating large plasma volume**
- **Maximizing TBR**

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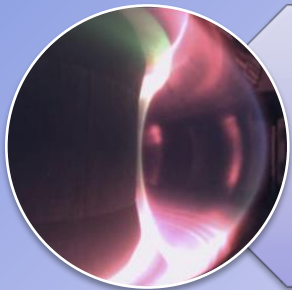

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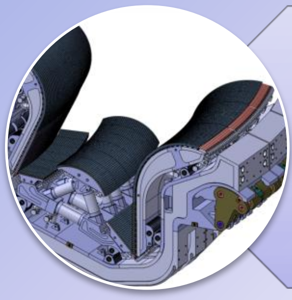

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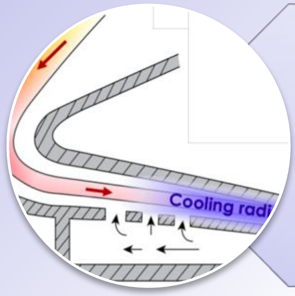
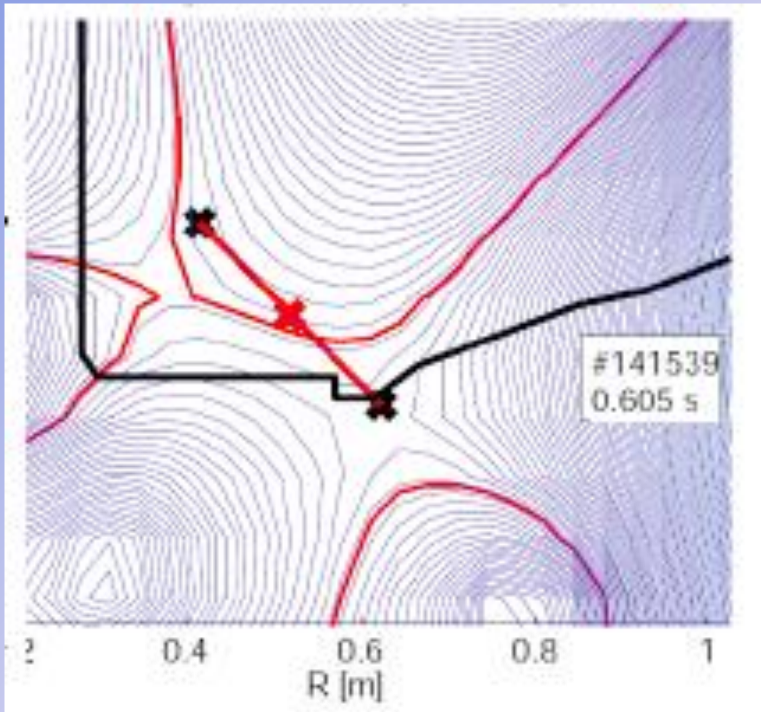


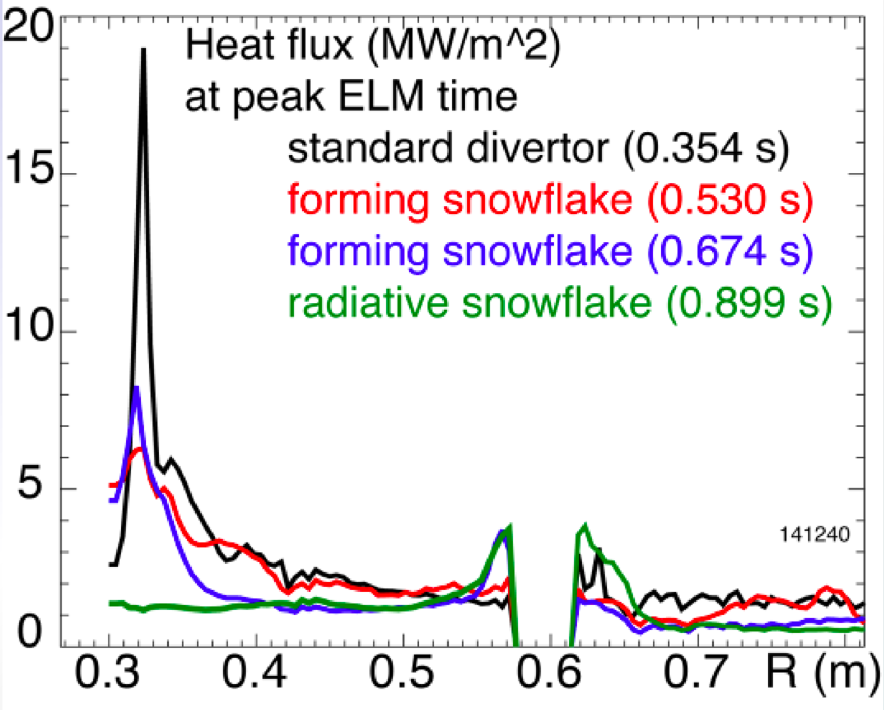
Alternative target concepts

Snow-Fake Divertor to Reduce Peak Heat Load

NSTX Snowflake Divertor

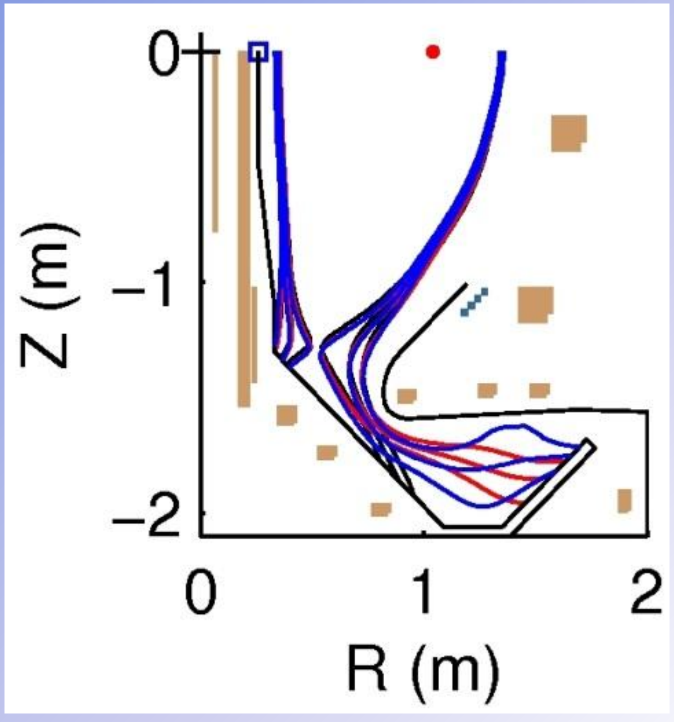
V.A. Soukhanovskii, NSTX-PAC 31, PPPL, April 17-19, 2012

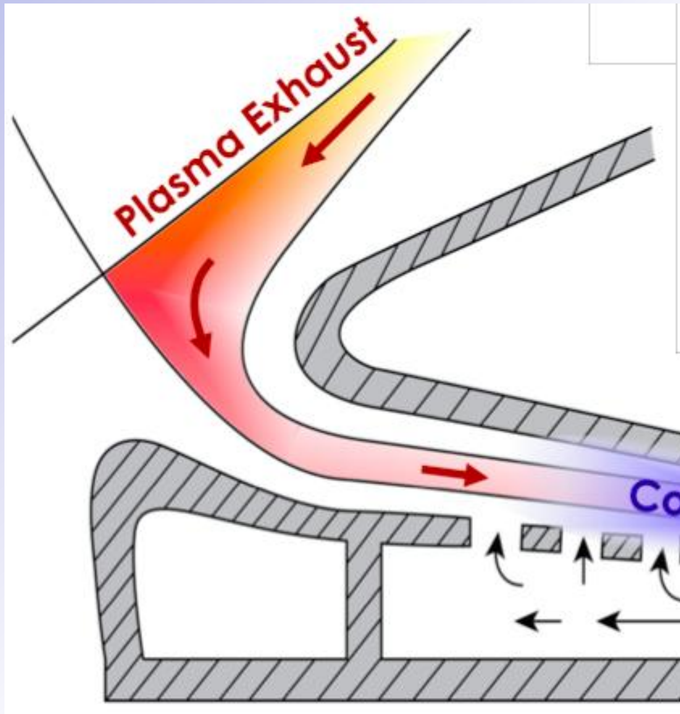




- **Reduction from 3-7 MW/m^2 to 0.5-1 MW/m^2 between ELMs; Reduction from ~20 MW/m^2 to 2-8 MW/m^2 at ELM peak.**

Super-X / Isolated Dovertor





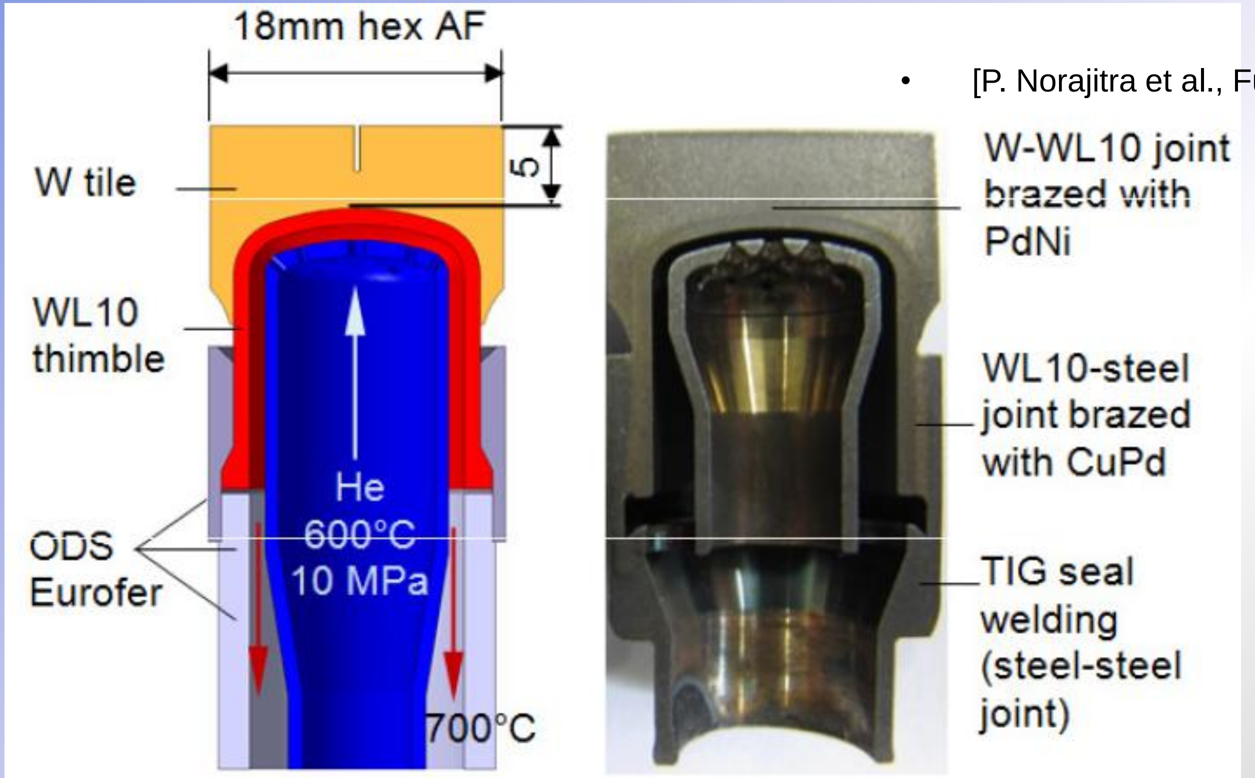
- Longer conn. length
- Larger flux expansion

Critical issue:

DEMO compatible coils to establish configuration

High Temperature Operation

- [P. Norajitra et al., Fus. Eng. Des. 83 (2008) 893.]



He-cooled modular divertor with jet cooling (finger concept, KIT)

Approaches to CFTER Divertor Design

Phase I	Phase II	Phase III
Fusion Power:50-100 MW	**Fusion Power: 400 MW**	**Fusion Power: 800 MW**
ITER-like Vertical Target, accommodating snowflake w/o additional coils	**Snowflake or more advanced configuration – SXD**	**Demo-relevant Divertor, e.g., KIT, or liquid divertor**

Approaches to CFTER Divertor Design

Optimize Magnetic configurations and target geometry :

1. Optimize Magnetic configurations --- physics design group
2. Design target geometry
3. Calculate distributions of particles and heat using SOLPS code
4. Optimize target geometry

Start engineering conceptual design:

1. Preliminary design on target, heat sink, support structure, cooling structure and cassette body…
2. Electromagnetic analysis of the divertor components (DINA/MIT+ANSYS)
3. Neutron volumetric heating calculations (code?)
4. Thermo-mechanical analysis and structure analysis (ANSYS)
5. Optimize divertor structure design