ITER Tungsten divertor and status

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On behalf of Tungsten Divertor Task Force at IO and all contributors

Background of Full-W Divertor Activity

- **New ITER divertor strategy**
  - From MAC-12 (Oct. 2011) [ITER_D_6SR5F7]: "[…] for budgeting purposes, the MAC supports the DG recommendation to de-scope to a single divertor during construction and initial five years of operation".[…] "As to the specific choice of divertor, MAC recommends delaying the decision for up to two years.
  - These recommendations were adopted by the ITER Council during its ninth meeting in Nov. 2011 so that IO started to investigate the possibility of beginning operation with a full-W armoured divertor.

→ Tungsten Divertor Task Force was established to coordinate the design activity in IO and monitor the technology R&D in DAs

W divertor development activity

❑ Full-W divertor design development } IO
- Extension of lifetime: update of the thermal loads specifications, nuclear aspects
- Introduction of W in the strike-point area (shaping aspects)
- Verification of the design via dedicated analysis

❑ Full-W Divertor qualification program (technology R&D) } Concerned DAs

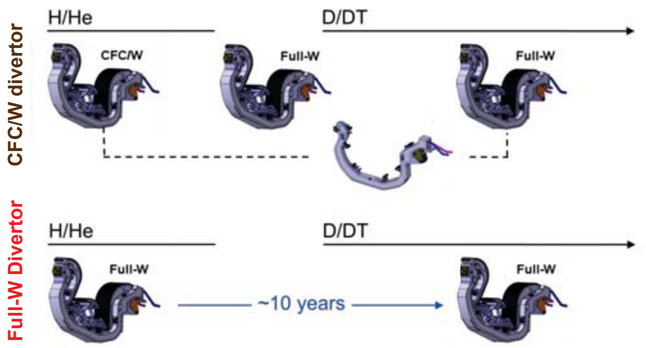
❑ Assessment of the physics and operational risks of starting ITER with a full-W divertor } Physics community, ITPA, etc…

Schedule for full-W Divertor Implementation

- **Final Design Review of Tungsten Divertor (26-28 June 2013) → close-out completed**
  - ✓ **Full-W Divertor design**
  - ✓ **Full-W Divertor technology qualification programme**
- **Physics Assessment → presented in STAC-14 and -15**
  - ✓ **Report from ITPA Topical Groups to STAC-14 (May 2013) giving physics/operational assessment on starting with a full-W divertor at ITER**
  - ✓ **JET misaligned lamella melt experiment**
- **STAC-15 (Oct 2013) recommended tungsten divertor as the first divertor**
- **ITER Council-13 (Nov 2013) endorsed the STAC recommendation on tungsten divertor as the first divertor**
- **Implementation of the decision into the baseline** via a PCR (end-2013, *SMP.0116.001032 milestone*)

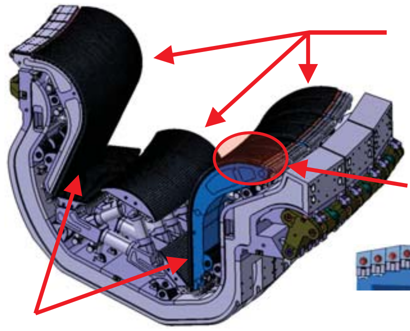
Divertor Maintenance strategy

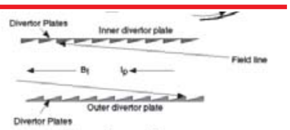
- **Extension of Lifetime**



Full-W Divertor design: Main Features

Objective: minimum changes compared with the baseline (CFC/W) variant

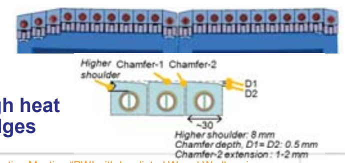




View fromTop

Optimize tilting of Vertical Targets and Dome to protect inter-cassette leading edges

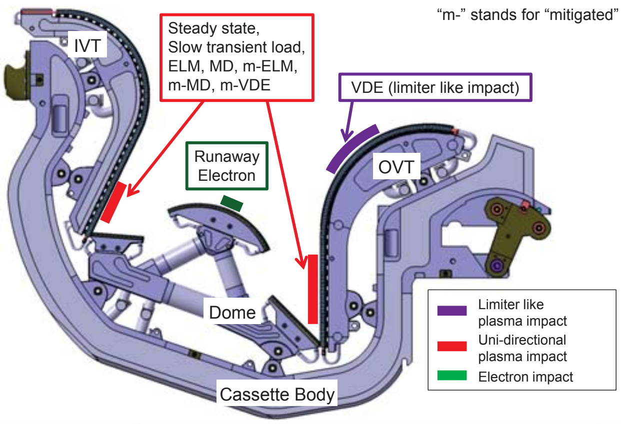
Outer baffle shaping to mitigate W melting at downward VDE impact



Individual monoblock shaping in high heat flux areas to protect all leading edges

Thermal Event Impact at Plasma-Facing Surfaces

"m-" stands for "mitigated"



Design Heat Flux and Number of Cycles

- **Input** (ITER Research Plan)
  - Available heating power during each ITER machine operation phase
  - Scheduled number of pulses during each ITER machine operation phase from He-H through to DT operation
- **Assumption**
  - A full-W divertor, installed from the beginning of operations, should survive at least until the end of the first full DT campaign

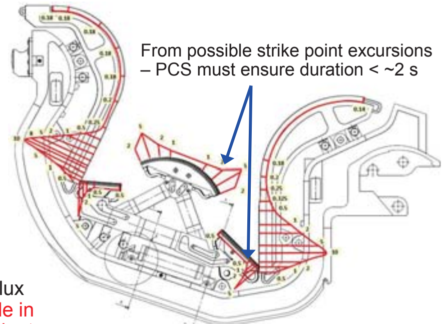
Campaign	No. Pulses	Flattop success rate	$P_{IN,max}$ (MW)	$P_{SOL,max}$ (MW)	Pulses to 10 MWm^{-2} (transient)	Pulses to 10 MWm^{-2} (stationary)	Pulses to 20 MWm^{-2} (transient)
H-He I	4200	0.8	60	58	0	0	0
H-He II	9800	0.9	60	58	450	0	0
DD	4950	0.9	73	68	1100	0	110
DT	5600	0.9	73	120	-	3700	180
Total	25000				1550	3700	290

Design Heat loads: 5000 cycles at 10 MW/m^2 ; 300 cycles at 20 MW/m^2

Thermal loads specifications

Determination of thermal loads envelopes for design supporting analysis:

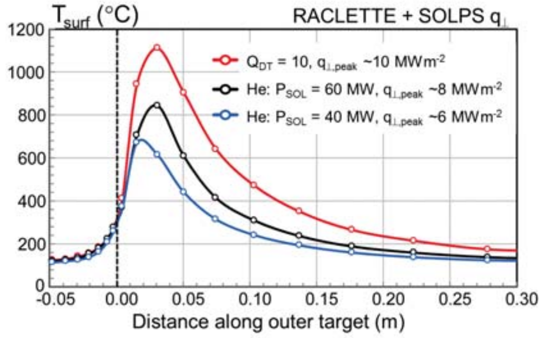
Plots of poloidal distribution for thermal analysis at highest steady performance (Q_{DT} = 10) → q_{pk} = 10 MWm^{-2}



ASSUMPTION: these heat flux envelopes may simply double in magnitude during slow transients

(C9RF33)

Surface temperature: a key parameter



Calculation for 8 mm W monoblock (rectangular shape) armour thickness

(R. Pitts, PSI 2012)

Thermal loads specifications

"Fast transients" loads (event numbers and magnitude)

Vertical Displacement Events (VDE); Major Disruption (MD)

As for stationary loads, a thermal load specification was developed for VDE and MD: 4 main campaigns, two characteristic stored energies for each campaign; Mitigated and unmitigated

ELMs

Controlled ELMs spec for ITER: $\Delta W_{ELM}/A_{DIV} \leq 0.5$ MJm^{-2} → **ΔW_{ELM} ~ 0.6 MJ** to avoid edge melting for unshaped (flat surface) monoblocks

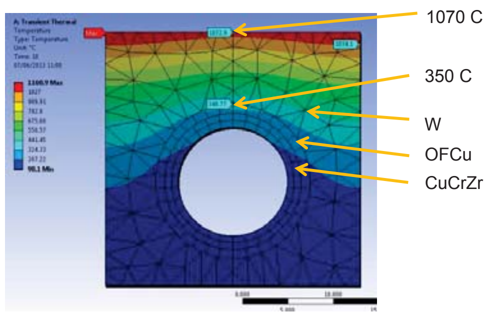
VDE	Plasma stored energy [MJ]	No. of pulses	Flat top success rate	Stored Energy achieve rate	DW VDE rate	DW VDE Mitigation success rate	No. of mitigated DW VDEs	Mitigated DW VDE parallel energy flux at LCFS at inner (outer) target [MJ m-2]	No. of unmitigated DW VDEs	Unmitigated DW VDE parallel energy flux at LCFS (outer baffle)
He-H I	30	4200	0.8	0.5	0.05	0.8	67	6 (2)	17	34
	90			0.5	0.05	0.8	67	18 (7)	17	102
He-H II	90	9800	0.9	0.5	0.02	0.9	79	18 (7)	9	102
	150			0.5	0.02	0.9	79	30 (12)	9	169
DD	150	4950	0.9	0.5	0.01	0.95	21	30 (12)	<2	169
	210			0.5	0.01	0.95	21	43 (16)	<2	237
Full Power DT Q_{DT} =10	210	5600	0.9	0.5	0.01	0.99	12	43 (16)	<1	237
	350			0.5	0.01	0.99	12	71 (27)	<1	395

MD	Plasma stored energy [MJ]	No. of pulses	Flat top success rate	Stored Energy achieve rate	Major Disruption rate	MD Mitigation success rate	No. of mitigated MDs	Mitigated MD parallel energy flux at LCFS at inner (outer) target [MJ m-2]	No. of unmitigated MDs	Unmitigated MD parallel energy flux at LCFS at inner (outer) target [MJ m-2]
He-H I	30	4200	0.8	0.5	0.2	0.75	252	6 (2)	84	49 (19)
	90			0.5	0.2	0.75	252	18 (7)	84	146 (56)
He-H II	90	9800	0.9	0.5	0.12	0.85	450	18 (7)	79	146 (56)
	150			0.5	0.12	0.85	450	30 (12)	79	243 (93)
DD	150	4950	0.9	0.5	0.08	0.92	164	30 (12)	14	243 (93)
	210			0.5	0.08	0.92	164	43 (16)	14	341 (130)
Full Power DT Q_{DT} =10	210	5600	0.9	0.5	0.05	0.95	120	43 (16)	6	341 (130)
	350			0.5	0.05	0.95	120	71 (27)	6	568 (216)

(TGFMB6)

Temperature distribution in Monoblock

10 MW/m^2 steady state load



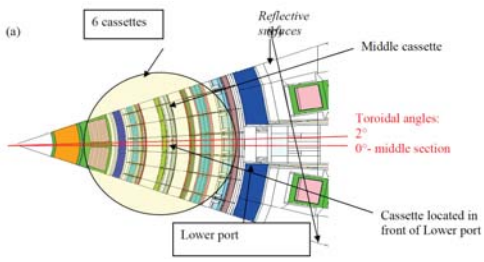
Calculation for 8 mm W monoblock (rectangular shape) armour thickness

Nuclear Analysis for ITER W Divertor

Model: with the latest ITER MCNP-5 Monte Carlo Code 3D model (MCNP ITER 40° model B-lite v-2)

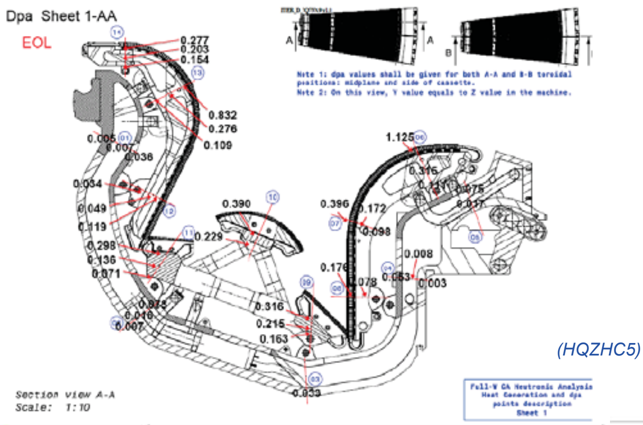
Assumption: 18% of the cumulated $3x10^{27}$ neutrons (ITER End of Life) during first divertor (up to end of the first full DT campaign)

Objective: Evaluate radiation damage, helium production and nuclear heating



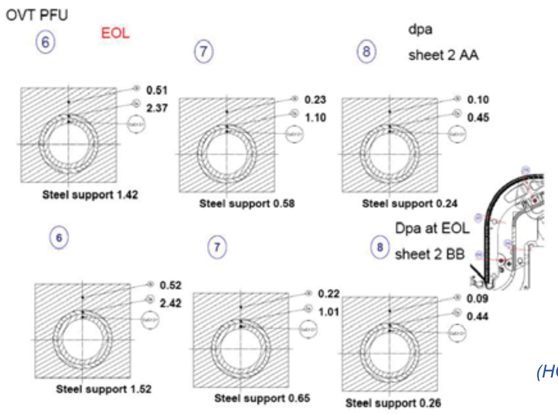
(HQZHC5)

Nuclear Analysis Results – DPA at End of Life



(HQZHC5)

Nuclear Analysis Results – DPA at End of Life



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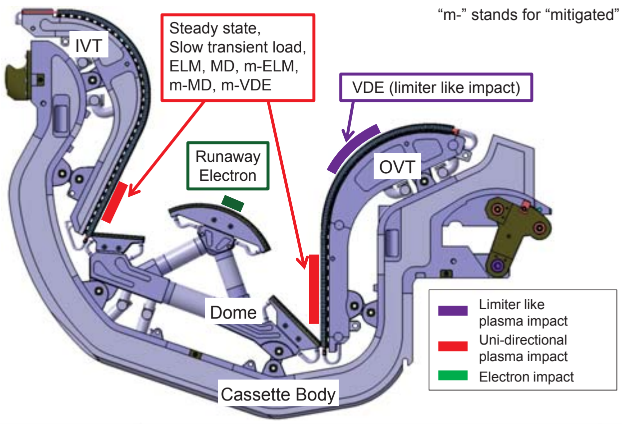

Divertor Procurement Arrangement Status

- **Procurement Arrangements signed**

5 are signed: 6 PAs allocated (in-kind contributions)

	PA17P-2A*	OVT	17 June 2009
	PA17P-2B	IVT	12 Mar 2010
	PA17P-2C	Dome	09 June 2009
	PA17P-2D	HHF Testing	23 Mar 2010
	PA17P-1A	CB+CA integration	08 May 2012

1 to be signed:

	PA17P-1B	Divertor Rails	Sept. 2014

(For rails: PCR290 implemented into baseline 27 Sept. 2010)

* To be renewed by Oct 2014 due to change to W divertor

W Material Specification (ITER_D_2EDZJ4v1.3)

1. Chemical composition (ASTM B760) : ≥ 99.94%

Element	Composition max, wt. %	Permissible variation in Check analysis, wt. %
C	0.01	±0.002
O	0.01	+10% relative
N	0.01	+0.0005
Fe	0.01	+0.001
Ni	0.01	+0.001
Si	0.01	+0.001

2. Hardness HV30 (ASTM E92): ≥ 410
3. Density (ASTM B311): ≥ 19.0 g/cm3
4. Grain size at perpendicular to the rolling direction (ASTM E112) : 3 or finer

NDT: Visual Test and Ultrasonic Test

Requirement for the surface roughness: Ra < 6.3 μm

Summary

- ❑ Showed: Divertor operation conditions: power and energy density (temperature) and dpa
- ❑ Appreciate: Assessment for machine operation conditions considering:
  - Fluctuation of power density and energy density (→ Fluctuation of temperature);
  - Temperature distribution in bulk W
  - Fluctuation of ΔT due to transient;
  - Fluctuation of particle flux
  - Helium and impurity flux,
  - Well-defined W material with engineering surface, i.e. Ra ~3.2 - 6.3 μm
  - Shallow surface melting events, etc.
- ❑ Procurement of First W divertor had started. Procurement of second divertor will start before the first major shutdown