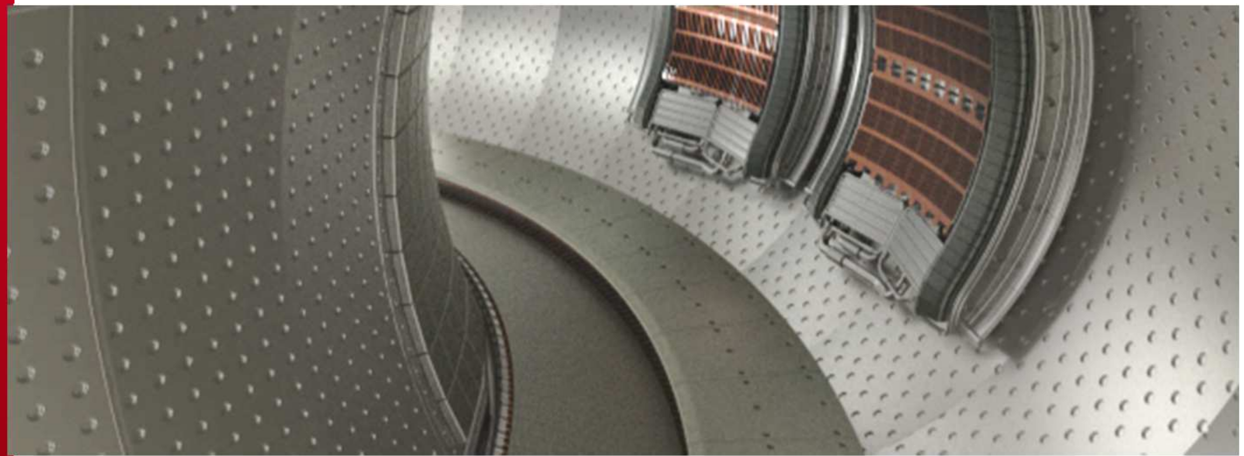
DE LA RECHERCHE À L'INDUSTRIE

WEST PROJECT AND OPPORTUNITIES FOR US-DOE COLLABORATIONS

WEST : W Environment in Steady state Tokamak



Project Head: J. Bucalossi,

Project Scientist : E. Tsitrone together with

Ph Ghendrih and C. Bourdelle

2014 FESAC Strategic Planning (SP) Panel 8-10 July , USA

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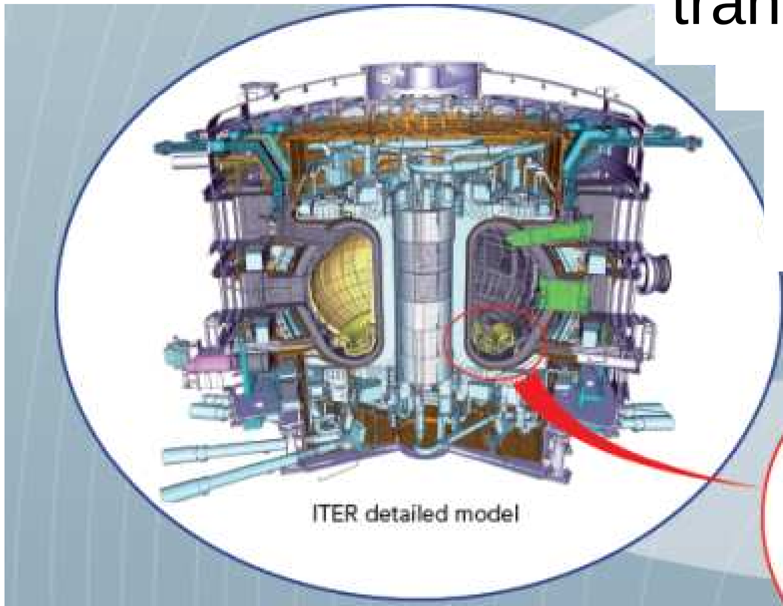
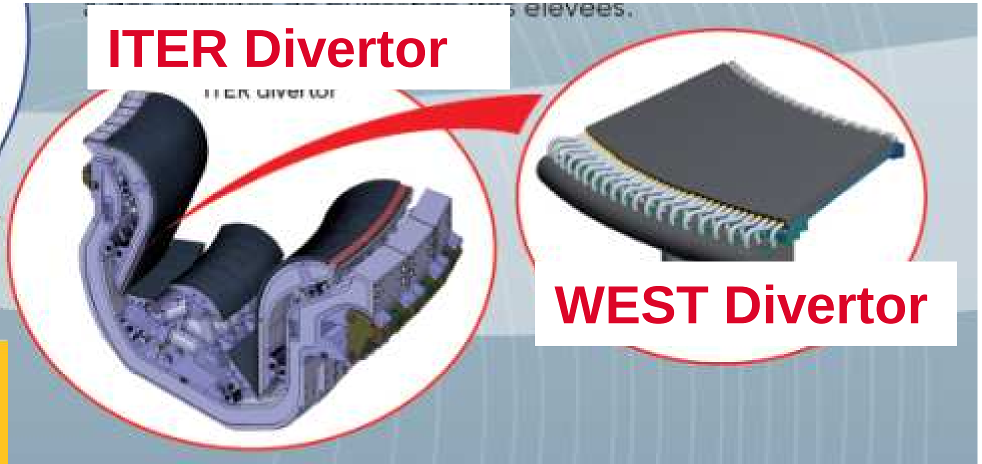
Power exhaust : a challenge for fusion, in ITER and DEMO

- ITER divertor : steady state up to 10 MW/m² and slow transients up to 20 MW/m² + lifetime issue: high particle fluence, erosion, potential melting, ELMs, disruptions,etc





Keys figures for ITER divertor risk analysis

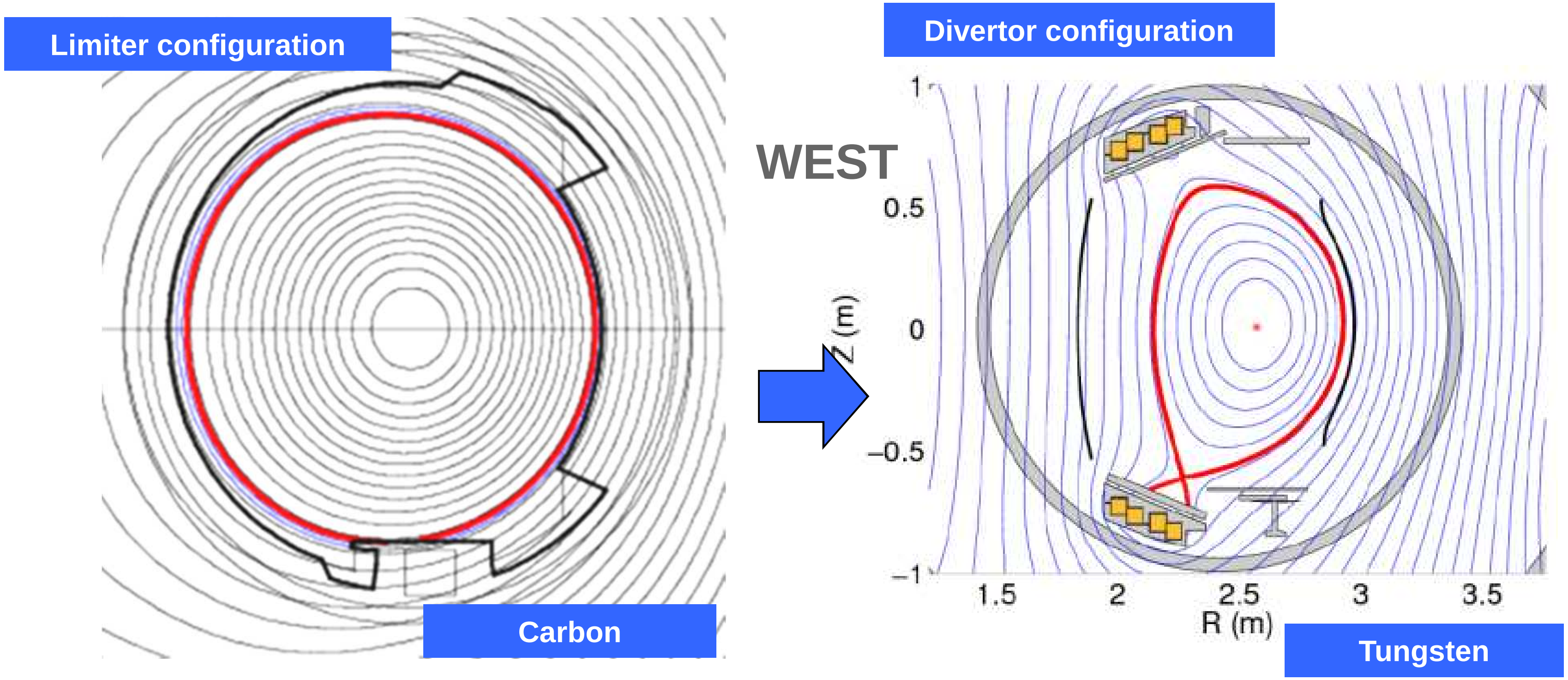
- *Cost > 100 M€*
- *Manufacturing: ~ 6 to 8 years*
- *Installation and commissioning in nuclear environment : ~1 year*

- **WEST : risk minimisation for ITER divertor and explore innovative PFC for DEMO**

WEST BUILDS ON THE ASSETS OF TORE SUPRA

- Long pulse operations pioneered for more than 20 years (first plasma 1988)
- World record of injected/extracted energy in a tokamak (1GJ)
- Several generations of carbon PFCs designed, manufactured and operated
- **Tore Supra designed for long pulse operation**
  - Superconducting toroidal coils
  - Cryogenic plant
  - Pressurized water loops
  - 15 MW of HF plasma heating
  - Fuelling systems
  - Diagnostics

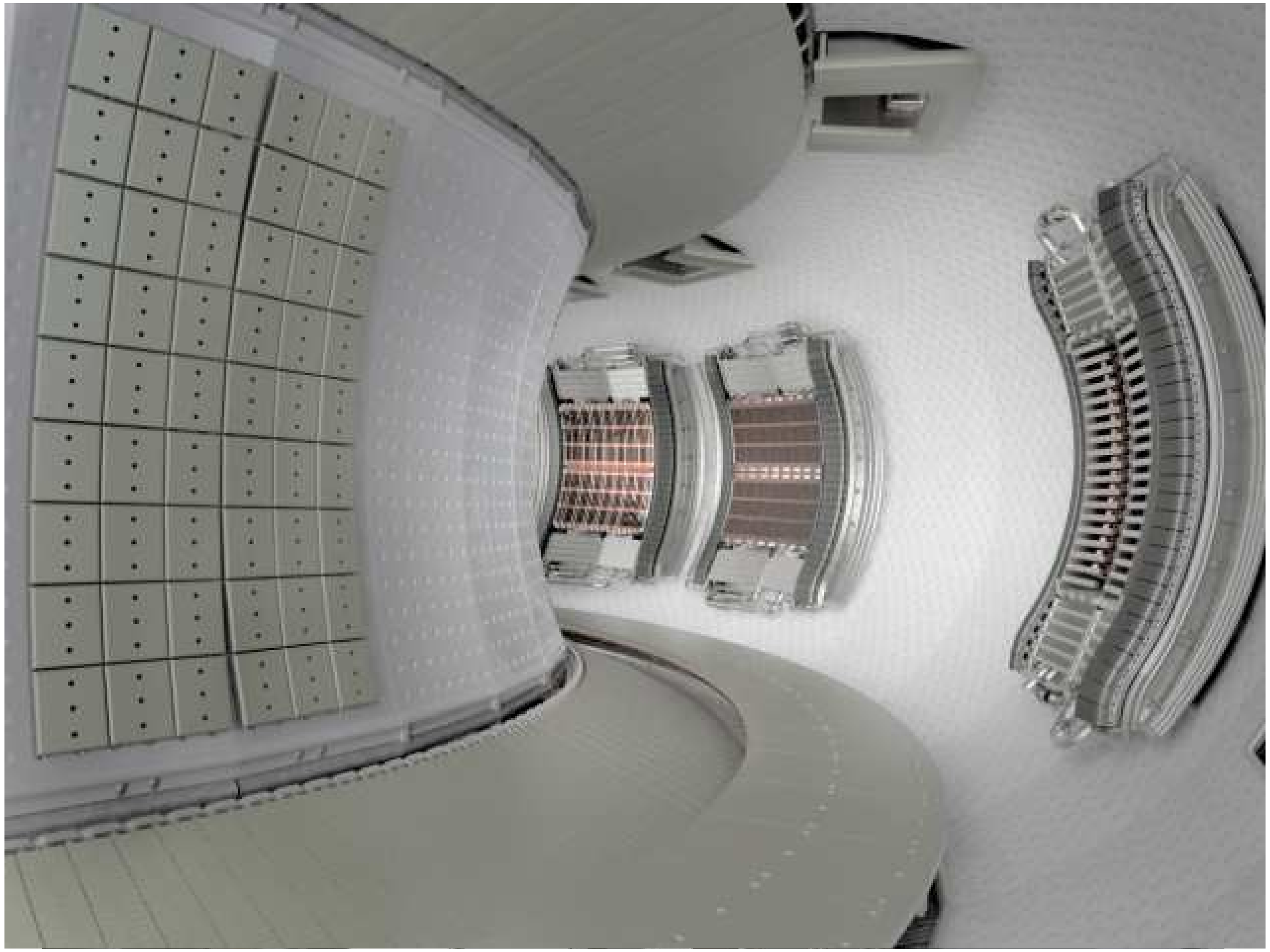
WEST project ~ few days of ITER operation



- **Two symmetric divertor coils and supporting structures**
- Plasma facing components: **ITER-like targets,** Upper divertor targets, Pumping Baffle, Bumpers, Vessel protection
- **3 new ICRH CW ELMs resilient antennas, 2 LHCD antennas**
- **Diagnostics:** Magnetics, IR , spectroscopy, Langmuir probes etc

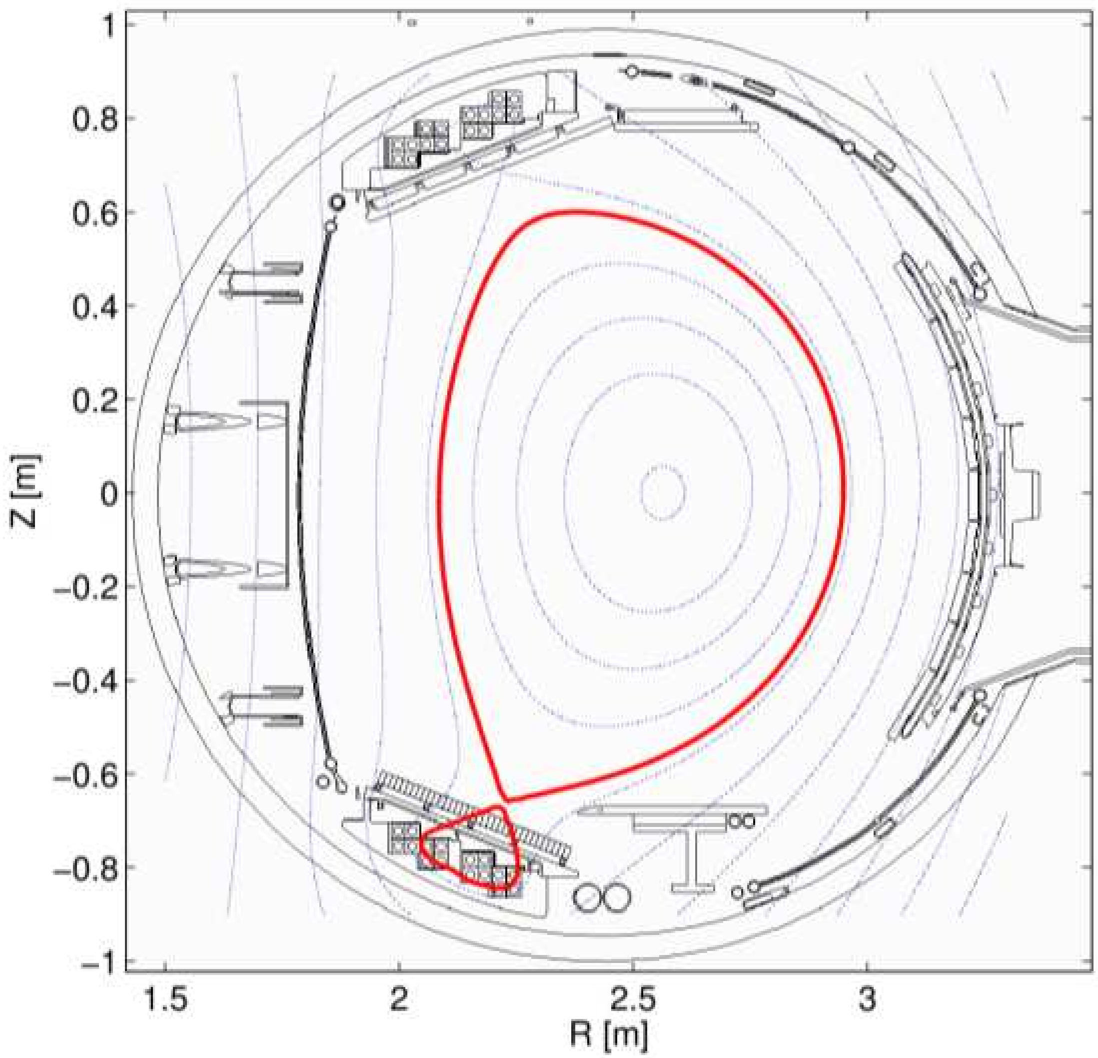
TORE SUPRA → WEST: FROM CARBON TO TUNGSTEN ENVIRONMENT

CIEL configuration



WEST configuration

WEST MAIN PLASMA PARAMETERS



I_p (q_{95}~2.5)	1 MA
B_T	3.7 T
R	2.5 m
a	0.5 m
A	5-6
k	1.3-1.8
d	0.5-0.6
V_p	15 m^3
n_{GW} (1MA)	1.5 $10^{20} m^{-3}$
P_{ICRH}	9 MW
P_{LHCD}	7 MW
P_{ECRH}	0.6 MW
$T_{flattop}$ (0.8 MA)	1000 s

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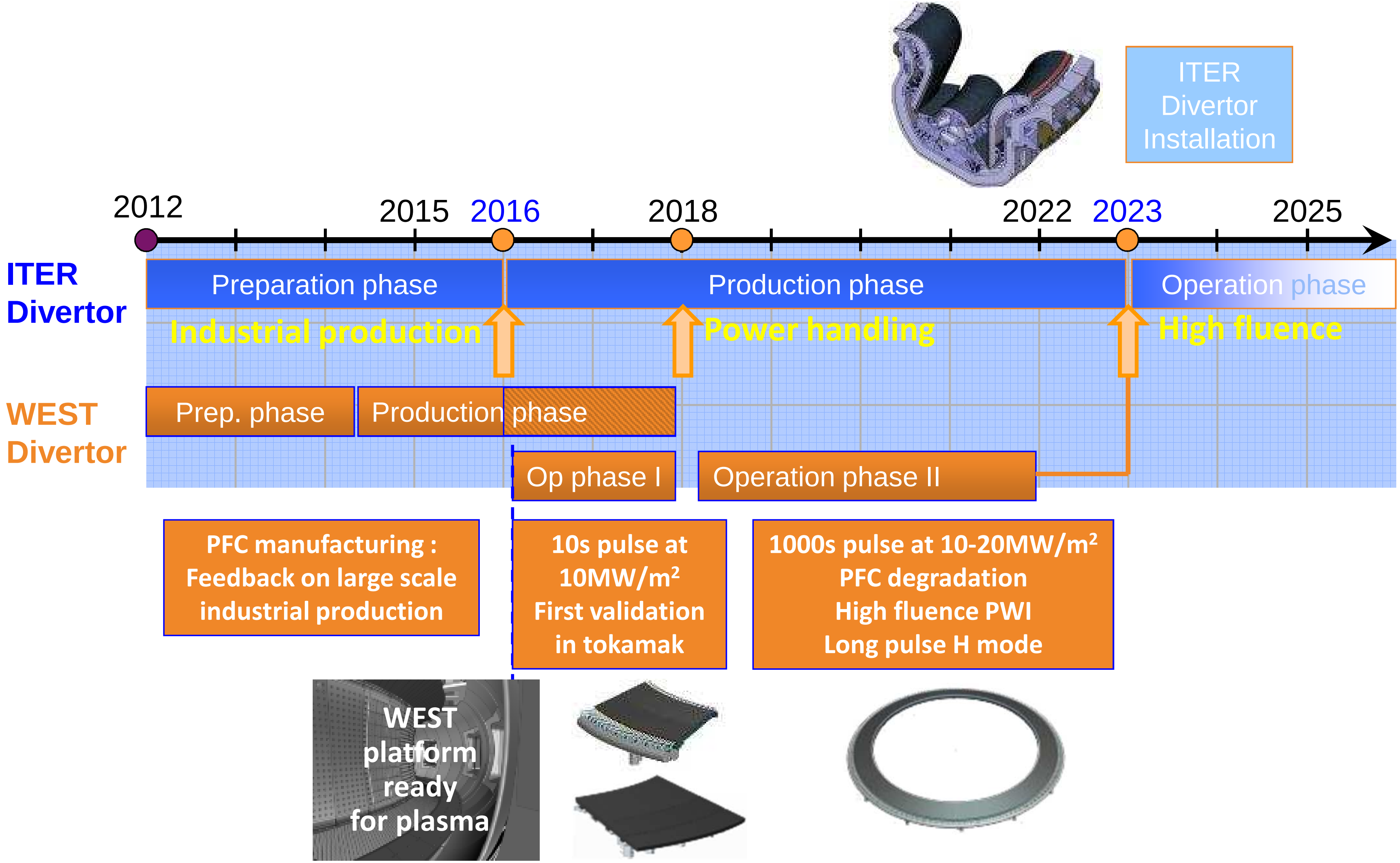
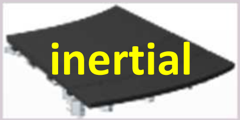
OPERATIONAL DOMAIN WITH ITER RELEVANT DIVERTOR HEAT LOAD

Scenario	High power	High fluence
I_p	**0.8 MA**	**0.6 MA**
n_e	$8x10^{19}m^{-3}$	$7x10^{19}m^{-3}$
f_{GW}	**70 %**	**70 %**
P_{heat}	**15 MW**	**10 MW**
LHCD	6 MW	7 MW
ICRH	9 MW	3 MW
W_{th}	0.9 MJ	0.5 MJ
Bootstrap fraction	30%	35%
LHCD fraction	30%	60%
Pulse length	**30 s**	**1000 s**
Expected heat load 2/3 vs 1/3 asym.	**10 to 20 MW/m²** depending on X point height and λ_q	
Operation time to reach one ITER pulse fluence ($10^{27}D/m^2$)	~ 6 months	**a few days**
f_{ELM}	~ 50-400 Hz	
ELM load	up to ~100kJ/m²	

WEST : bringing answers in time for ITER divertor



A staged operation to provide answers in time for ITER / DEMO

	Phase 1	Phase 2	Phase 3
WEST divertor	Mix of actively cooled ITER like / inertial divertor sectors  + 	Full actively cooled ITER like divertor 	Innovative PFC concepts (tbd depending on outcome of EUROfusion R&D)  
Heating power	Full power	Full power	Full power
Plasma duration	~10 s	Up to 1000 s	Up to 1000 s
Main focus for divertor testing	ITER div 1 / Power handling	ITER div 1 / High fluence PWI	ITER div 2 / DEMO

TORE SUPRA READY FOR NEW COMPONENTS INTEGRATION: FIRST PLASMA EXPECTED IN 2016

Toward WEST configuration

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WEST missions and high level deliverables

- **Pave the way towards the ITER actively cooled tungsten divertor procurement and operation**
  - Optimization of industrial scale production / qualification processes ahead of ITER divertor procurement
  - Assessment of power handling capabilities / lifetime of ITER high heat flux tungsten divertor components in tokamak environment
  - Validated scheme for protection of actively cooled metallic plasma facing components
- **Master integrated plasma scenario over relevant plasma wall equilibrium time scale in a metallic environment**
  - Demonstration of integrated long pulse H mode scenario (optimization of RF heating, control of tungsten contamination and plasma density)
  - Investigation of advanced scenario regimes (fully non inductive H mode operation, highly radiating scenario, …)

Main objectives of the headlines of the WEST Research Plan

H1 : testing ITER tungsten PFCs

Objective : 10-20 MW/m^2 on PFC

Questions : Design of leading edges ?
Performance under combined heat+plasma loads ?
Monitoring of metallic PFCs ?

H2 : towards long pulse H mode operation

Objective : H mode >100 s

Questions : Integrated scenario for long pulse H mode ?
Impurity transport (tungsten accumulation) ?

H3 : exploring PWI at high fluence

Objective : ITER particle fluence(10^{27} D/m^2)

Questions : Evolution of tungsten surfaces (D/He) ?
Fuel retention in tungsten at high fluence ?

(H1–H3: ITER)

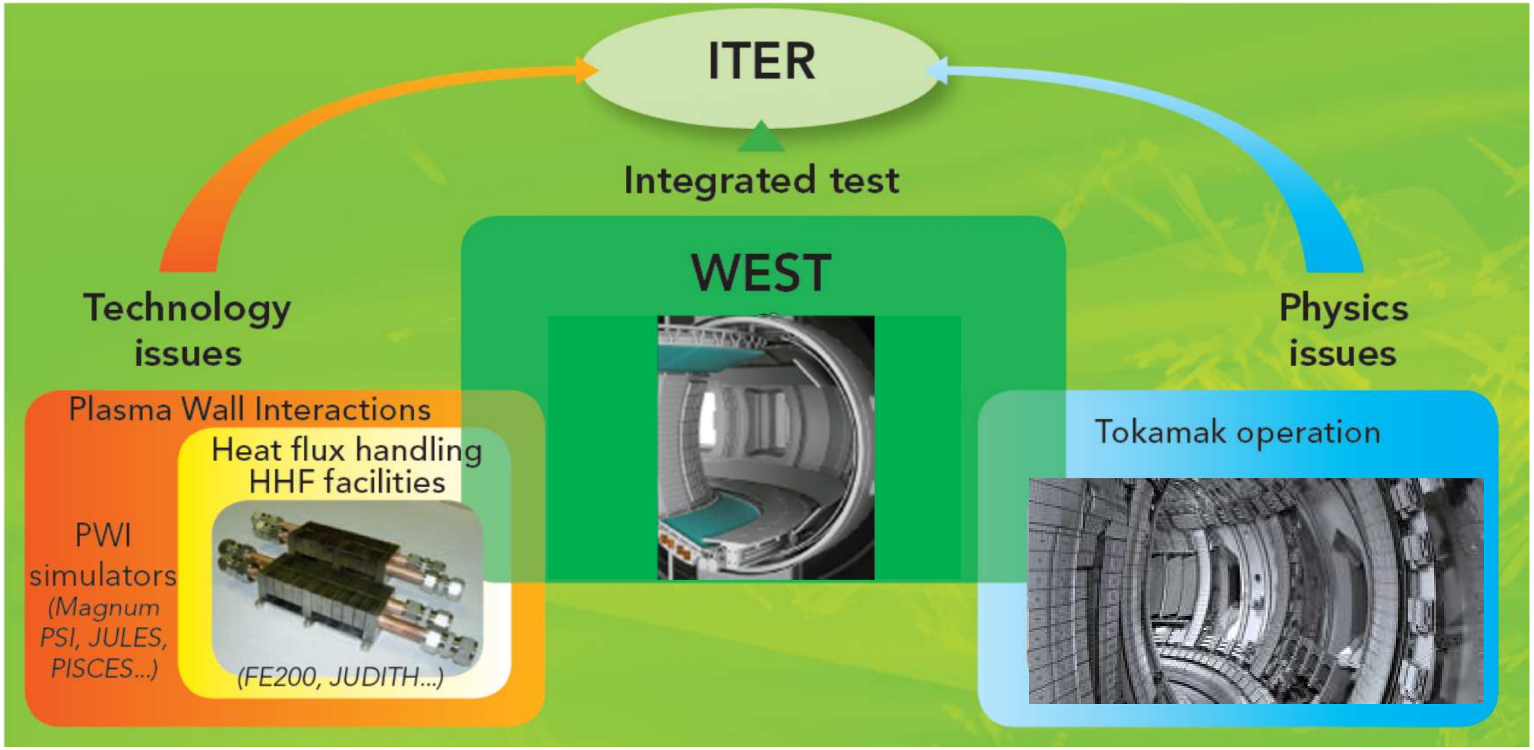
H4 : preparing advanced tokamak modes

Objective : high power / high bootstrap

Questions : Current profile control for long pulses ?
Hybrid scenario ?

(H4: JT60-SA)

WEST INTEGRATES COMPONENT TECHNOLOGY IN A TOKAMAK ENVIRONNEMENT



- **WEST complementary to PWI simulators (Magnum PSI, PISCES, JULES,…) and to heat flux handling facilities (FE200, JUDITH, GLADIS,…)**
- **WEST complementary to metallic tokamaks (JET, AUG, EAST, Cmod, FTU, …) and to steady state programmes (W7X, JT60-SA, LHD, SST-1, HL-2M,…)**

WEST PARTNERSHIPS (DEC 2013)

- Jan 2013: China National Nuclear Corporation (associated lab)
- Jul 2013:
  - Chinese Academy of Sciences (associated lab)
  - India Department of Atomic Energy
  - IPPLM Poland
- Sept 2013:
  - US-DOE
- Oct 2013:
  - Fusion For Energy (Europe)
- Nov 2013:
  - JADA (Japon)
- Dec 2013:
  - South Korea


Chengdu, Jan. 2013


Beijing, July 2013


Warsaw, July 2013


Ahmedabad, July 2013


Cadarache, Oct 2013


Washington DC, Sept. 2013

LONG STANDING COOPERATION BETWEEN CEA AND US-DOE

1985: Cooperation established on long pulse operation in Tore Supra (very strong partnership with ORNL on heating, fueling, particle control, diagnostics)

2013: Signature of Letter of Intend. CEA-DSM and DOE-Fusion Energy Science intend to continue and extend their collaboration on:

- ❑ Actively cooled metallic plasma facing components
- ❑ Operation of long-duration plasma in actively cooled metallic environment
- ❑ Preparing ITER generation

In addition 2011-2014: Collaboration agreement between CEA & MIT on LHCD, ICRH, intrinsic plasma rotation, diagnostics

POSSIBLE US-DOE CONTRIBUTION TO WEST ?

WEST actively cooled metallic plasma facing components

- Operational assessment of ITER W divertor design & technology
- Tungsten erosion, PFC lifetimes, plasma-materials interaction at high power, high fluence plasma
- SOL characterization and modelling

Research programs on PMI/PFC of WEST and MPEX (Material Plasma Exposure eXperiment) would provide a good synergy for integrated solutions suitable for long-pulse operation

Operation of long duration plasma in actively cooled environment

- Diagnostics plasma core and plasma wall interactions studies and protection of plasma facing components
- Development of long-pulse RF wave heating systems
- Development of safe & integrated controlled operation: controlled schemes, disruptions, ripple losses…
- Joint theory & modelling

WEST AS A NEW EUROPEAN FACILITY ?

- According to the EUROfusion proposal some EU facilities exploited as common facilities under campaign-oriented approach.

- EU facilities selected following 2008 Facility Review.

- For possible new facilities to be supported under the same provisions, in the EUROfusion proposal it has been stated:

  - **Should other tokamaks become available, their use under the campaign-oriented approach will be assessed as during the 2008 Facility Review, and, <u>in case of a positive assessment</u>, included within this Work Package**

EVALUATION PANEL REPORT AND ASSESSMENT

- Panel in charge of the evaluation of WEST as a EUROfusion facility

Boris Sharkov (chair) , C. Linsmeier (FZJ), A. Loarte (ITER Org), G. Matthews (CCFE), P. Mertens (FZJ), W. Morris (CCFE), Y. Ueda (University of Osaka), R. Parker (MIT), H. Zohm (IPP), + D. Maisonnier (Commission Observer) + D. Borba (EUROfusion PMU)

- The panel evaluates the potential contribution of WEST to the European Fusion Roadmap, the added value and the cost/benefit ratio of WEST compared to the already existing or upcoming EU facilities (JT60-SA) :
    - to address the ITER & DEMO heat exhaust problem (Mission 2),
    - to reduce gaps identified in the Facility Review and the European Fusion Roadmap
    - to minimize risks for ITER construction and operation.

- **The panel report/recommendation: an important input for the decision at EUROfusion General Assembly and then for the detailed implementation by the EUROfusion Programme Management Unit**

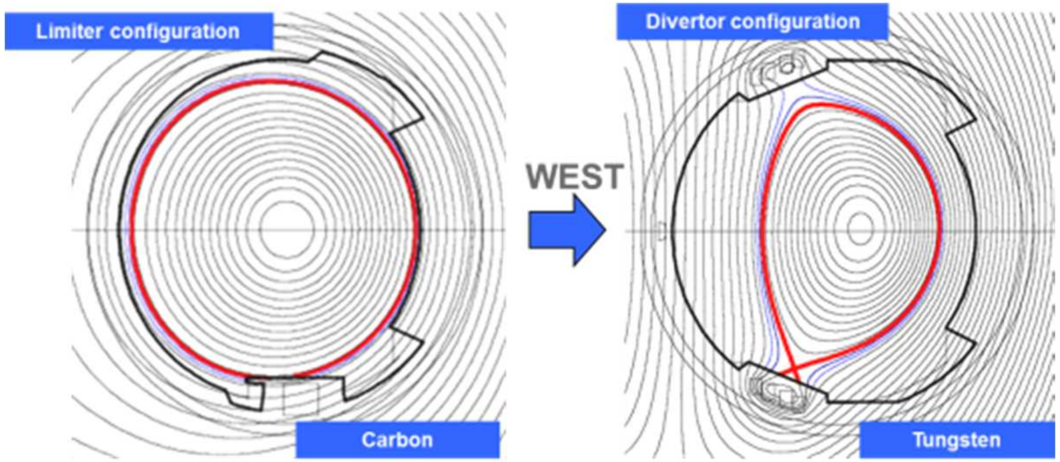
WEST fills the gap of long pulse operation in the EU program

- steady state / long pulse physics and technology : key area towards fusion power plant

Facility Review 2008, gaps analysis for Mission 4 « Physics and technology of long pulse and steady state » :

Gaps exist since TORE SUPRA, the only European device with superconducting coils, cannot access fully ITER relevant scenarios (circular limiter plasma and non-metallic wall)

- This gap is now filled with WEST.



➔ access for EUROfusion to steady state operation / metallic environment

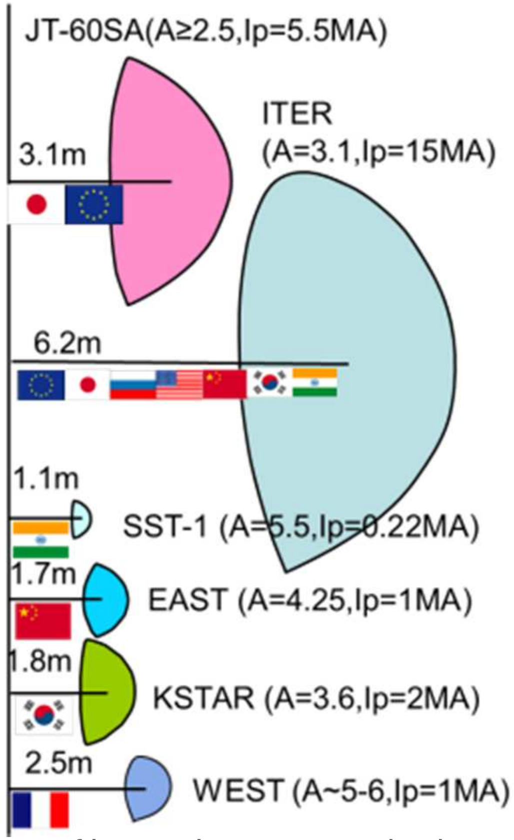


Chart of long pulse superconducting tokamaks

[Courtesy Y. Kamada]

CONCLUSION

- WEST provides a long pulse facility to prepare actively cooled tungsten divertor operation and train ITER generation
- Research Plan (V0) written
- Modelling of the WEST operational scenario has started
  - sustainement of long pulse H mode with the available power
  - possibility to explore hybrid and steady-state operation
  - address ITPA priorities
- On-going effort with more sophisticated modelling and validation on existing experiments (JET, ASDEX-U, EAST, ALCATOR-C)
  - full CRONOS modelling with LUKE, EVE, TGLF/QuaLiKiz, impurity transport …
  - ELMs modelling with JOREK
  - W source & W transport modelling (COREDIV, DIVIMP)
  - SOL modelling (SOLEDGE2D-Eirene) and coupled core-SOL modelling

NEXT STEPS : PREPARATION OF WEST EXPLOITATION

2014: Consolidating the Research Plan with WEST partners

- WEST international workshop (June 30-July 2, 2014, Aix en Provence)
  http://west.cea.fr/Workshop2014/
- V1 of the WEST Research Plan: end 2014

2015: Preparing WEST exploitation

- Preparation of the 2016-2017 experimental campaign
- Organization for operation with WEST partners
- WEST platform = user facility open to ITER partners