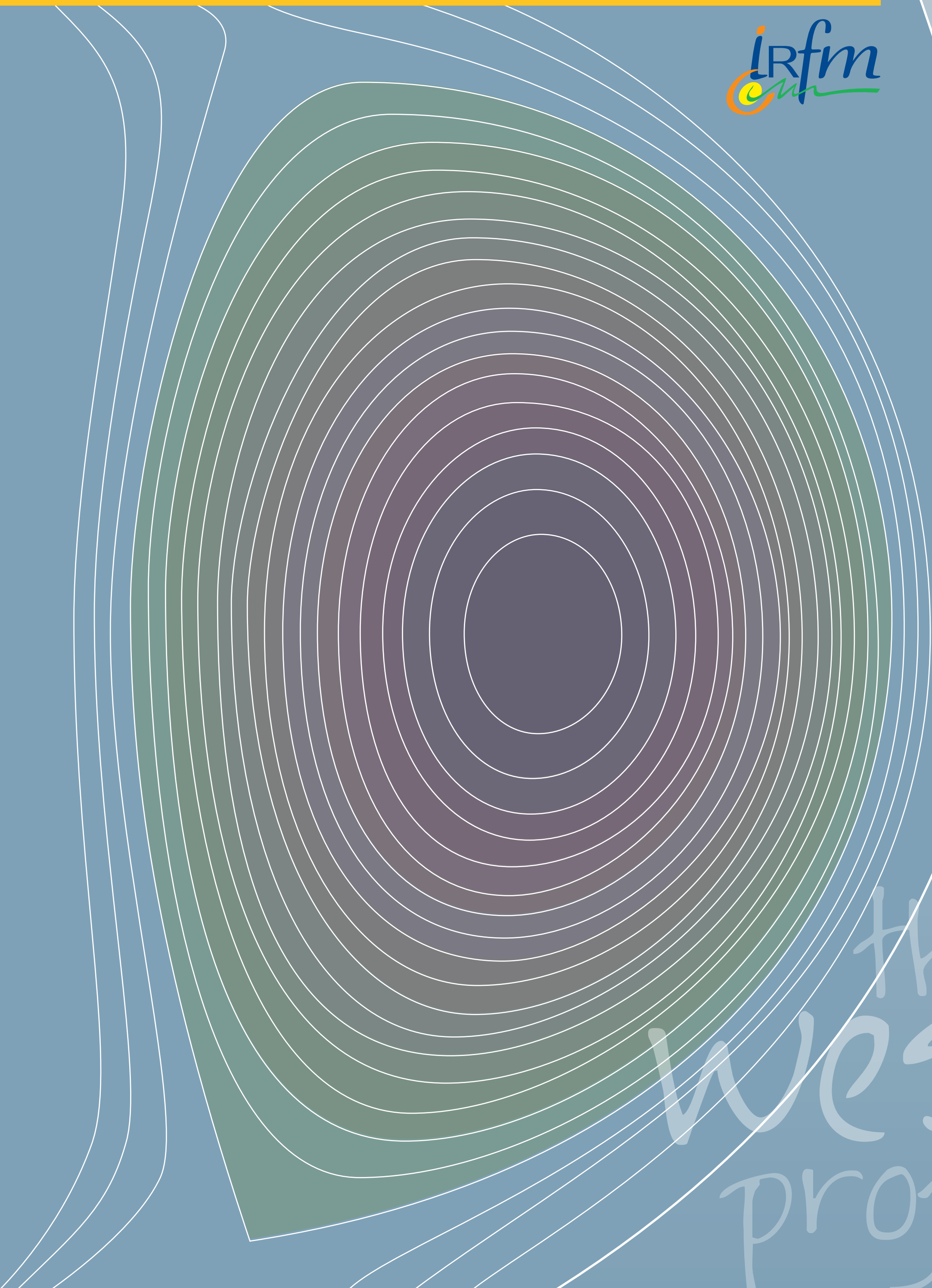
The WEST project

Tungsten (W) Environment in Steady-state Tokamak



the west project

The WEST project

In support of the ITER divertor strategy

«In the present decade, the highest priority for the European fusion programme is to ensure the most efficient construction, operation and scientific exploitation of ITER.
For this purpose, the scientists and engineers of the Magnetic Fusion Research Institute of CEA propose to fully dedicate the Tore Supra facility to contribute to a safer and more reliable operation of ITER, taking benefit of the 20 year experience in mastering long plasma discharge. The WEST project is based on an upgrade of Tore Supra, transforming it in an X-point divertor device, capable of testing the ITER technologies of high heat flux components in relevant plasma conditions. This concerns in particular the challenging tungsten divertor.
The aim is to significantly minimize the risk and save ITER commissioning time… and money.
After feasibility and design studies, performed with our academic partners in France, worldwide experts in the field assessed the proposal and gave a very positive feedback. We also received a clear support from ITER Organization. This encourages us now to step up the project, and to fully open it to partners in France, in Europe and worldwide.
I am confident that this proposal will now get the full support from the European fusion programme, with great complementarities to MAGNUM-PSI, JET and ASDEX Upgrade, but also in view of the future developments in W7-X and JT-60SA. I am also confident that several ITER partners will now join our effort and contribute to the success of WEST. I am finally sure that **WEST will shed new light on tokamak physics, operation and technology and on their mandatory integration to make ITER a success.**»

Alain Bécoulet,
Head of the Magnetic Fusion Research Institute
and of the Euratom-CEA Association Research Unit

Tore Supra Tokamak

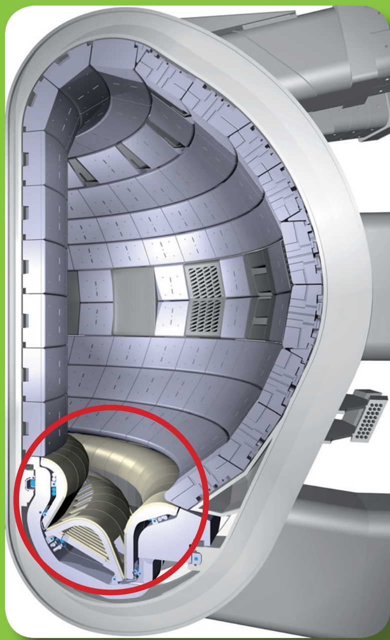
A full tungsten divertor for ITER

The challenge

The divertor is a crucial component for fusion devices which must handle the highest thermal and particle loads in the vessel.

In the first non-nuclear phase of ITER, it was initially planned that the divertor will include carbon in the most loaded areas and tungsten elsewhere to benefit from the resilient properties of carbon.
In the second nuclear phase of ITER, the divertor will be changed to full tungsten to avoid excessive tritium retention with carbon.

However, **the ITER organization is presently evaluating the possibility to start directly with a full tungsten divertor.**



The ITER vessel, showing the divertor at the bottom of the machine (red circle)

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This brings **news challenges**, summarized in the table bellow:

Challenges for tungsten	Impacts
Heat resistant, **but melts**	Component integrity Difficult subsequent operation
Recent technology development, **never tested in fusion devices**	Delay for component procurements
Plasma pollution acceptable **<<10^{-4}**	Prevents access to plasma performance

Keys figures for ITER divertor risk analysis

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

Implementing a full Tungsten divertor in ITER brings **risks both in terms of industrial procurement and operation**. The **WEST project addresses both aspects** and is targeted at minimizing the associated risks.

From the procurement standpoint, WEST will require for the first time the fabrication at industrial scale of a large number of ITER like tungsten components, **contributing to the optimization of the series manufacturing process for ITER**.
From the operation standpoint, WEST will allow to perform an accelerated lifetime test of the tungsten components in tokamak conditions thanks to its long pulse capability, and **to detect potential operational issues in advance of ITER exploitation**.

The WEST project

Filling a gap in the tungsten R&D in Europe

A strong R&D programme on tungsten plasma facing components has been implemented **in Europe** for more than 10 years.
ASDEX Upgrade is successfully pioneering full tungsten operation, TEXTOR is exploring tungsten melting issues, and JET has been restarted in its new ITER-Like Wall configuration, with a tungsten divertor and a beryllium first wall.

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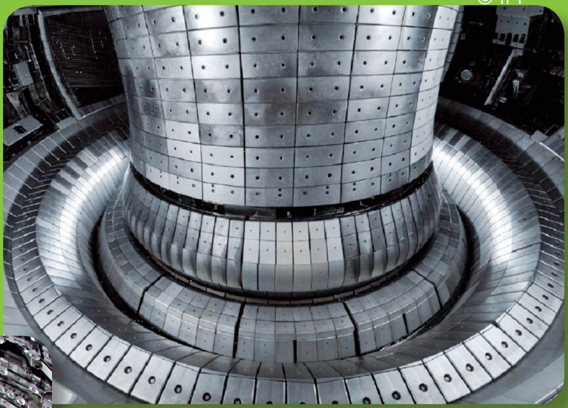

ASDEX Upgrade full tungsten configuration

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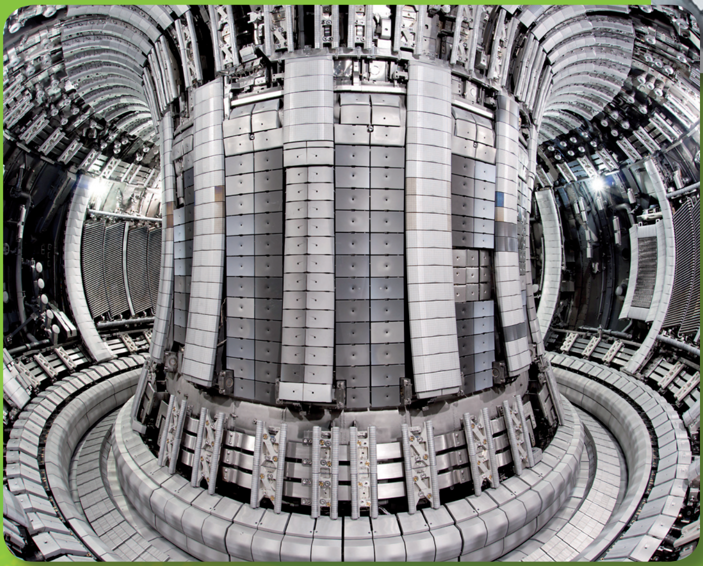


JET: ITER-Like Wall

However, up to now, the components tested in fusion devices have been mostly inertial tungsten coated components. This allows one to address some of the physics issues, such as the compatibility of plasma scenario with tungsten components. Conversely, actively cooled massive tungsten components, as required for ITER, have been tested exclusively in dedicated high heat flux facilities to assess their heat flux handling performance.

An integrated test of actively cooled tungsten components in a fusion device is still lacking.
It would bring key insight in steady state operation of a tungsten divertor and its impact on plasma performance.
Critical issues are optimisation of the active cooling design, components monitoring during operation, and impact of off-normal events on component ageing.

A tungsten actively cooled component after high heat flux testing performed under a contract from the European agency F4E (20 MW/m^2, 1000 cycles), showing no failure but cracks and melting damage.

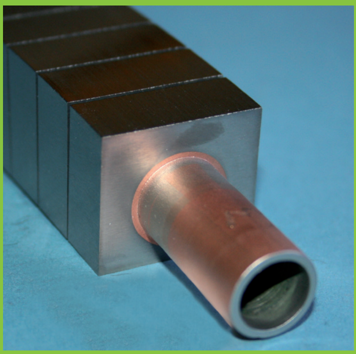
Active cooling brings specific issues

Tokamak operation with active cooling lies in the heart of the expertise of the Tore Supra team. In contrast with large tiles used for inertial components, active cooling implies castellated structures.

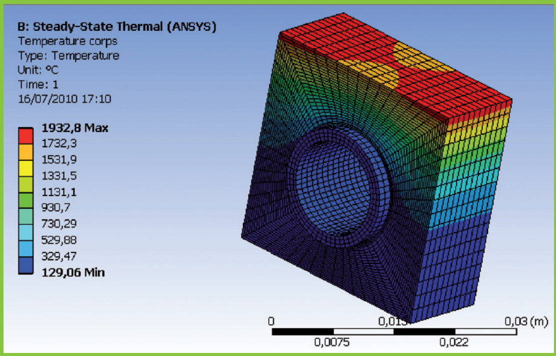
These set specific constrains on the design. In particular the detailed configuration of the gaps between tiles must minimize the risk for serious melting of tungsten.

The temperature distribution within the component is different, with strong gradients between the cooling channel and the plasma exposed surface, and, consequently, specific damage patterns under cycling.

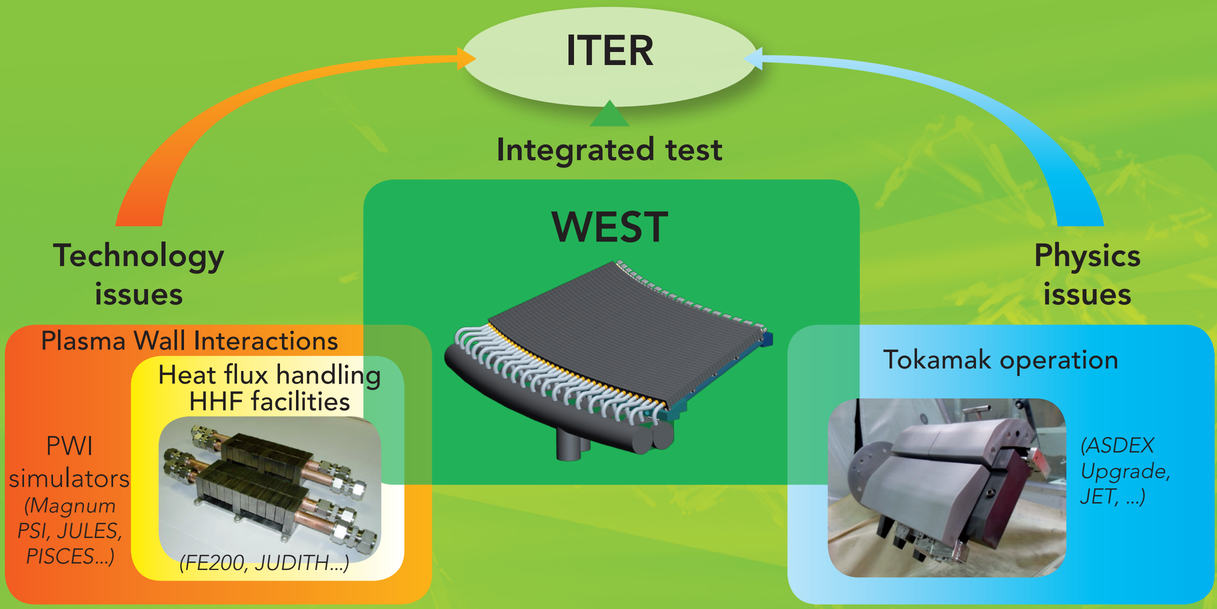
Component failures are more severe, leading to potential water leak and requesting a careful monitoring during operation.



The ITER divertor "Monoblock" concept showing the W tiles, the copper heat sink with its cooling channel, and the copper interlayer.



Thermal calculation for a WEST tile under very high heat flux (~20 MW/m²), showing the strong temperature gradient between the cooling channel (130 °C) and the surface (near 2000 °C)



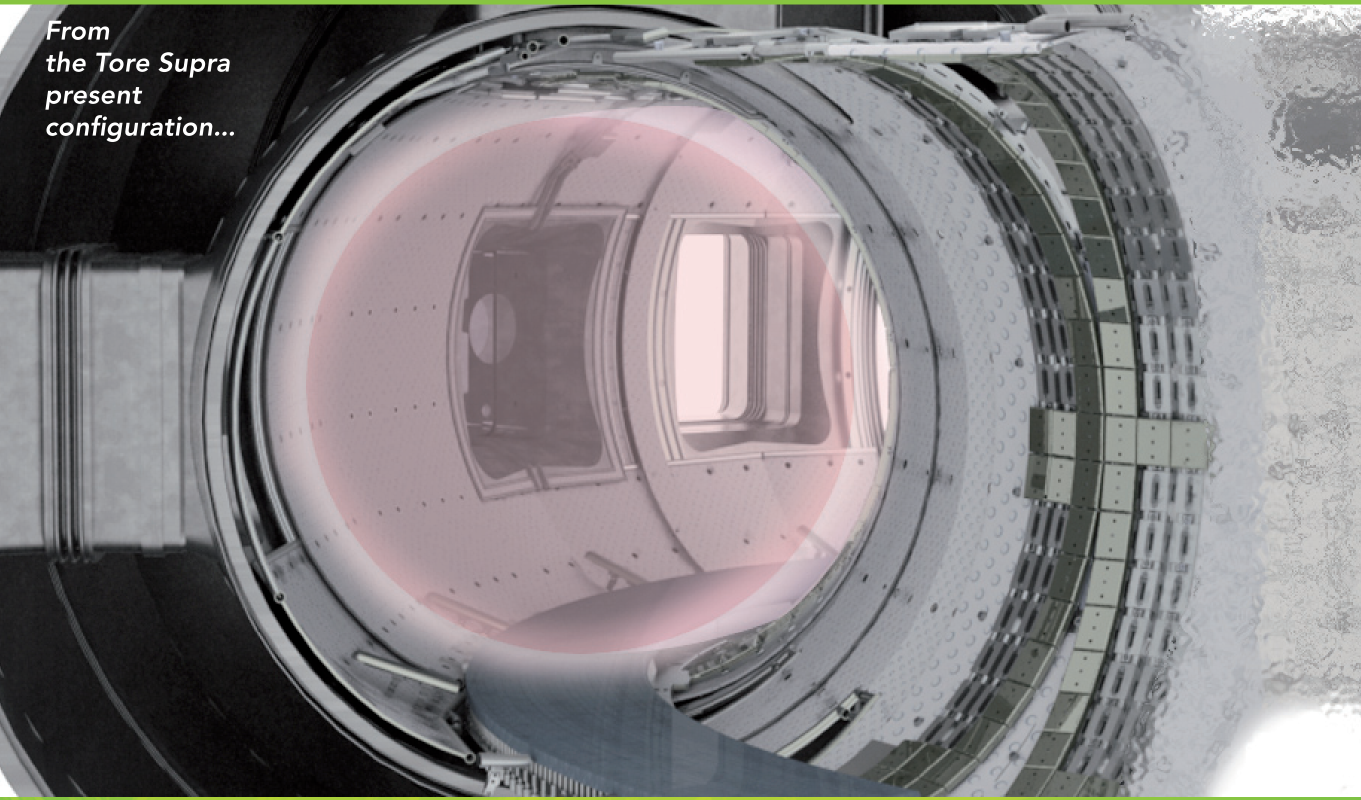
WEST: bringing together the technology of high heat flux components and tokamak operation in support of ITER

Turning Tore Supra into
to address the challenge of tung

Implementing the ITER W divertor technology in the framework of the WEST project will provide key expertise and know-how regarding industrialisation of component production, full series qualifications, safe and high performance operation. To properly address those issues Tore Supra will change to an X-point magnetic configuration. Combined to its long pulse active cooling capability, Tore Supra will then provide an optimum setting to address this challenge.

TORE SUPRA: A UNIQUE COMBINATION OF COMPONENTS FOR LONG PULSE OPERATION...

- Superconducting toroidal coils, cryogenic facility,
- Pressurized cooling water loops,
- 15 MW of radiofrequency plasma heating,
- Strong capacity for non inductive generation of plasma current,
- Original diagnostics for plasma control (in particular a set of infra red cameras for monitoring of the plasma facing components),
- A continuous data acquisition system.



...LEADING TO MAJOR ACHIEVEMENTS IN STEADY STATE PHYSICS AND TECHNOLOGY:

- Long pulse operation pioneered for 20 years,
- World record of injected / extracted energy in a 1 MA class tokamak : 1 GJ with ~400s steady state plasmas,
- Several generations of actively cooled plasma facing components designed, manufactured and successfully operated,
- Providing ITER relevant particle fluence within reduced operational time.

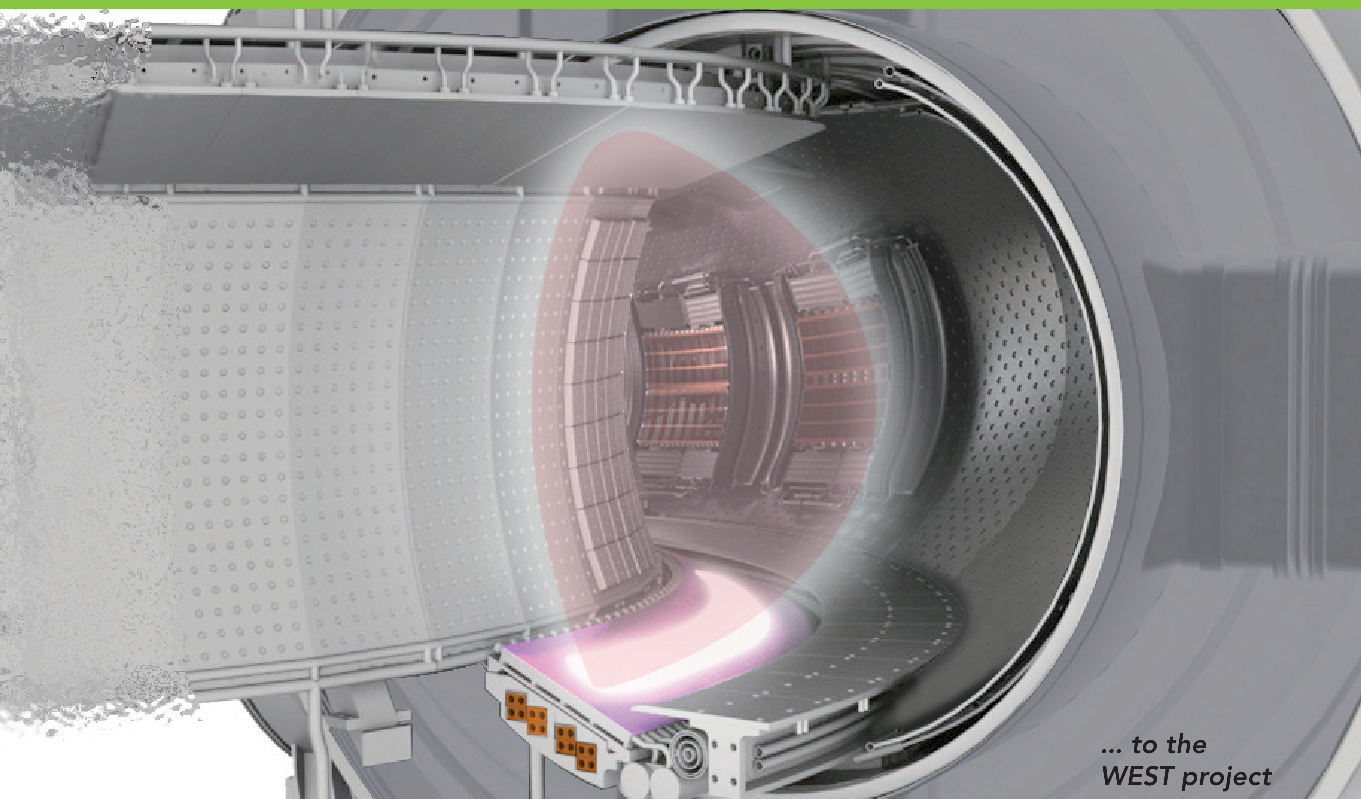
a divertor configuration
gsten plasma facing components

The transformation from the present circular limiter geometry of Tore Supra to the required X-point configuration will be achieved by installing a set of copper poloidal coils inside the lower and upper parts of the vacuum vessel.

The new setup will be compatible with the existing poloidal field system and radiofrequency heating and current drive systems, while maximizing the plasma volume.

A wide range of plasma equilibria will become possible, from lower single null to upper single null passing through double null geometries.

An outboard baffle will complement the divertor structure to enhance the particle exhaust.



... to the WEST project

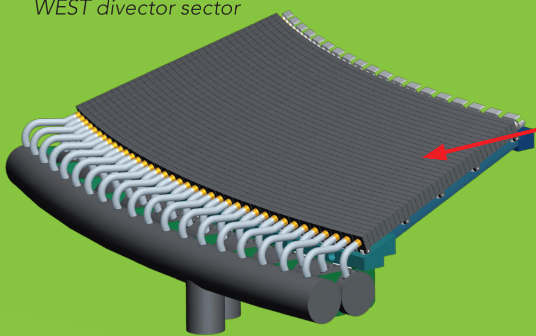
"The CEA/IRFM team plays an exceptional role for ITER, moving even closer to ITER objectives with the WEST project, contributing to steady state physics and technology."

Professor F. Wagner, IPP Greifswald; Germany.

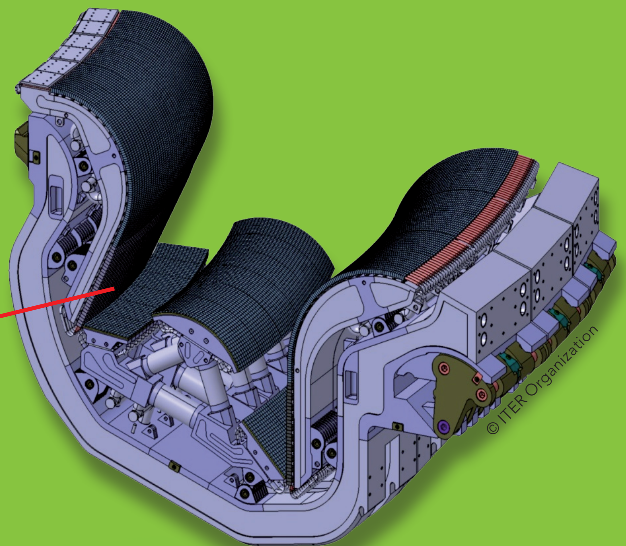
WEST representative of ITER plasma facing components

The tungsten plasma facing components to be tested with the WEST platform are **fully representative** of the high heat flux flat part of the ITER divertor plasma facing units (see table below for a comparison between WEST and ITER elements). The same technology as used for ITER elements will be implemented and operated in similar thermal hydraulic conditions as foreseen for ITER. In addition, **the modular design** of the WEST divertor sectors will offer the possibility to test variants (e.g. detailed design shaping, tungsten grades...). The overall number of tungsten elements to be manufactured for WEST represents roughly 15 % of the amount needed for ITER, which makes the WEST procurement a relevant pre series for ITER .

WEST divector sector



The modular design of the divertor (30° sector) will enable easier plasma facing component testing



ITER divertor

	WEST vs ITER
Plasma Facing Unit (PFU)	**Identical for high flux flat part**
Assembling technology	**Identical**
Area	~14 % ITER
Length of PFU	Scale 1/3
Number of PFU units	~ 1/2 ITER
Total number of tiles	~14 % ITER
Thermal hydraulic conditions	**Identical**

Comparison of WEST and ITER Tungsten elements

WEST scenarios targeted for plasma facing components testing

The WEST configuration will provide **for the first time** the capability to run **long pulses in the high confinement regime** (H mode) foreseen for ITER, and **test plasma facing components** under realistic plasma conditions.

Three types of plasma scenarios are contemplated, summarized in the table below. They include :

- A **standard 1 minute mode of operation**, for routine long pulse operation at 10 MW/m^2,
- A **high fluence scenario** to cumulate ITER relevant particle fluence within a few days of operation,
- A shorter **high power scenario** to explore high performance plasmas.

For the three scenarios, the heating power is expected to be well above the H mode threshold. The associated edge localized mode instabilities (ELMs) will not reach the very high values expected in ITER but will provide sufficient temperature excursions around the re-crystallisation temperature to assess the evolution of the W surface.

SCENARIO (3.7 T)	HIGH POWER	STANDARD	HIGH FLUENCE
Plasma current	**0.8 MA**	**0.6 MA**	**0.5 MA**
Plasma density	9 $10^{19}m^{-3}$	6 $10^{19}m^{-3}$	4 $10^{19}m^{-3}$
Total radiofrequency heating power	**15 MW**	**12 MW**	**10 MW**
Lower Hybrid Current Drive	6 MW	6 MW	7 MW
Ion Cyclotron Resonance Heating	9 MW	6 MW	3 MW
Plasma current flat-top duration	**30 s**	**60 s**	**1000 s**
Expected heat load*	**10 MW/m^2**	**10-20 MW/m^2**	**10-20 MW/m^2**
Expected ELM frequency	59 Hz	76 Hz	77 Hz
Expected ELM load	40 kJ/m^2	52 kJ/m^2	74 kJ/m^2
Expected operation time to reach one ITER pulse particle fluence	**~6 months**	**~2 months**	**~few days**

**Note that the heat load on the divertor target increases when reducing plasma current, due to the modification of the magnetic flux expansion at the target increasing the power flux density. Calculations are performed assuming λ_q = 5 mm.*

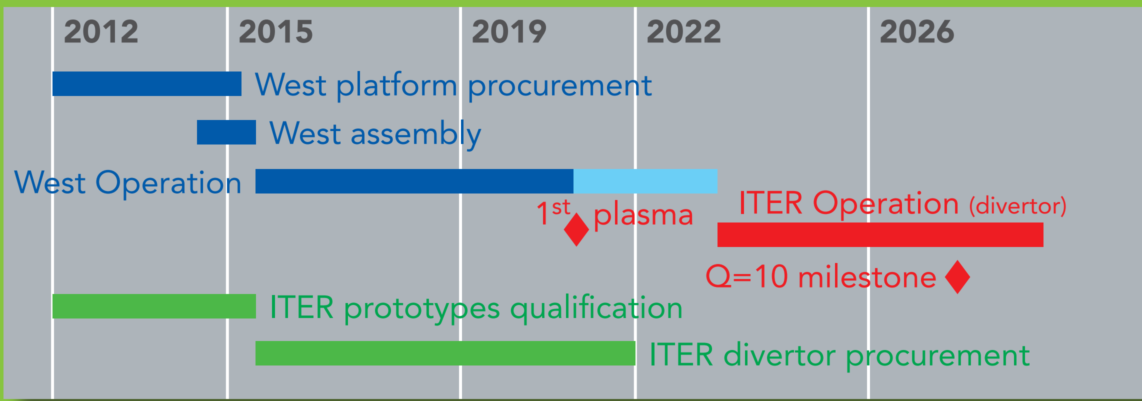
This large scope of scenarios is made possible by the combination of the existing radiofrequency heating and current drive systems, taking advantage of their recent upgrade (CIMES project to be completed in 2012).

The major expected outcome are summarized below:

- **Qualify** the high heat flux tungsten component technology for the ITER divertor targets conditions,
- **Control** the plasma contamination by tungsten, in all phases of the discharge,
- **Demonstrate** high performance and safe long pulse H mode operation (real time control).

Bringing answers in time for ITER

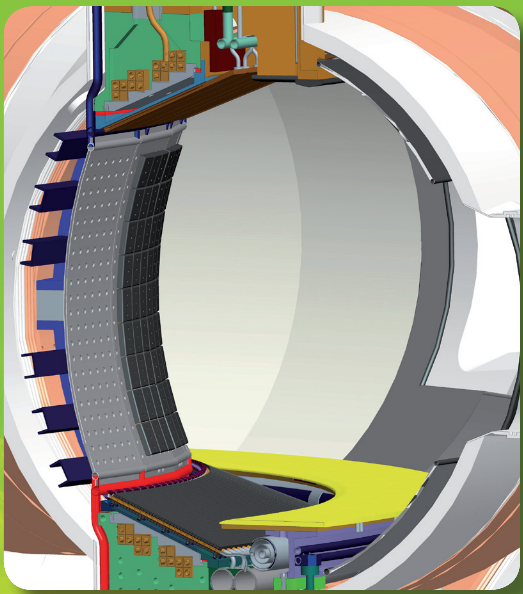
The feasibility study has been performed in 2010 and was reviewed by an international panel of experts. Following its positive feedback, conceptual design activities have been launched and carried out through 2011. Detailed design activities are underway and the operation of Tore Supra in the WEST configuration should start in 2015.



Indicative planning for WEST and ITER

Should the ITER full W divertor be operated from the first phase of operation in 2023, as displayed on the above schedule, **its procurement should be launched by mid 2015**.
Thus, information gained in the manufacturing of the WEST divertor elements can contribute **to risk minimization for the ITER full W divertor manufacturing and qualification**.

In the present ITER schedule, the main scientific goal (Q = 10*) is expected to be reached within a very short operation time. This underlines the utmost importance of **gaining operational experience with a full W divertor** prior to this crucial milestone. WEST will allow detecting operational issues early enough for corrective measures to be implemented for ITER.



Design of the WEST vessel

**Q = 10 represents the scientific goal of the first exploitation phase of ITER: to deliver ten times more power than used to heat the plasma.*

Come and join WEST

An open platform for international partners and industry

The WEST platform provides **great opportunities to contribute** to the project in various fields :

- ➤ Divertor structure & coils,
- ➤ Plasma facing components,
- ➤ Power supplies & distribution,
- ➤ Water Cooling System,
- ➤ RF Heating Systems,
- ➤ Diagnostics & control.

WEST, once in operation, will provide a **key facility to prepare and be prepared for ITER**, fully open to national and international partnership .

It will bring to the scientific community a research infrastructure where some of the crucial ITER physics and operation challenges will be addressed.

For ITER stakeholders and industries involved in the ITER procurement, WEST will offer a platform designed for the validation of industrial components before delivering to ITER.

Tore Supra Control room

WEST: a key element in risk mitigation for ITER …

WEST will *"undoubtedly offer ITER substantial benefit in terms of risk mitigation concerning the divertor material and operational strategy, provided the platform can be implemented on the timescale proposed."*

[...]

"I am thus fully convinced of the high pertinence of the WEST proposal as a key element of the R&D activities which must progress throughout the ITER partners in support of the ITER divertor procurement and implementation."

Osamu Motojima, Director General of ITER Organization.

… proposed for collaboration to the ITER partners

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