Les Challenges de la Robotique dans le cadre des Tokamak

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Avec la collaboration de l'équipe CEA de Tore Supra à Cadarache

L’équipe Tore Supra

L’équipe de Robotique pour les TOKAMAK

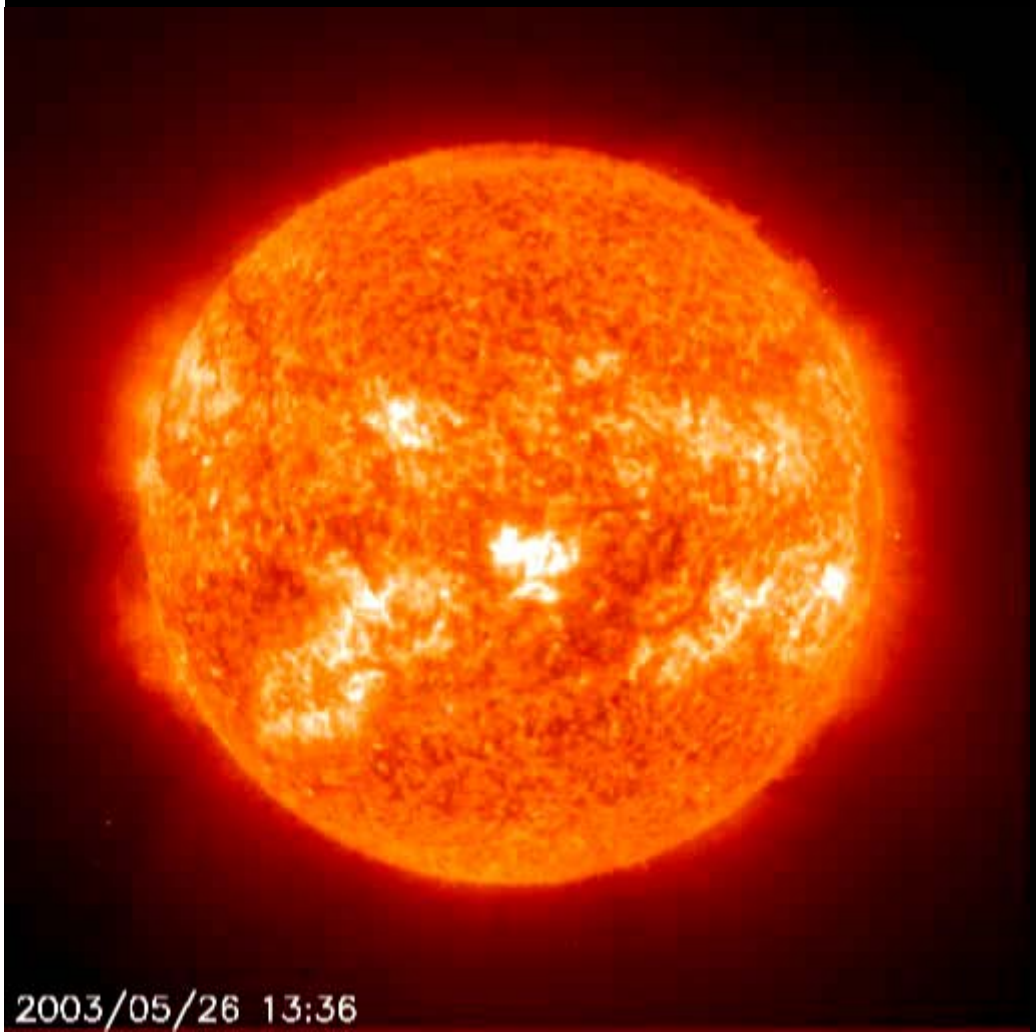
ROBOTIQUE & Tokamak

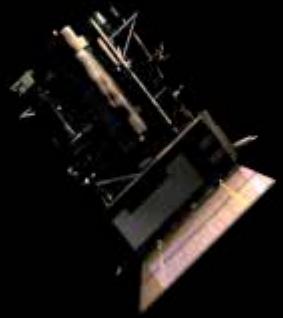
- *Contexte Fusion- Tokamak*
- *Maintenance de ITER*
- *Quelques Robots*

L’énergie : un enjeu majeur pour le 21ème siècle

- L’énergie est un élément clef du développement économique
  - La Chine et l’Inde (37 % de la population mondiale) ne consomment que 17 % de l’énergie
- Plus de 80 % de l’énergie primaire provient des ressources fossiles
- Les nouvelles découvertes de pétrole sont désormais plus faibles que l’accroissement de la consommation
- Les gaz à effet de serre représentent un danger potentiel pour la planète
- Il est impératif de maîtriser la consommation d’énergie (en particulier en Occident) et de diversifier le “mix” énergétique
- La fusion présente de grands avantages. C’est **une** des voies à explorer !

Fusion…
dans le soleil



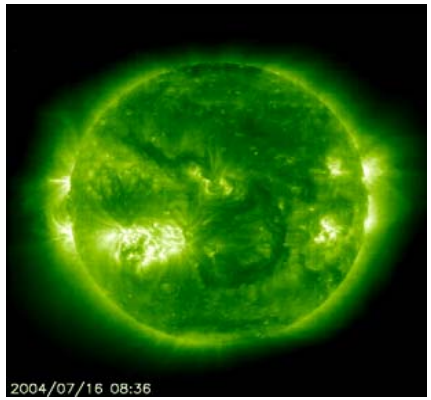


esa
ISD VisuLab

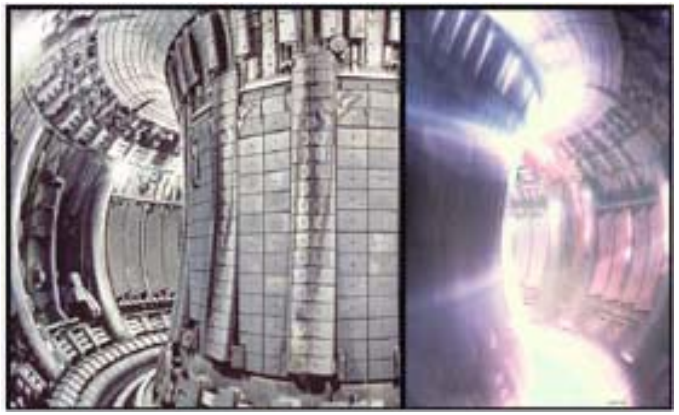
Extreme ultraviolet Imaging Telescope

(304 Å, i.e. 60 to 80 000 K)

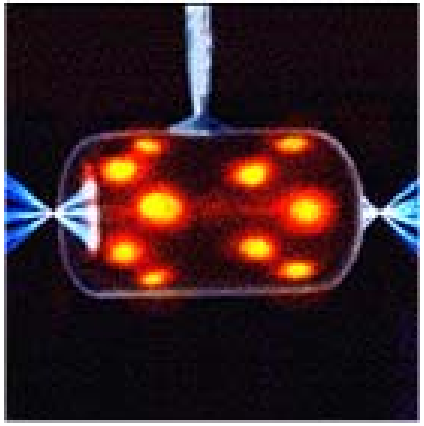
Sun



Tokamak JET

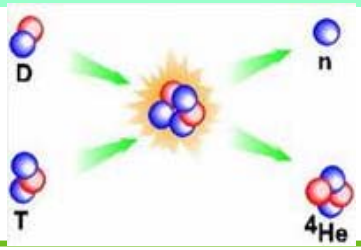


NOVA (laser on target)



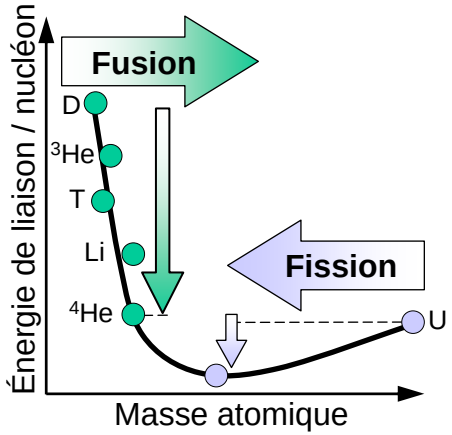
Confinement:	Gravitational	Magnetic	Inertial :
Size:	1.3 10^8 m	10 m	10^{-2} m
Duration:	3 10^{16} s	400 s	10^{-8} s
Pressure:	10^9 atm	2 atm	10^9 atm

Temperature : 10^8 K ⇔ thermal energy : 10 keV

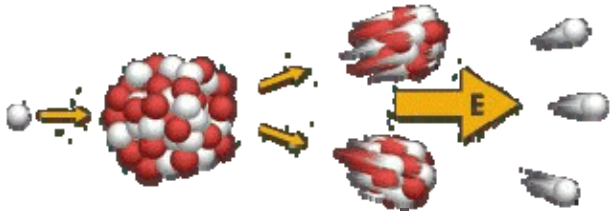


Fission/Fusion : E = mc²

Fusion

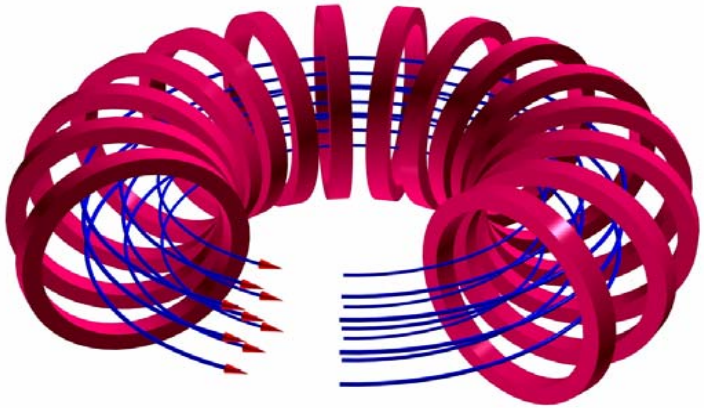


Fission

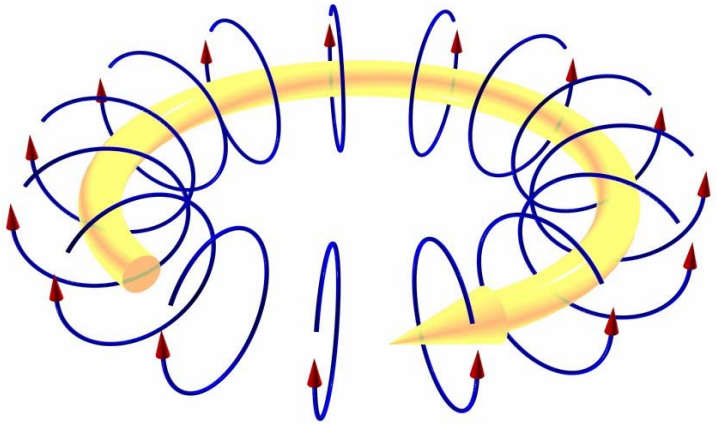


Principe du tokamak : confinement magnétique

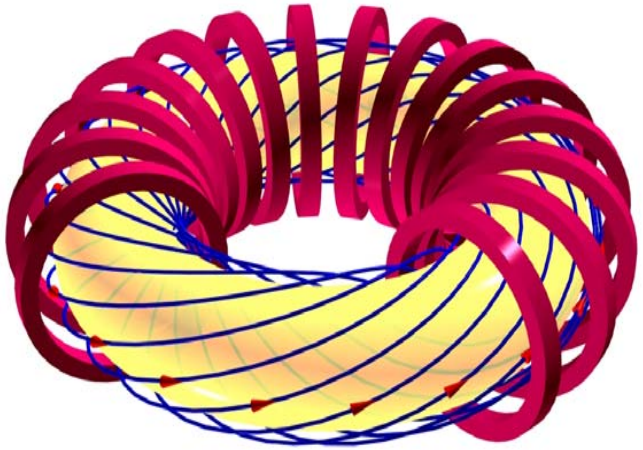
En Russe
Tok: courant
Mak: machine



Champ toroïdal

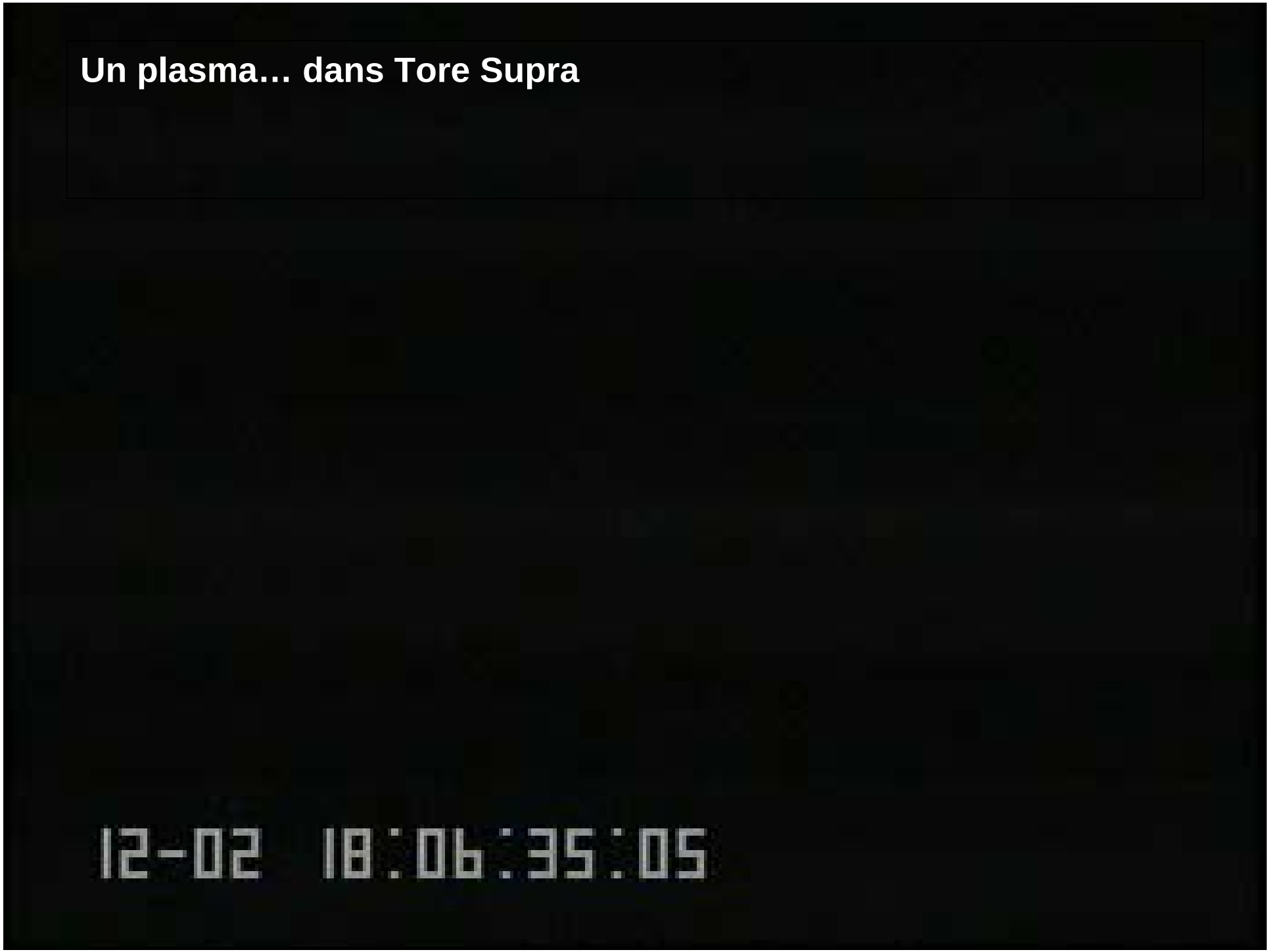


Champ poloïdal induit par le courant plasma

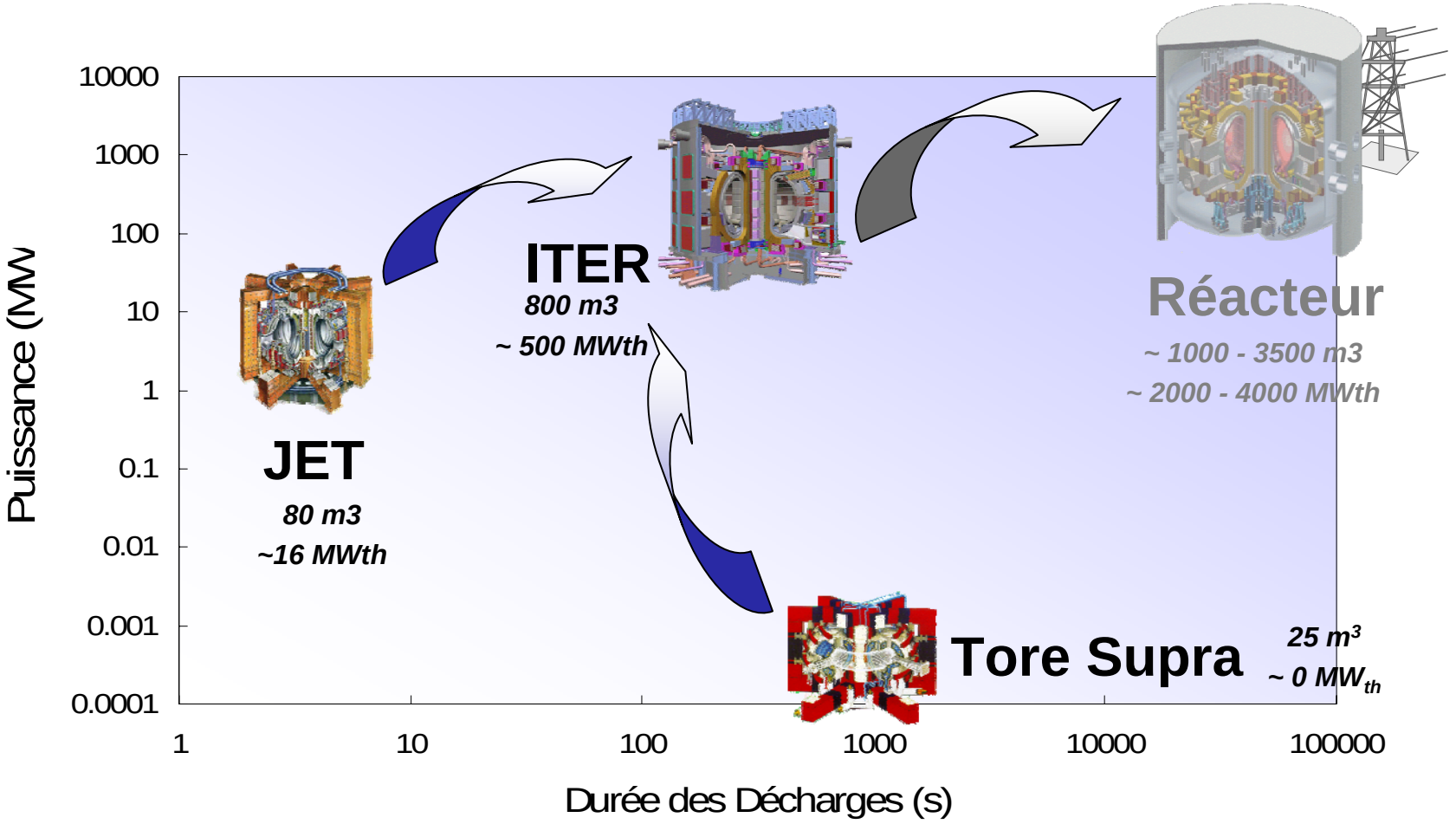


Champ résultant

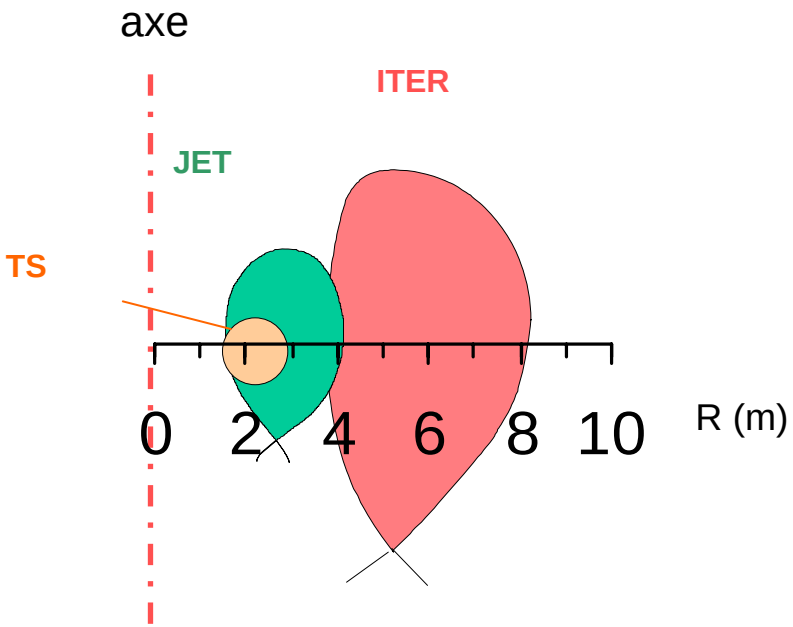
Un plasma… dans Tore Supra



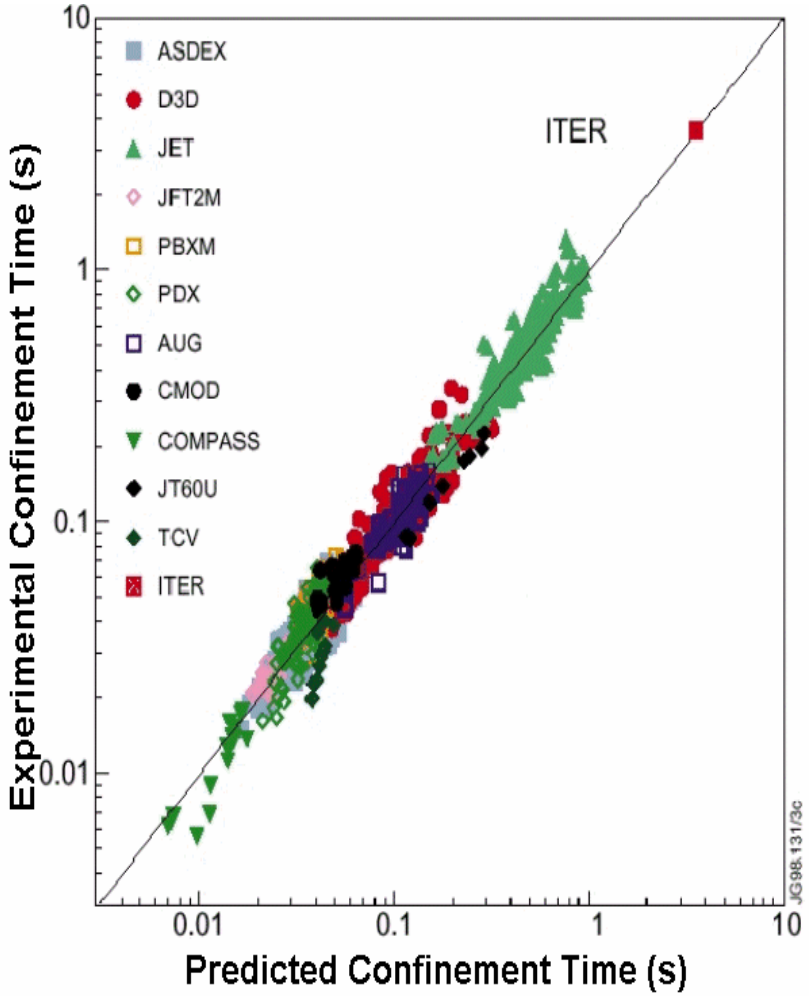
ITER : le *chemin* vers le réacteur



PLASMA CONFINEMENT TIME HAS BEEN IN CONSTANT PROGRESS

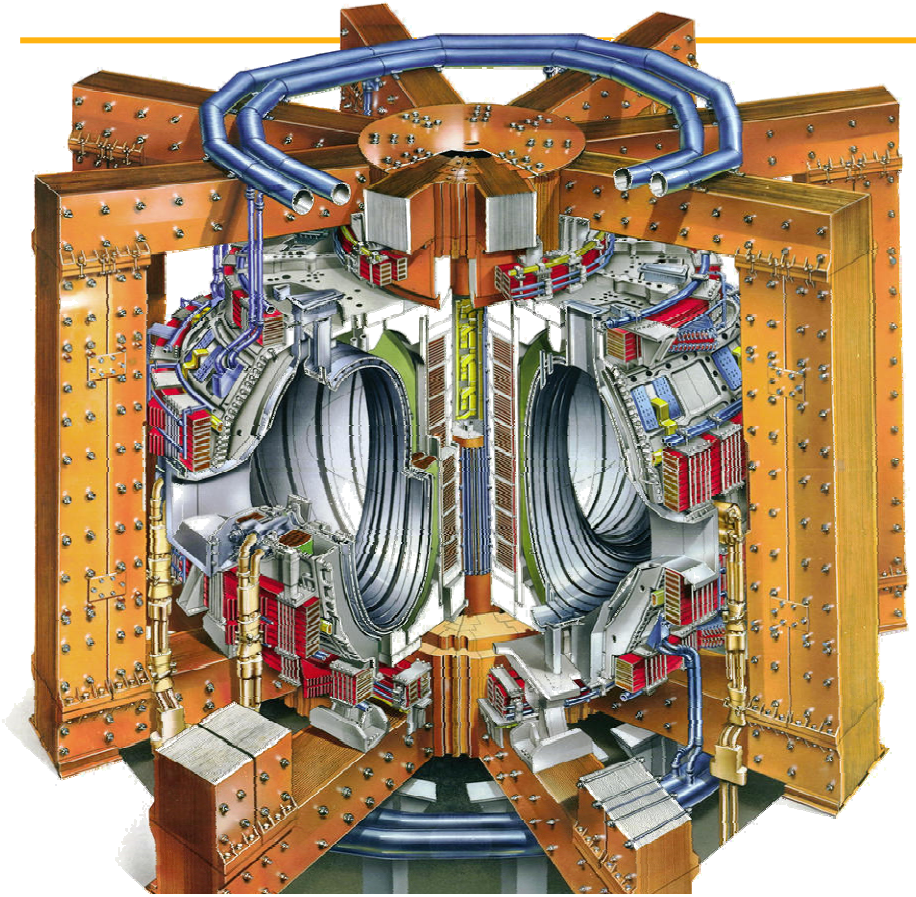


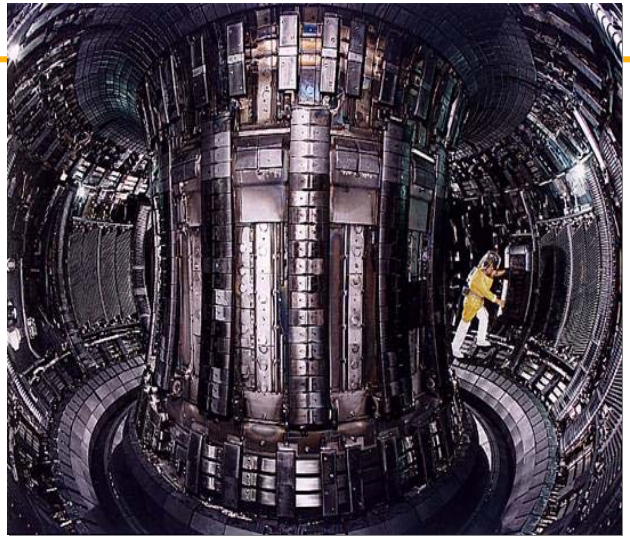
The scaling law of the confinement time is today well understood

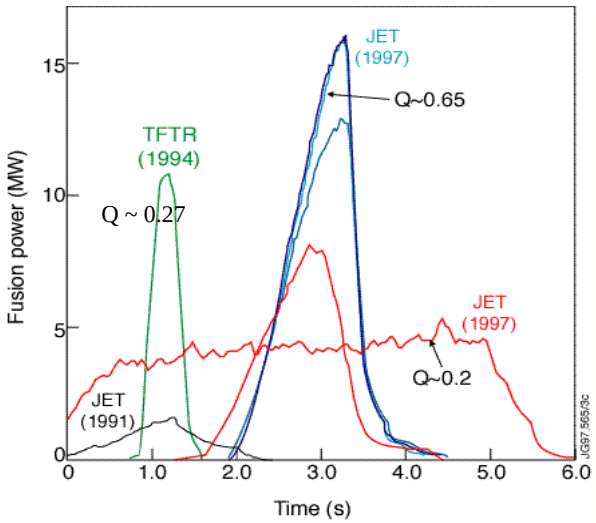


ITER @ Cadarache

JET AND JT60-U REACHED NEAR “ BREAKEVEN”







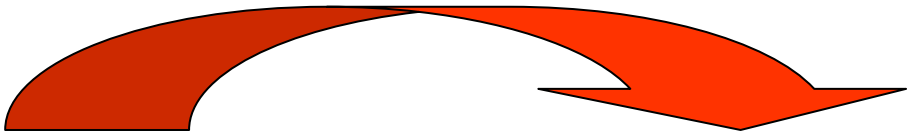
JET (constructed and operated by the EU)

D / T , beryllium

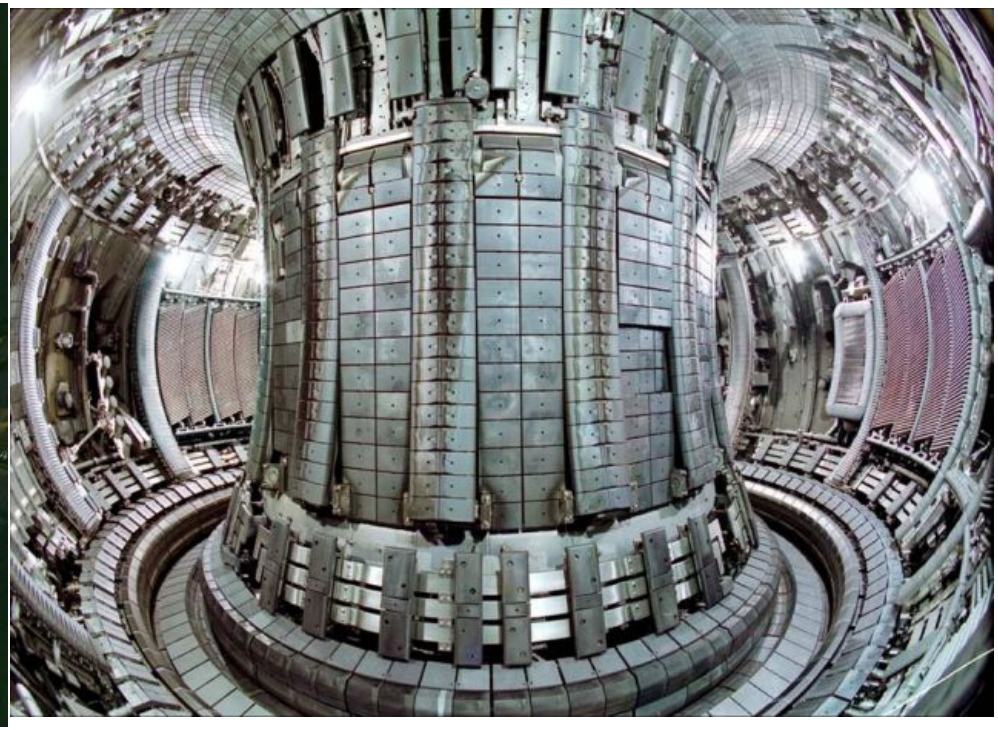
Remote handling

International organisation since 1978

JET Experience : VV configuration

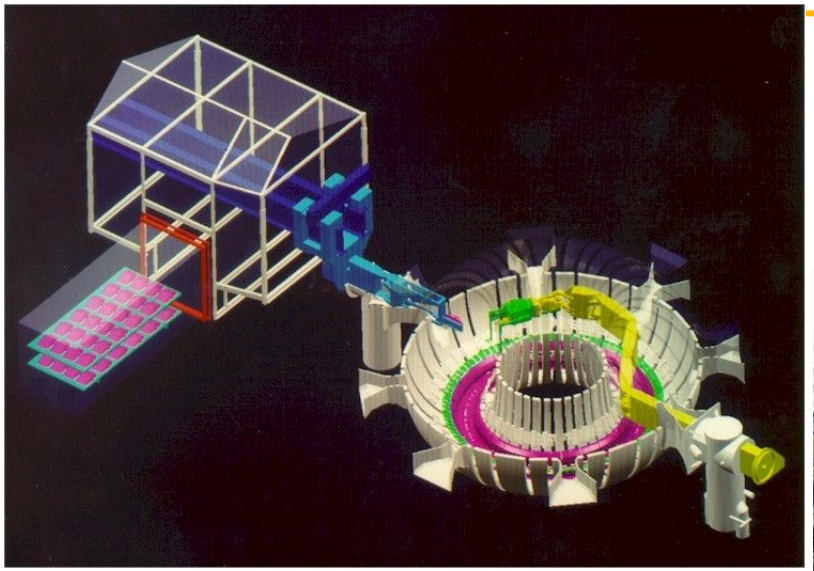


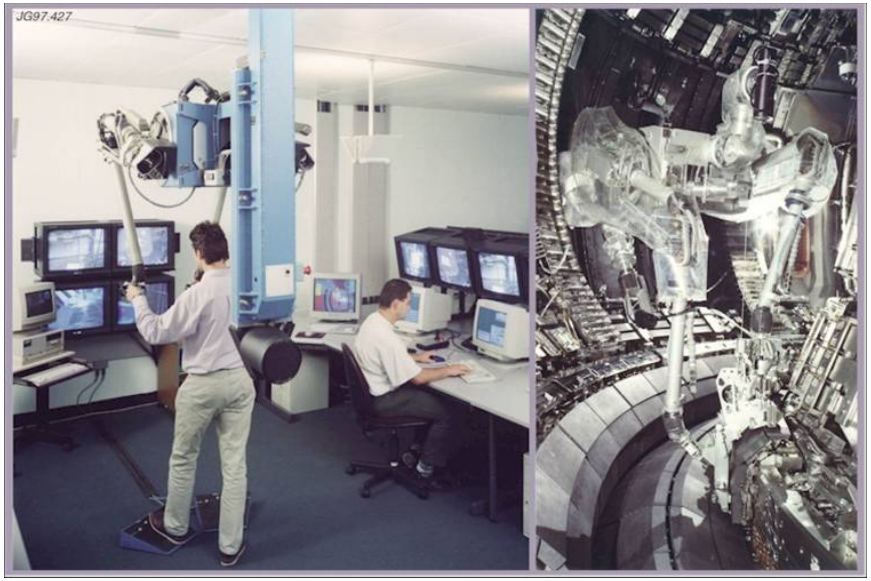
JET 1987



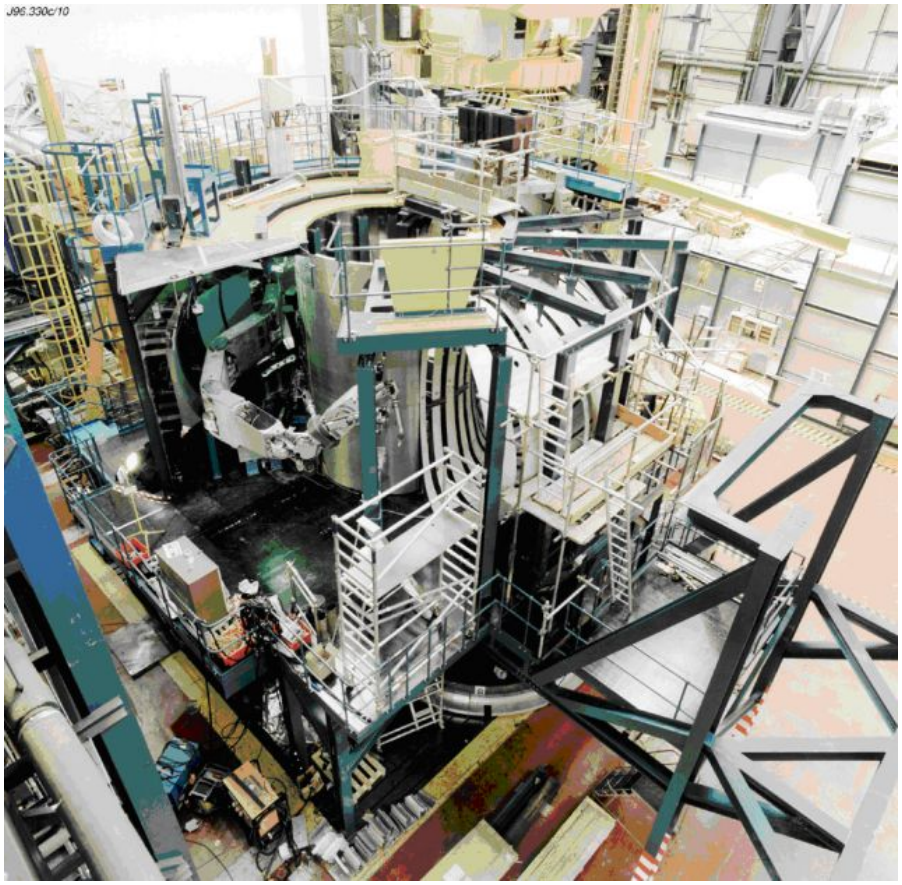
JET 2005

JET Experience

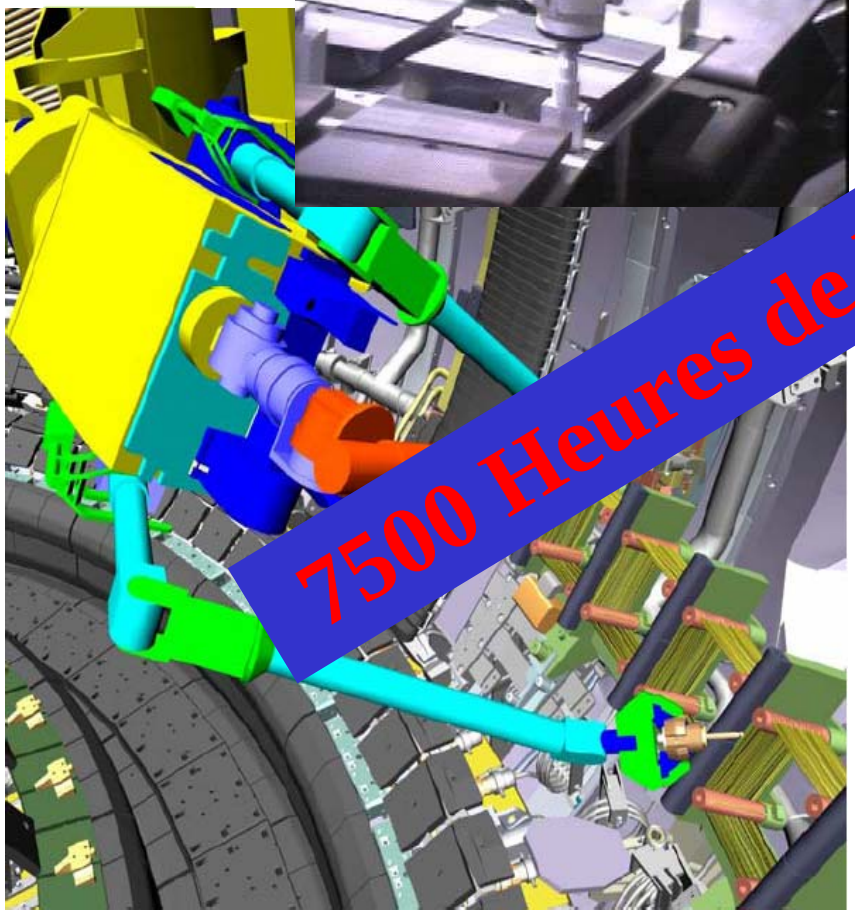




Banc test échelle 1



JET Experience



1998 - Remote Tile Exchange(RTE)

All **144 high** power Mark I[illegible]vertor tile carrier modules were replaced[illegible] **2 new** Mark IIgb modules

1999 - Inb[illegible]t Launcher Installation

All **25 type[illegible]** over 7 weeks.

« se[illegible]locking 12mm diameter pipes **[illegible]he torus wall ».**

[illegible]1 – Septum Replacement Plate

[illegible]ll **66 types of tasks** over 16 weeks.

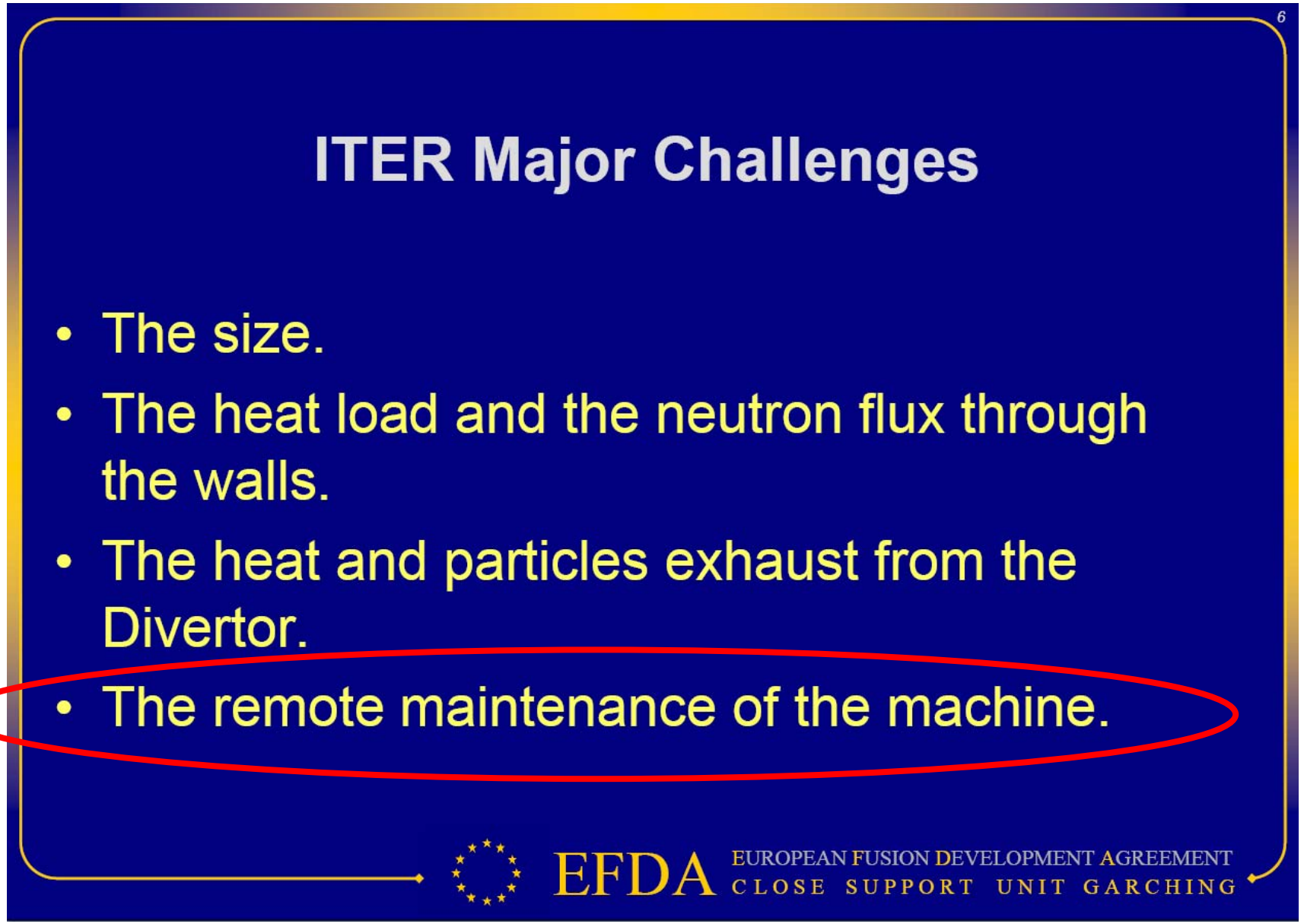
7500 Heures de Remote Handling

2004 JET Shutdown

- 212 remote tasks from Mar 2003 to Jan2004
- ~ 2000 remote tools used.
- 2 years planning & preparing remote tasks

JET enhanced Performances

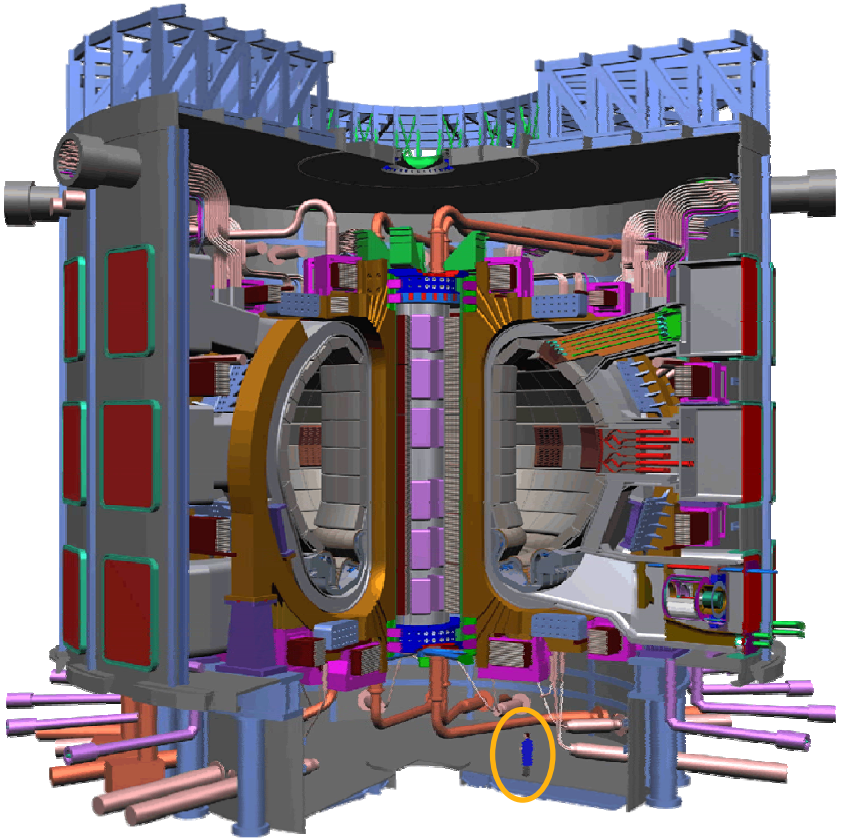
All **300 types of tasks** over 58 weeks.

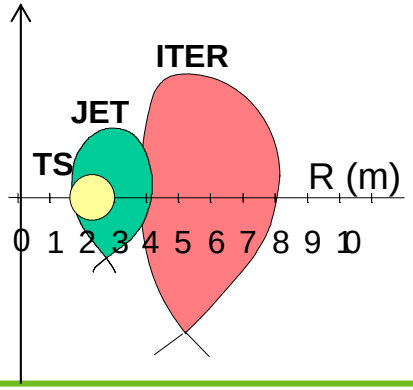


Workshop de Barcelone des 13 et 14 décembre 2005 : "ITER : des opportunités pour l'industrie européenne "

ITER : principales caractéristiques

Paramètre	ITER
Grand rayon (m)	6,2
Petit rayon (m)	2
Élongation verticale	1,7 / 1,85
Volume plasma (m^3)	837
Champ magnétique (T)	5,3
Courant plasma (MA)	15
Puissance fusion (MW)	500
Flux de neutrons (MW/m^2)	0,5
Facteur d'amplification (Q)	10 (ignition possible)





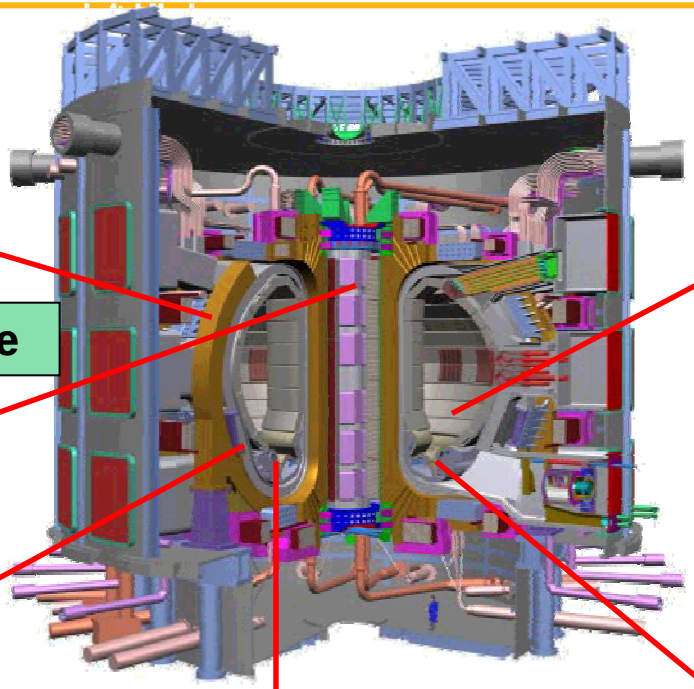
Ingénierie	Construction	Exploitation
1990	2008	2016 2035

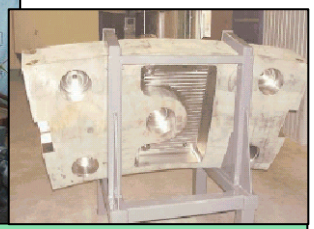
ITER : les enjeux technologiques

L2 : bobine toroïdale

L1 : solénoïde central

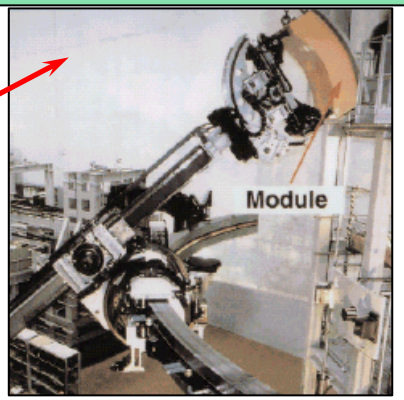
L3 : fabrication de l'enceinte



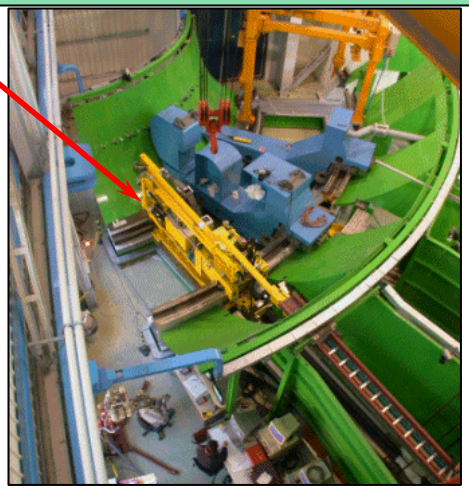


L4+L5 : module de couverture + divertor

L6 : maintenance couverture JAPON



L7 : maintenance divertor EUROPE



LA ROBOTIQUE SUR ITER

ACCES CRYOSTAT

- Vide Cryostat & température
- Accès personnel temps limité
  (de 0,001 à 1Gy/h)

Maintenance exceptionnelle

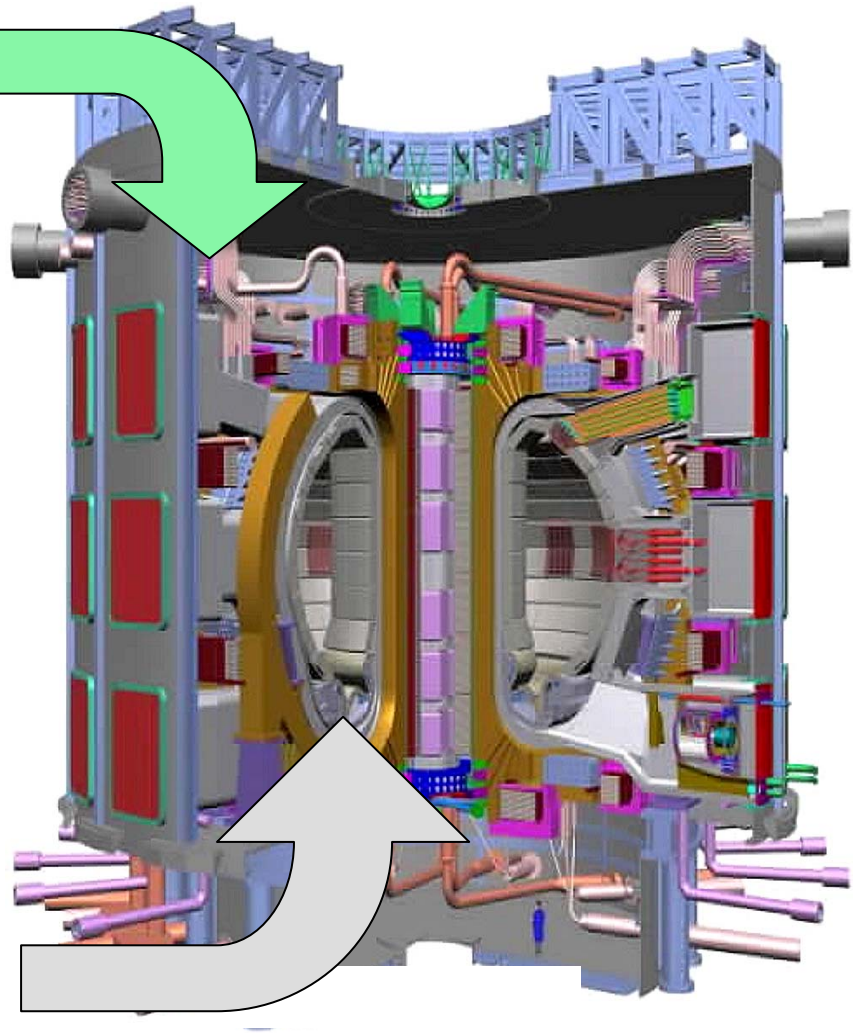
- Accès personnel difficile => Protection biologique
  mise en « air » du Cryostat
- « Assistance Téléopérée »

Maintenance régulière

- **54 cassettes @ 12 t, 420 blanket modules @ 4 t**
- « larges » accès à la chambre à vide sur 2 niveaux
- **Maintenance téléopérée exclusivement**

ACCES CHAMBRE A VIDE

- Rayonnement gamma (**630 Gy/h**)



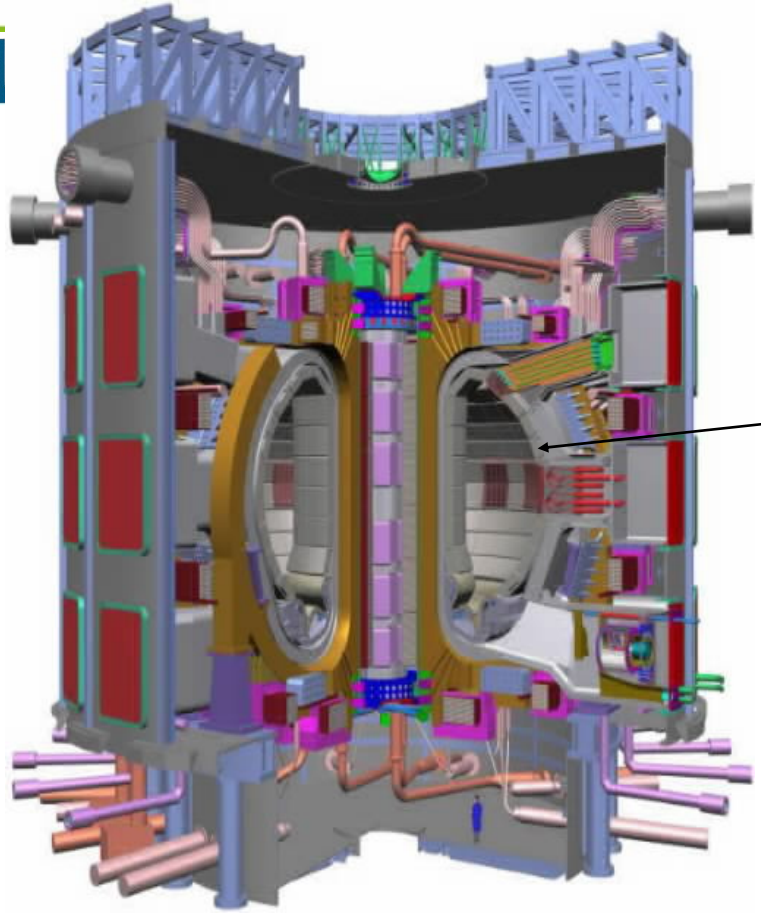
LA ROBOTIQUE SUR ITER

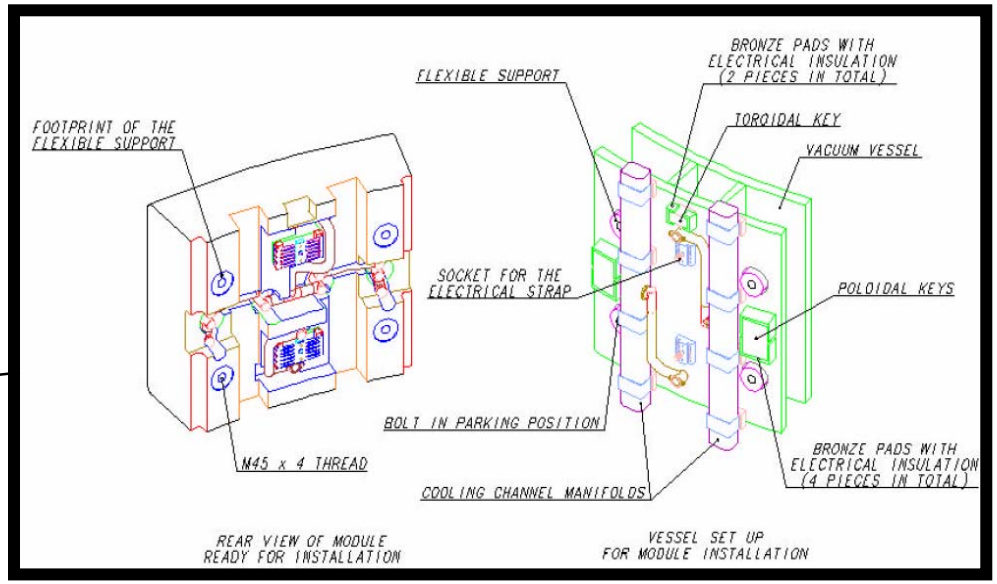
DEFI TECHNOLOGIQUE

- Masse, dimensions et forme des composants.
- Nombre important de composants
- Trajectoires de manipulation complexes
- Assemblages à jeu réduit, tolérances de positionnement
- Environnement extrême
- Peu de capteurs disponibles (tenue au rayonnement)
- Fiabilité des équipements de maintenance

ITER L6 - Maintenance des blankets

PROJET L6 JAPON
MAINTENANCE DES MODULES BLANKET





ITER L6 - Maintenance des blankets – IVT

In Vessel Transporter

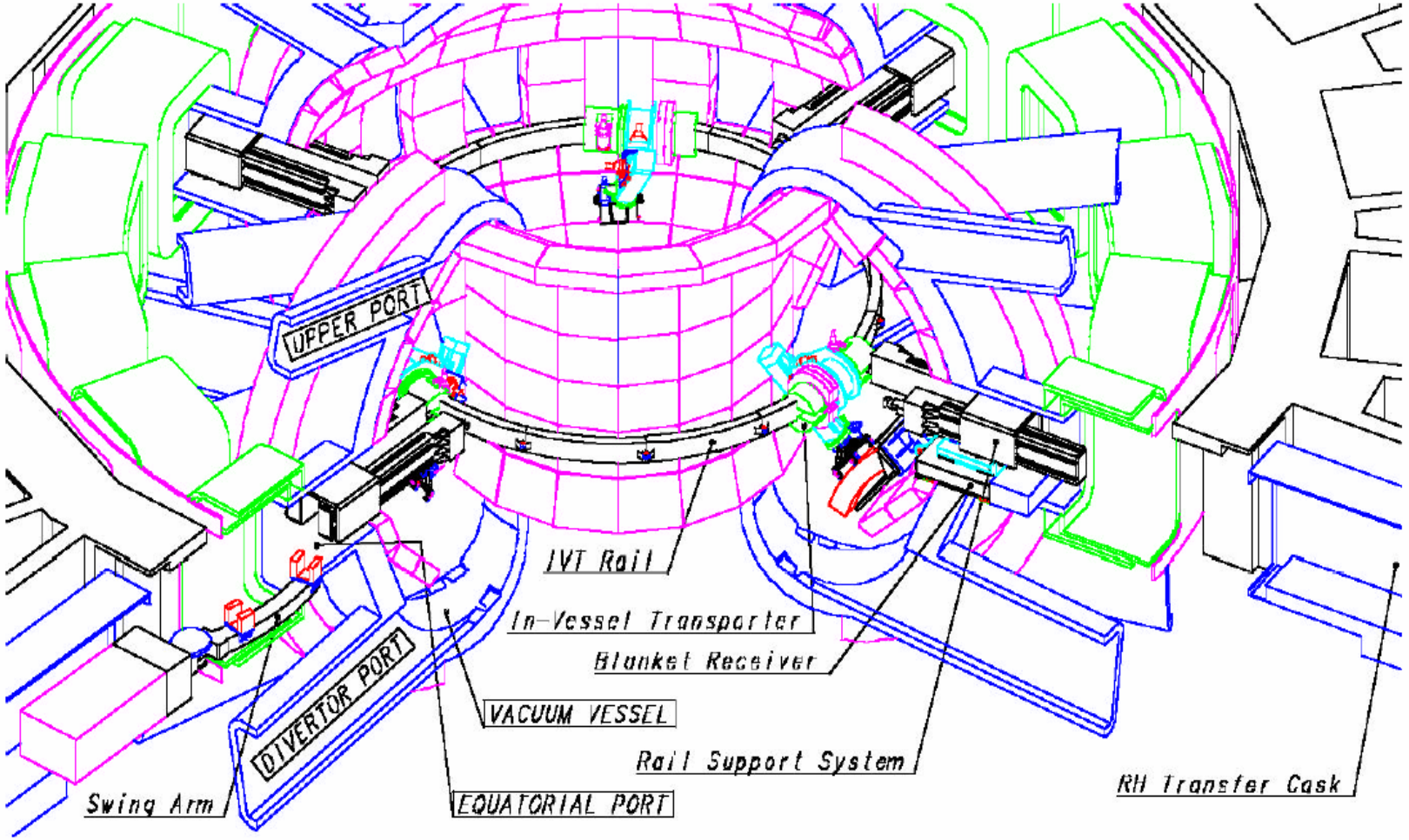
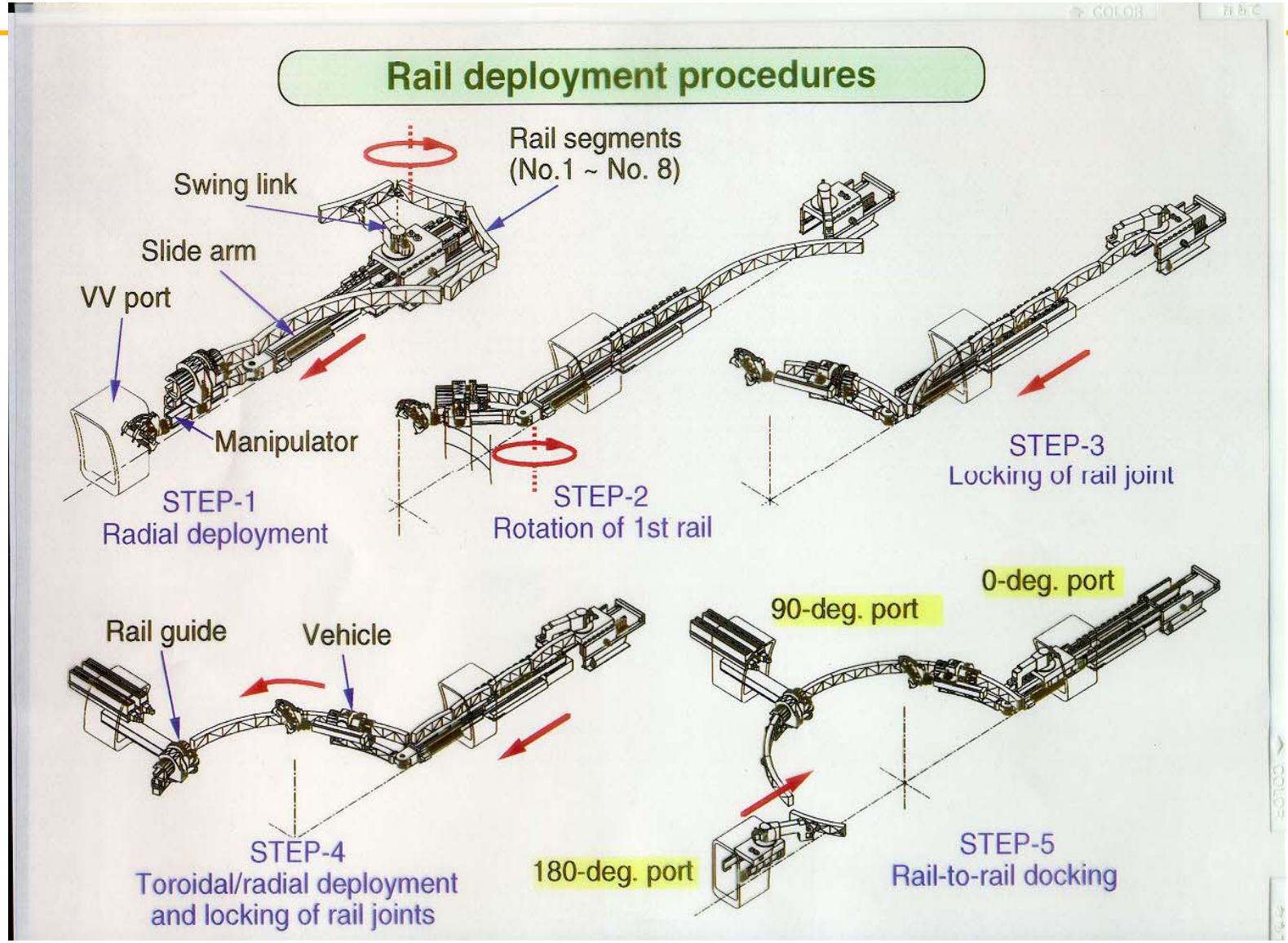
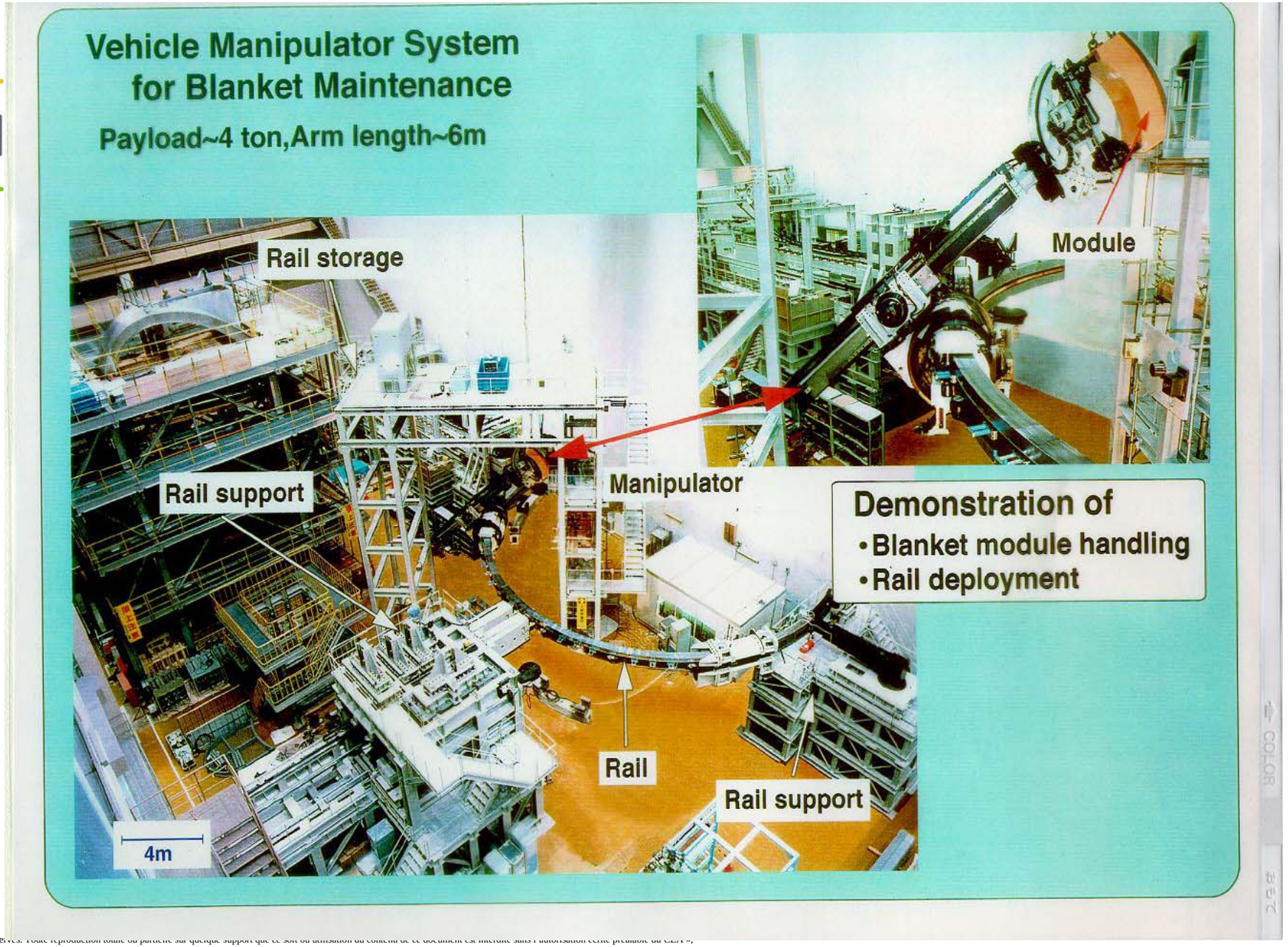


Figure 2.9.3-1 Blanket Maintenance Concept

ITER L6 - Maintenance des blankets – IVT



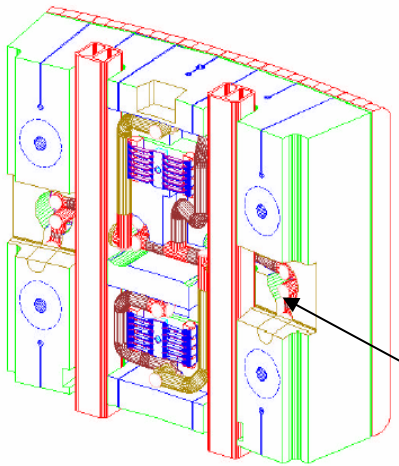
ITER L6 - Maintenance des blankets – IVT



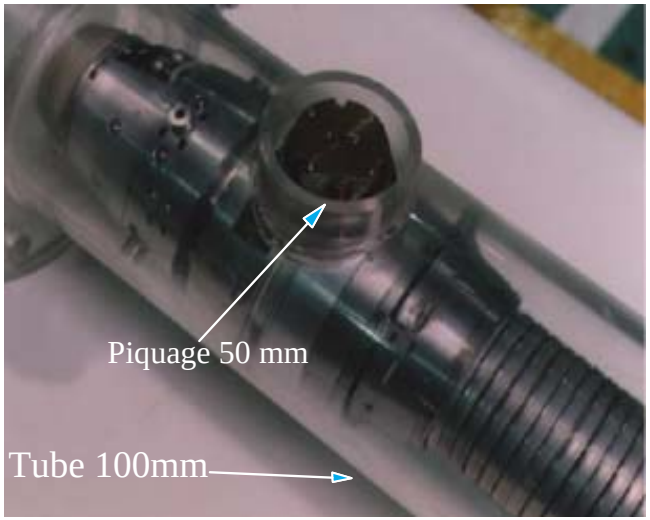
ITER L6 - Maintenance des blankets – IVT

ITER L6 - Maintenance des blankets

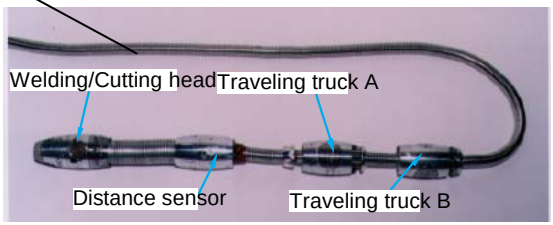
« BORE TOOLS » DECOUPE SOUDAGE CONDUITES REFROIDISSEMENT DES BLANKETS - PIQUAGE



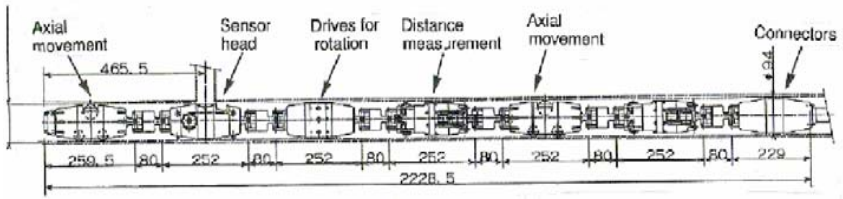
In Board Blanket Module



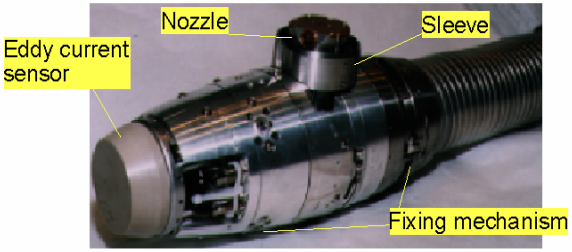
Welding / cutting nozzle



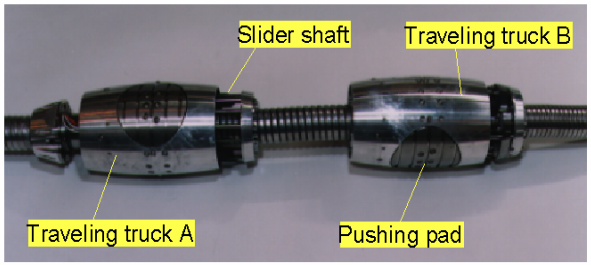
YAG Laser Processing Head



Drive mechanism of the bore tool



Processing head

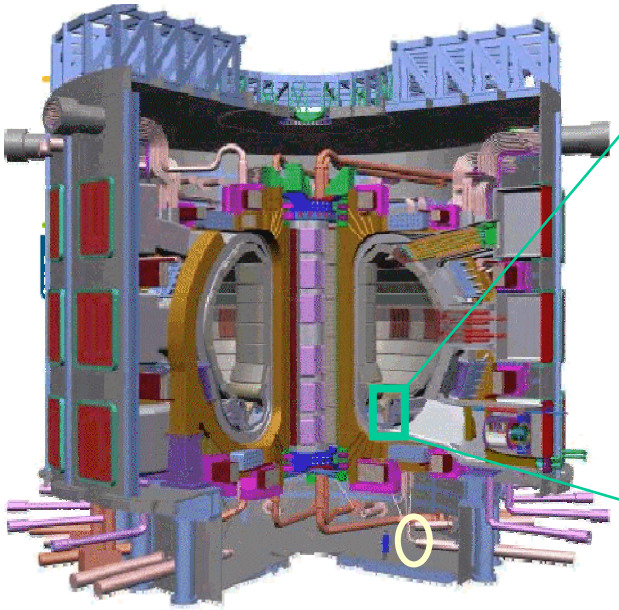


Traveling trucks

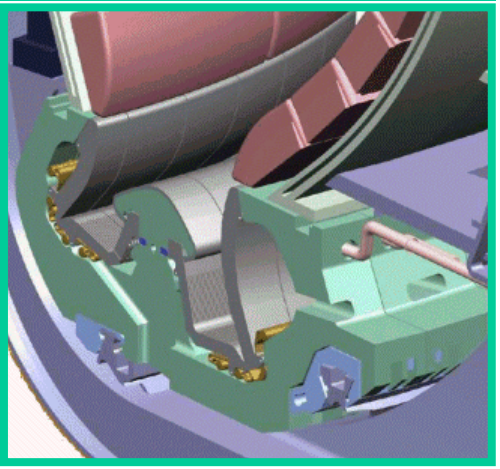
Axis name	Symbol	Velocity	Movement range	Axis name	Velocity	Movement range
Head rotation	θ	16 sec/rev	±180 deg.	Truck A support	8 mm/sec	8 mm
Nozzle movement	Z	30 mm/sec	20 mm	Truck A slider shaft	21 mm/sec	60 mm
Nozzle up & down	R	0.3 mm/sec	0~37 mm*	Truck B support	8 mm/sec	8 mm
Nozzle rotation	ρ	15 sec/rev	± 180 deg.	Truck B slider shaft	21 mm/sec	60 mm

* Welding/cutting region : 8 mm

ITER L7 - Maintenance du Divertor

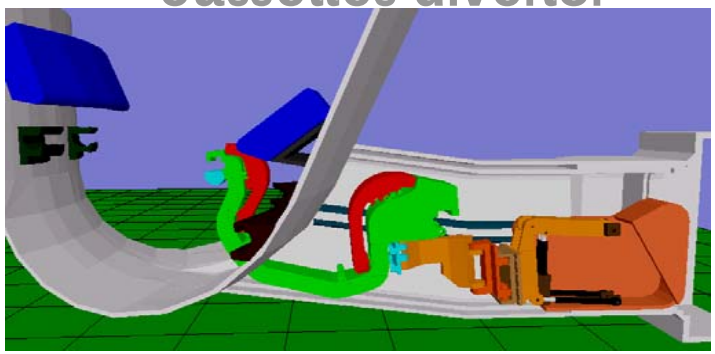


54 cassettes de 12t

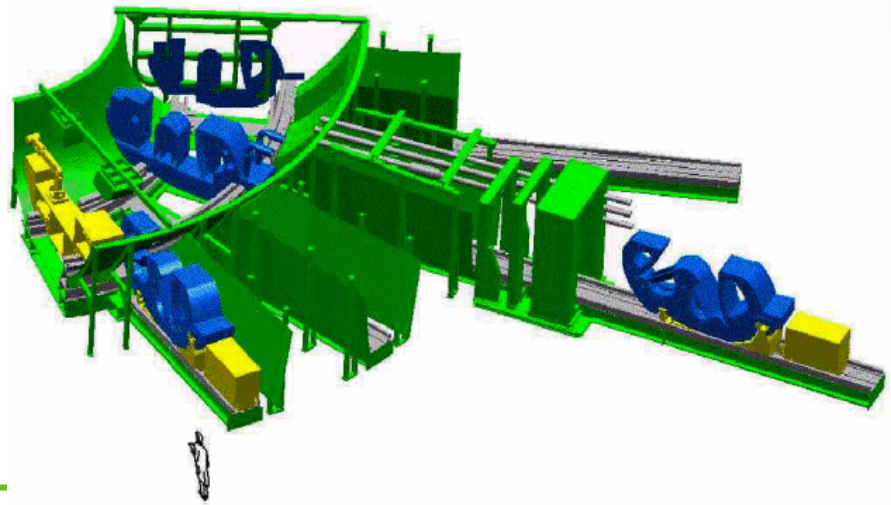


Projet L7 - EUROPE

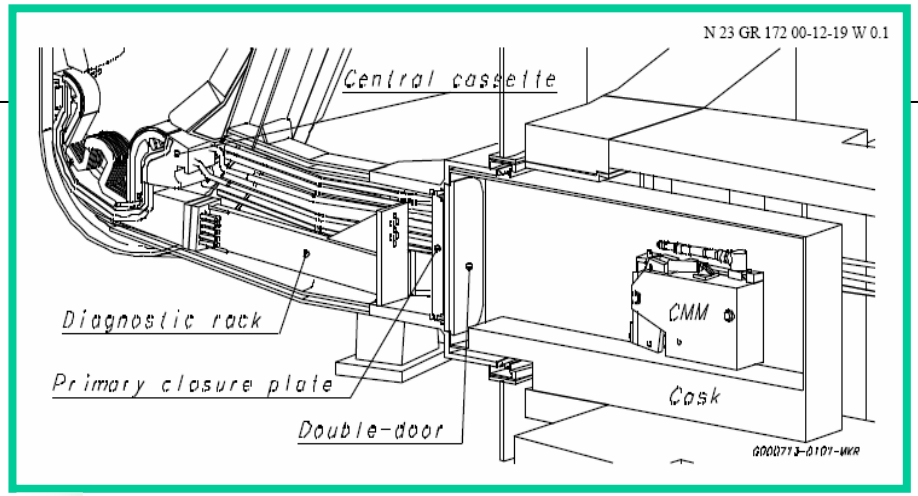
Maintenance des cassettes divertor

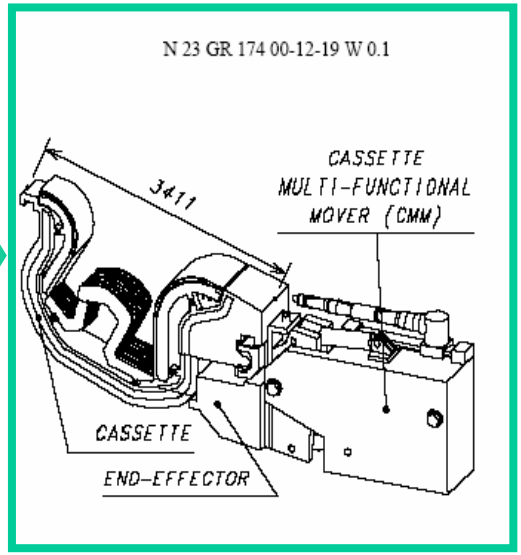


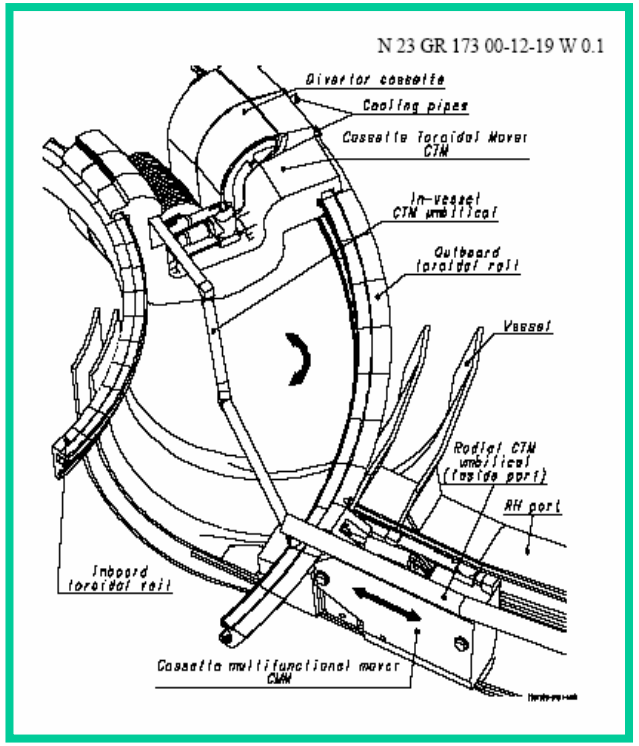
Divertor Test Platform (ENEA)

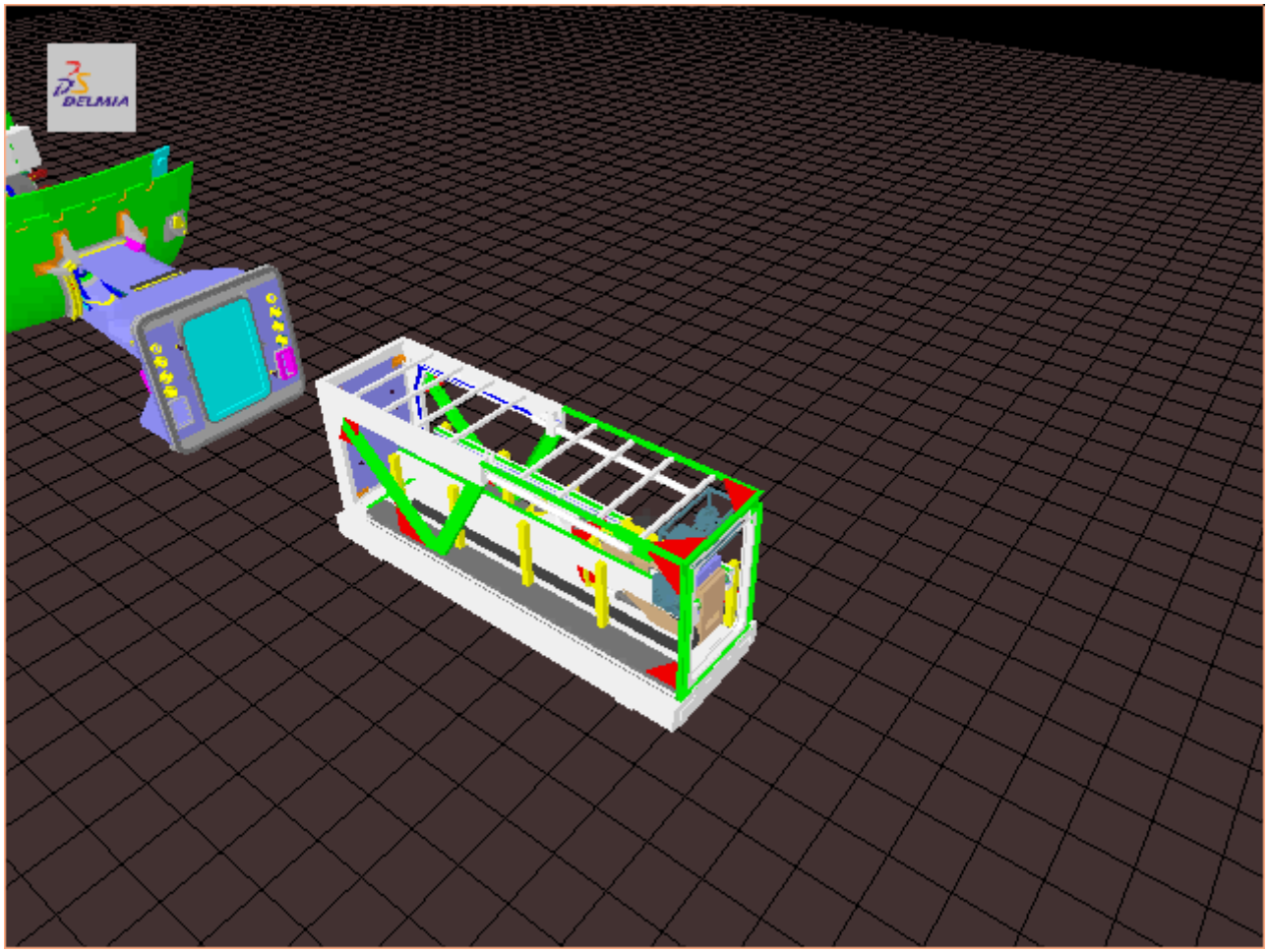


DTSI / Service Robotique Interactive

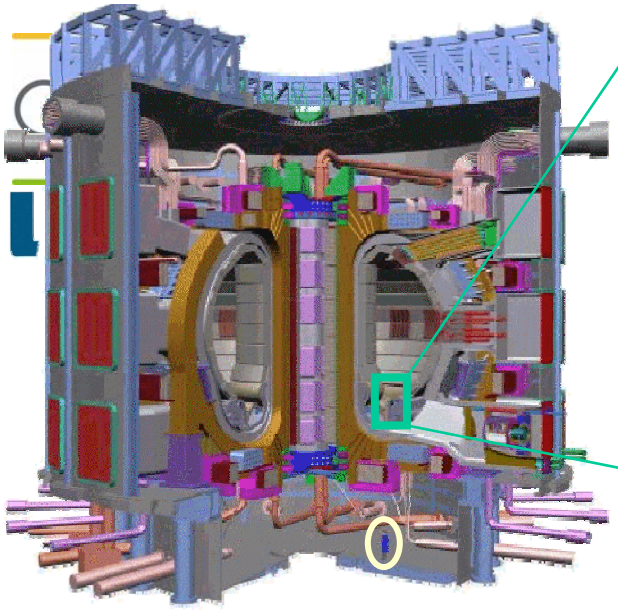


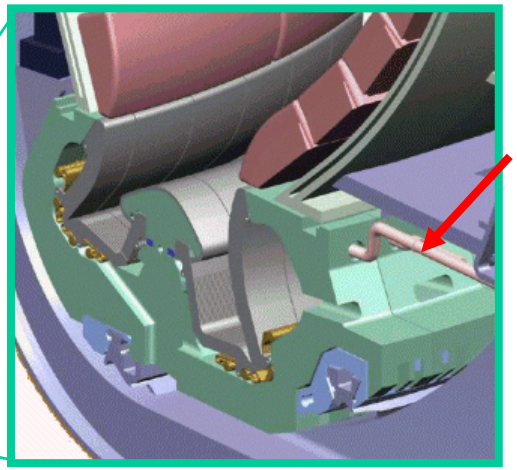






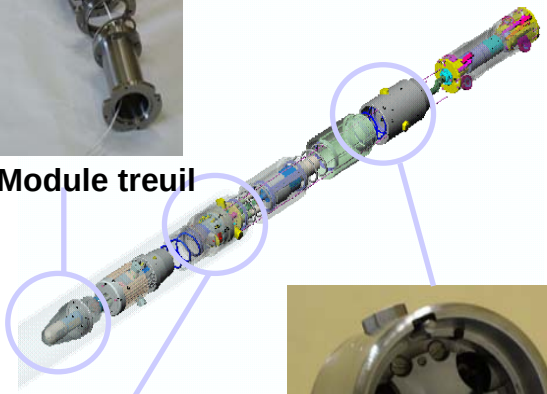
ITER – L7 Maintenance du Divertor

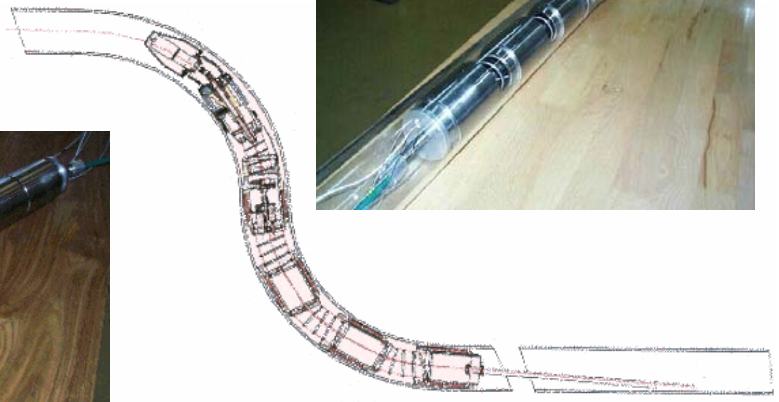




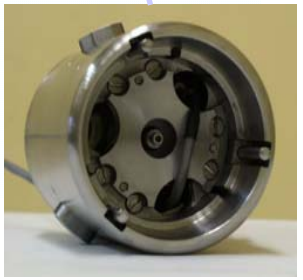
Maintenance des conduites de refroidissement du divertor d'ITER (CEA/LIST)

Module treuil





Torche de pointage

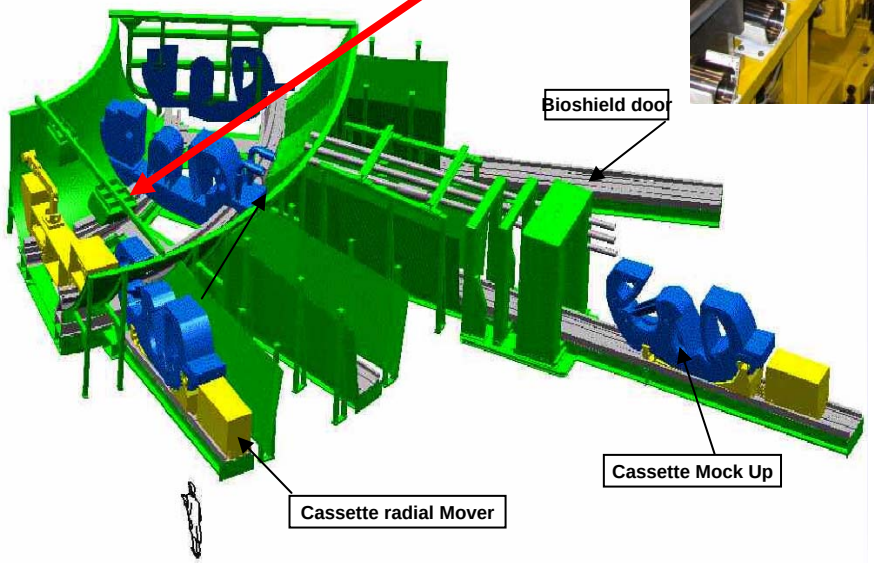


Module de clampage

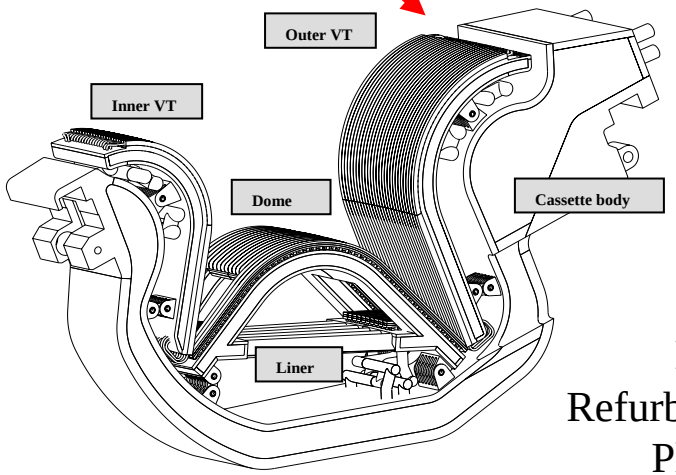
ITER – L7 Maintenance du Divertor

MAESTRO (CEA)
ROBOT
HYDRAULIQUE

Télérobotique à retour d'effort (CEA/LIST)

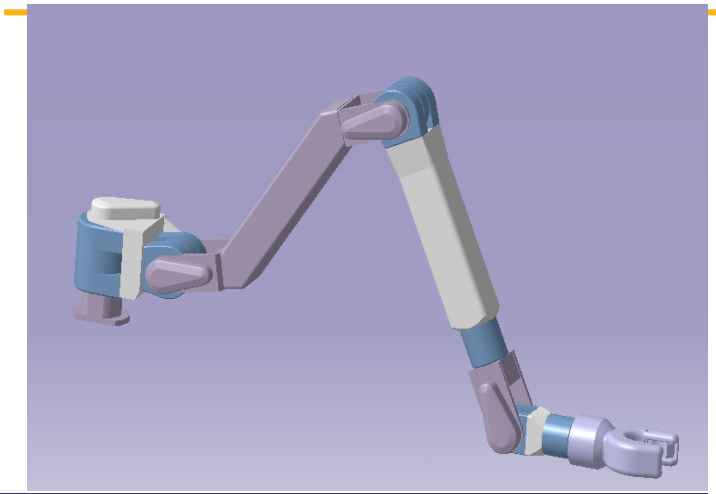


Divertor Test Platform (ENEA)

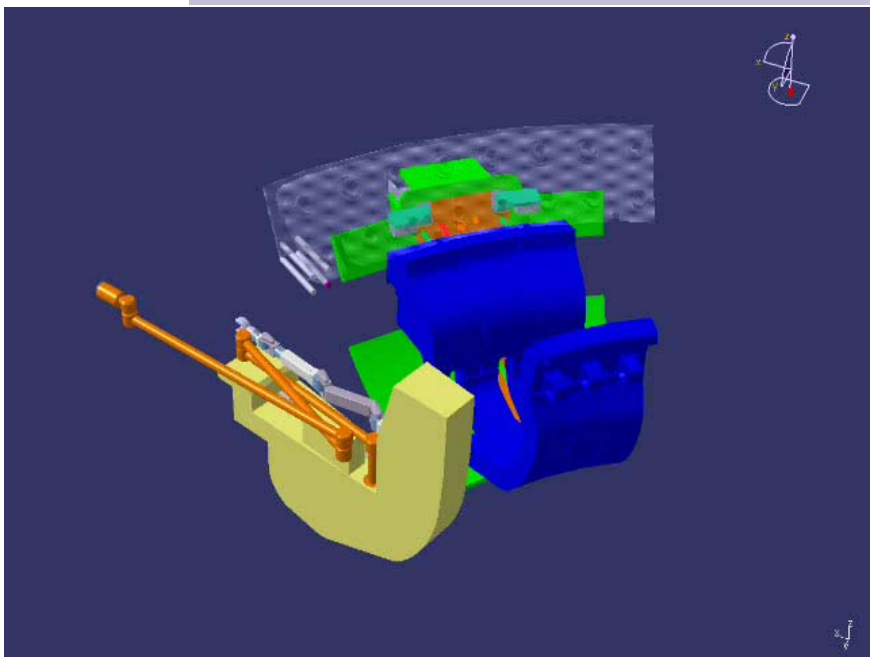


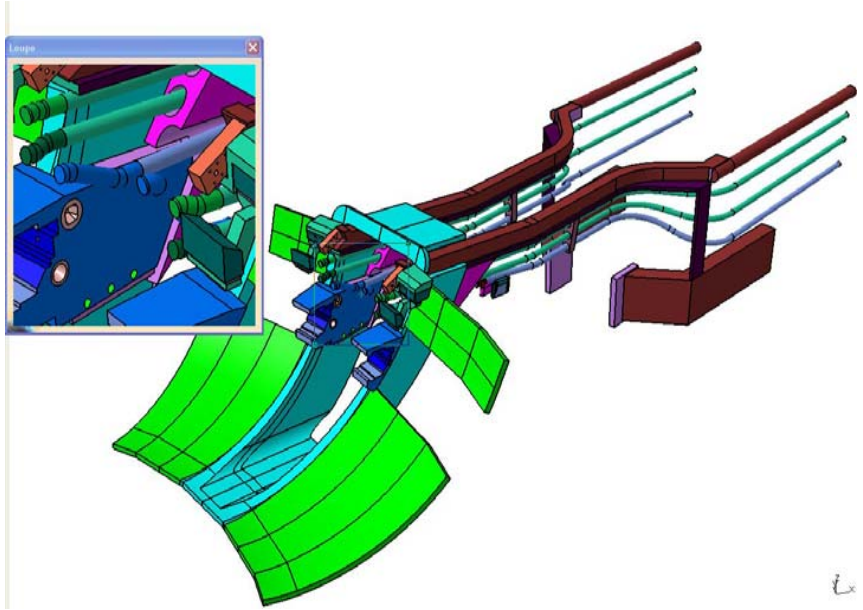
Divertor Refurbishment Plateform

ITER – L7 Maintenance du Divertor



- Manipulator geometry based on the MAESTRO hydraulic slave arm :
  - 2m30, 150kg
  - 70kg Payload
  - Only existing today with oil technology.





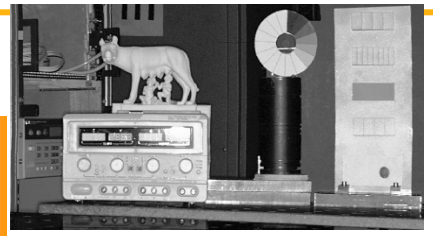
ITER – L7 Maintenance du Divertor - Inspection

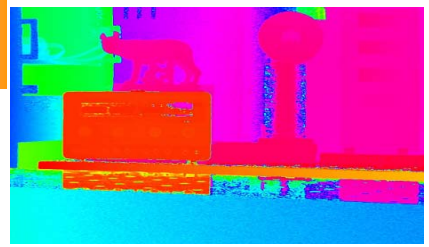
IVVS
In Vessel Viewing System

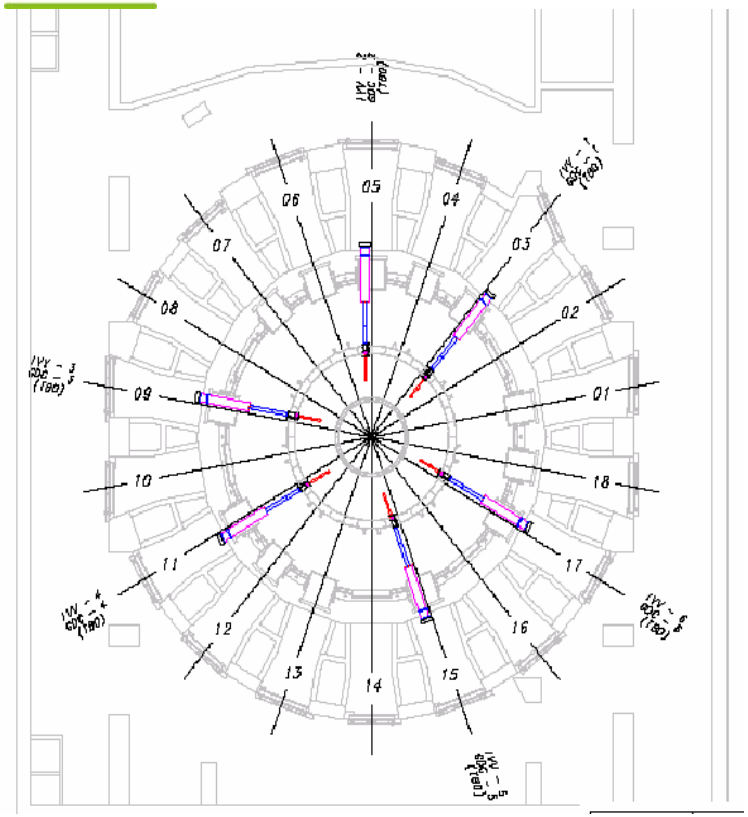
Vision

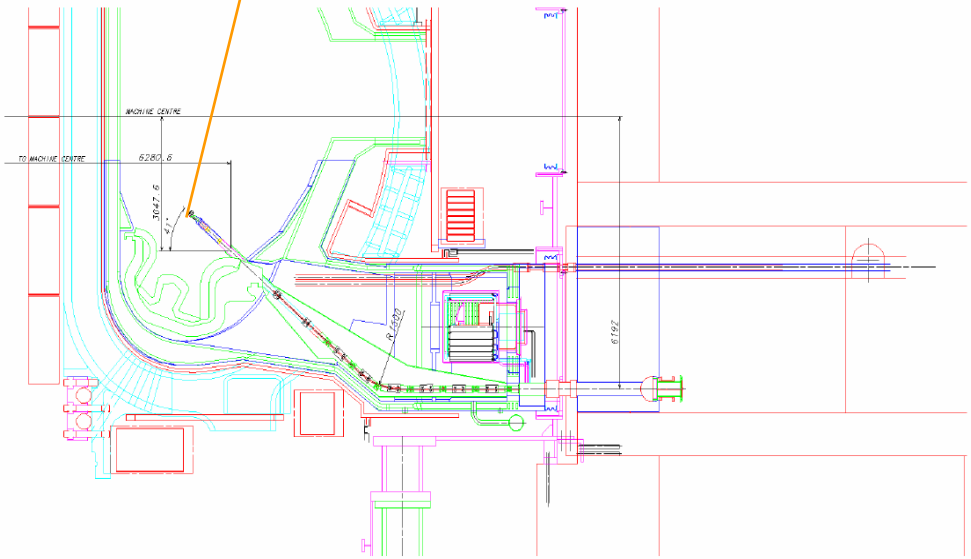
&

Métrologie









ITER – L7 Maintenance du Divertor - AIA

Objectifs :

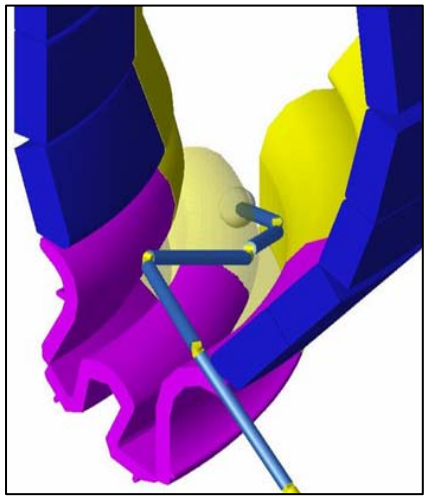
- **inspection visuelle première paroi et Divertor,**
- **recherche de fuite sur K7 ou module de blanket,**

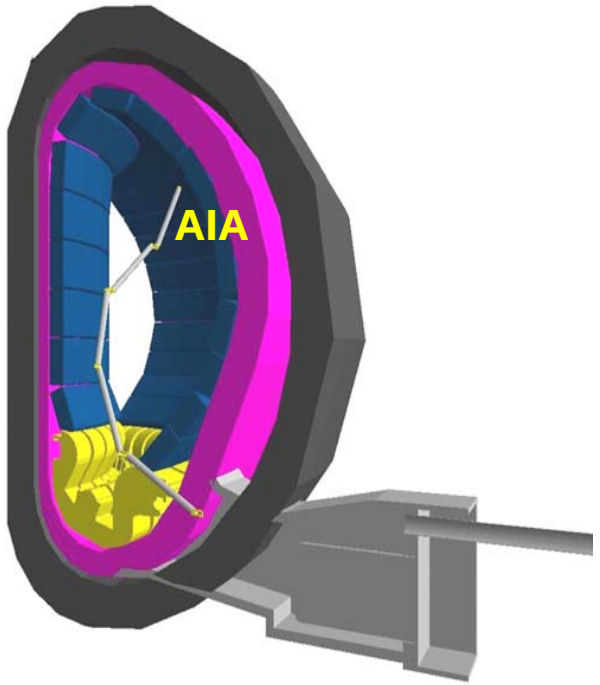
Autres applications possibles à développer :

- **métrologie,**
- **aspiration poussières Be, W et CFC,**
- **détritiation laser**
- **prélèvement d'échantillons...**

AIA

élancement : 8m
charge en bout : 10 kg
Vide et température (120°C)



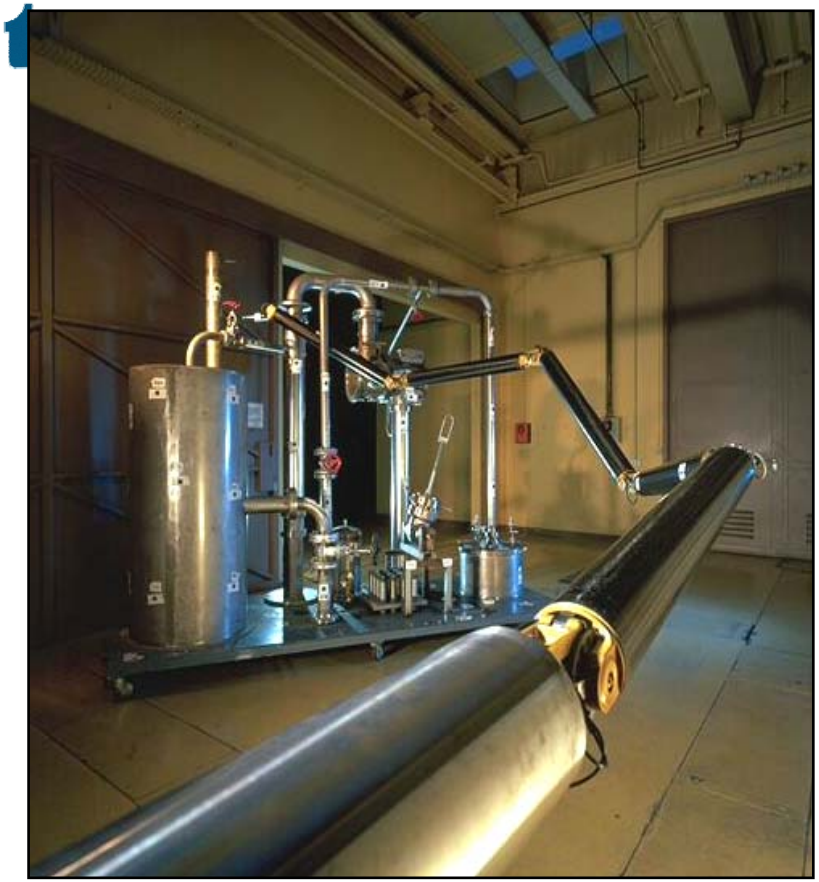


Articulated Inspection Arm

ITER – L7 Maintenance du Divertor - AIA

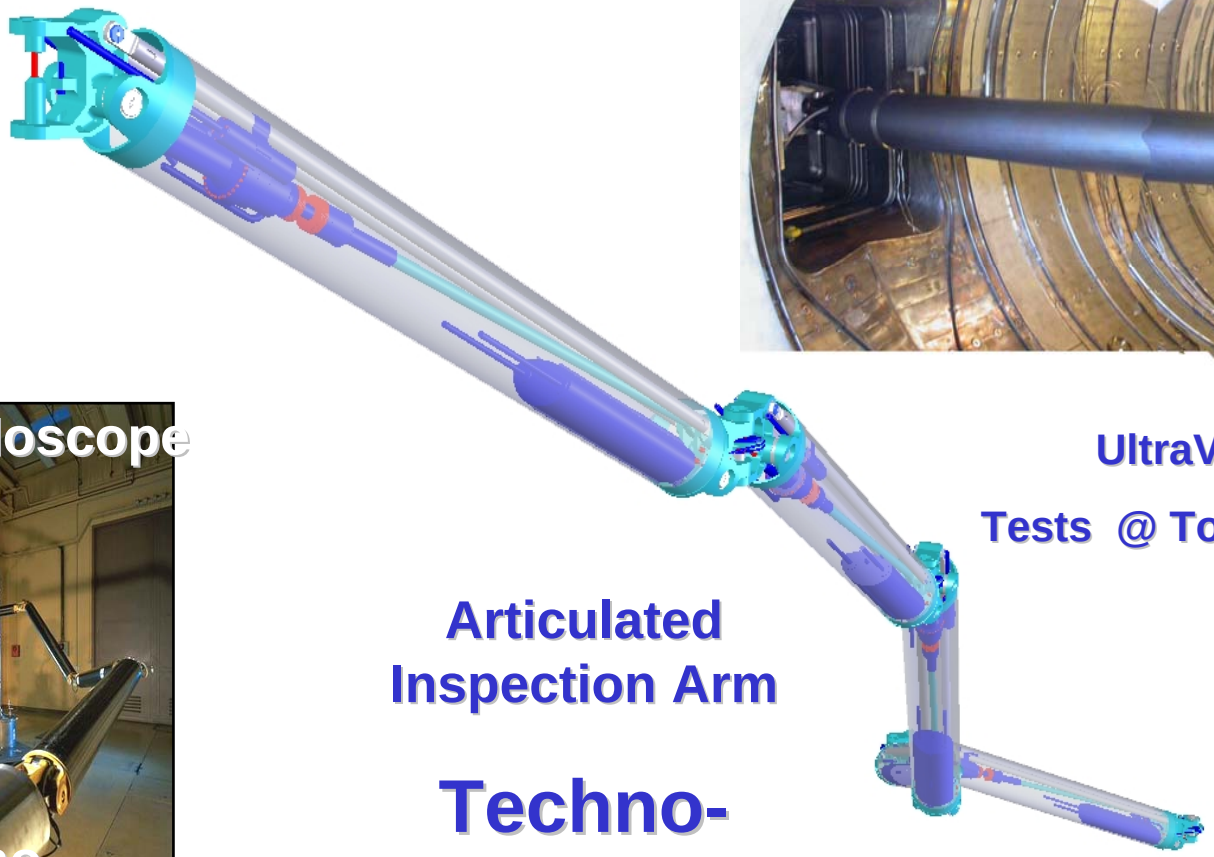
Prototype « en air » - AREVA

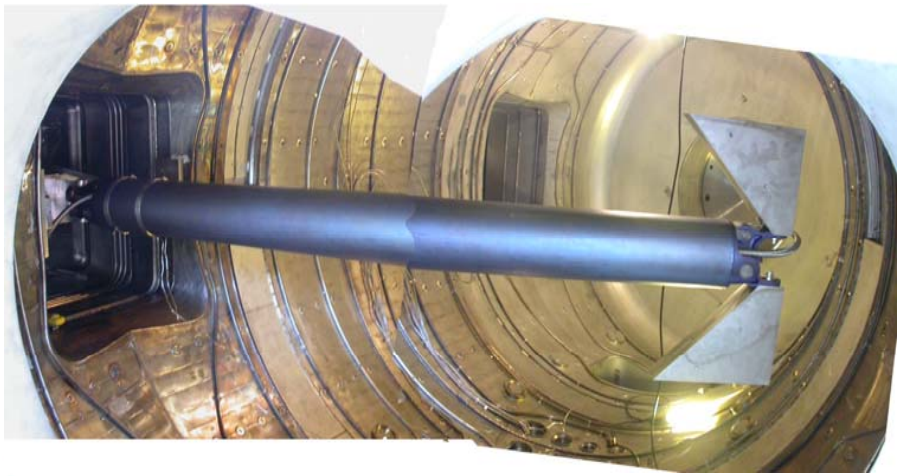
(6 segments 11 axes, L=7.2m, pression atmosphérique, T ambiante)



Robotique – Articulated Inspection Arm

Premiers succès du robot AIA en Ultravide et Température





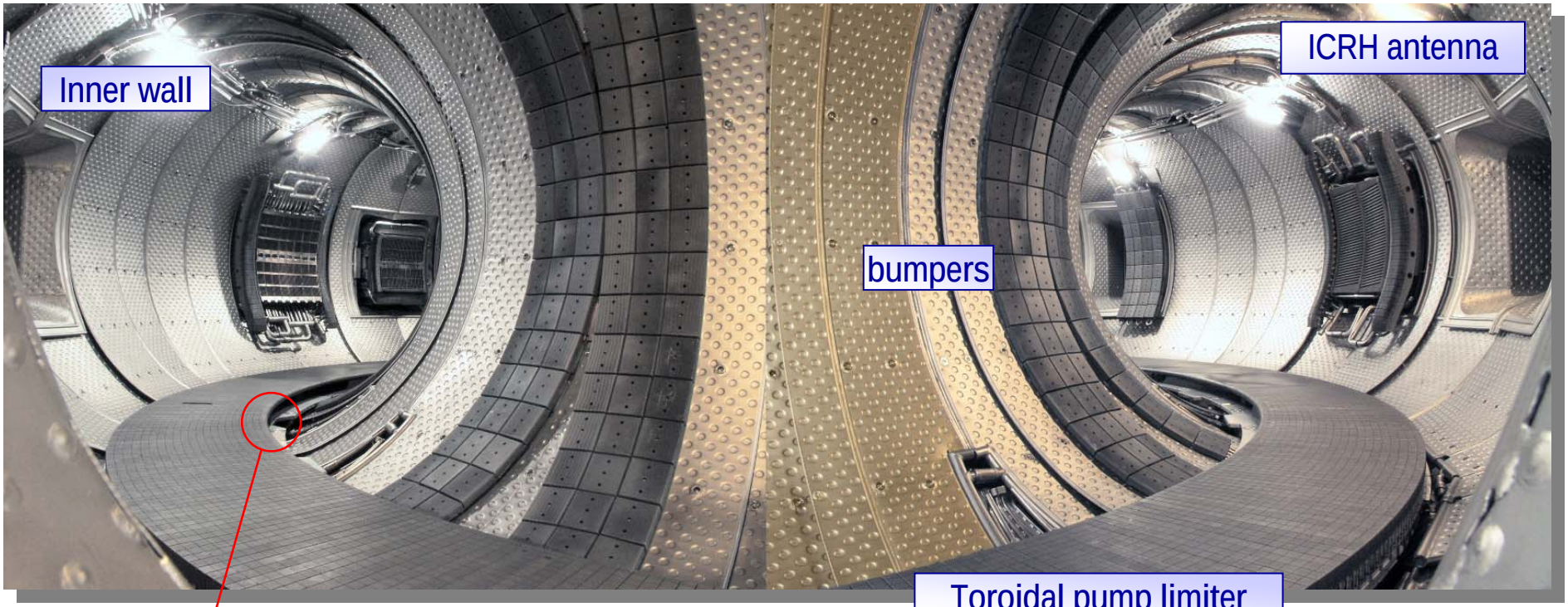
UltraVide & T° (120°)

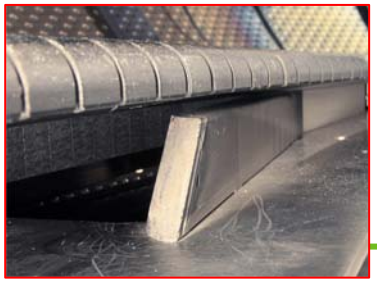
Tests @ Tore Supra Cadarache

Articulated Inspection Arm

Techno-Fusion

TEST AIA en configuration réelle sur Tore Supra

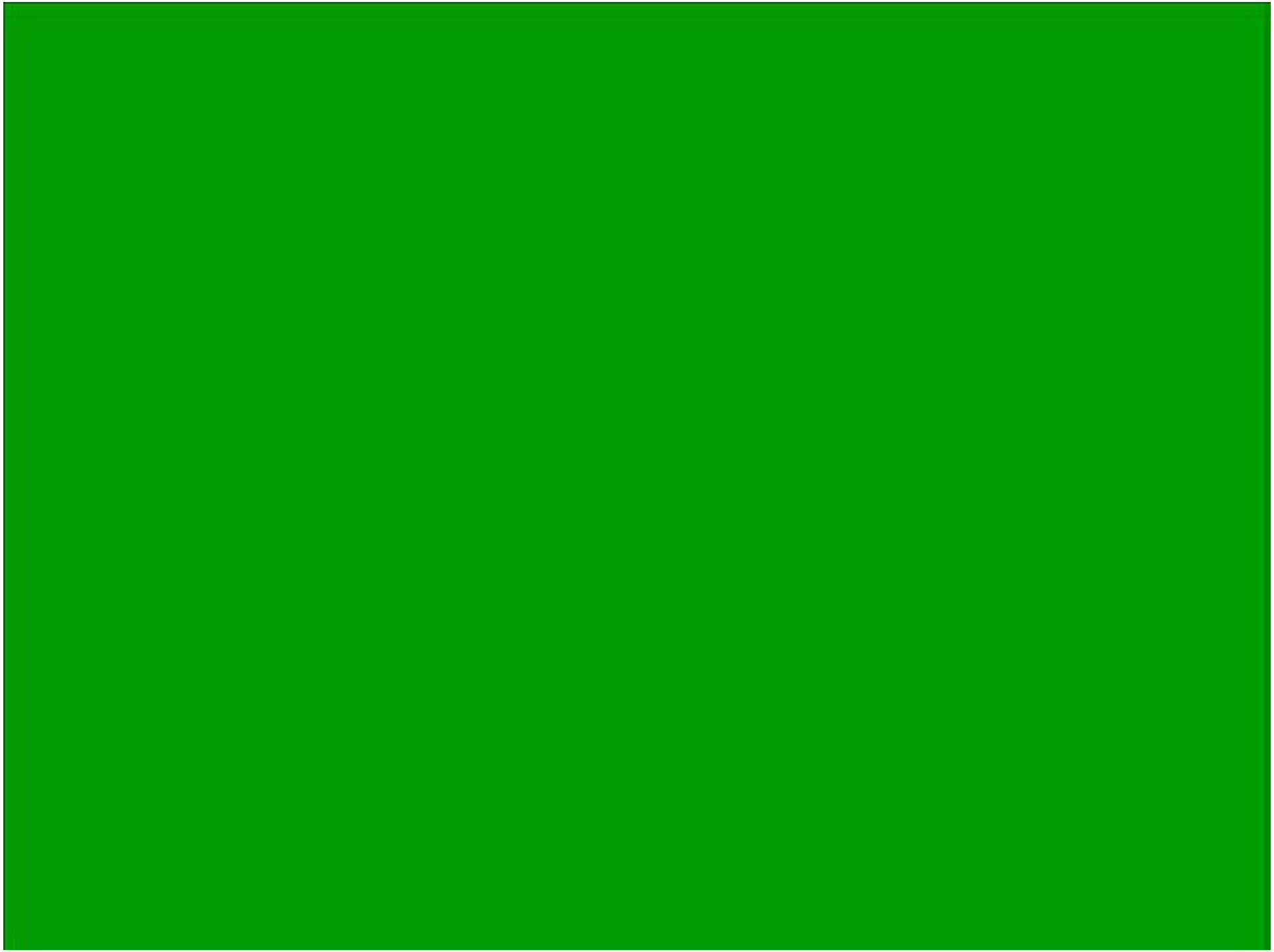




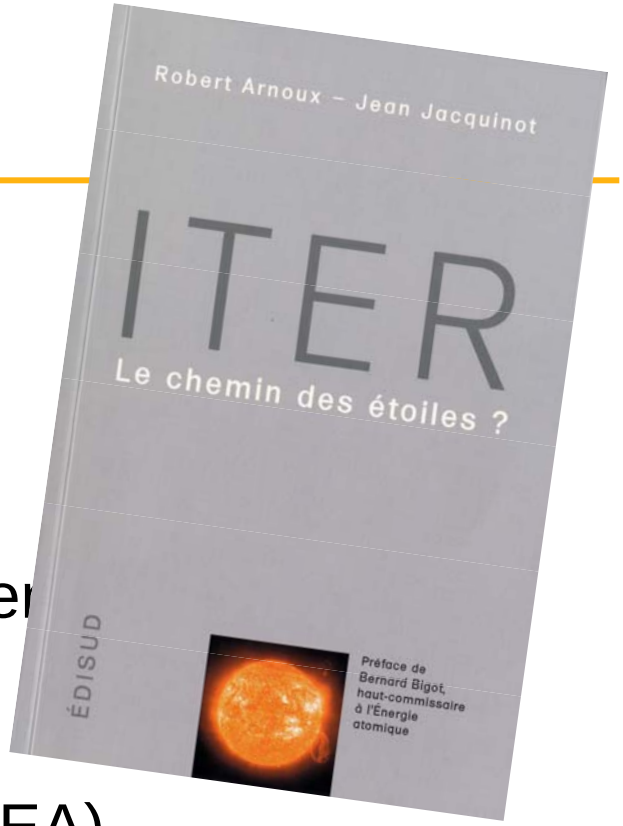
Rather Large Tokamak

R_0 = 2.35 m

a = 0.75 m



Pour plus d'information…



- Projet ITER
  - www.iter.org
- European Fusion Development Agreer
  - www.efda.org
- Information sur la fusion contrôlée (CEA)
  - www-fusion-magnetique.cea.fr
- Cadarache, site de construction d'ITER
  - www.itercad.org