The Remote Handling Systems for ITER

Isabel Ribeiro

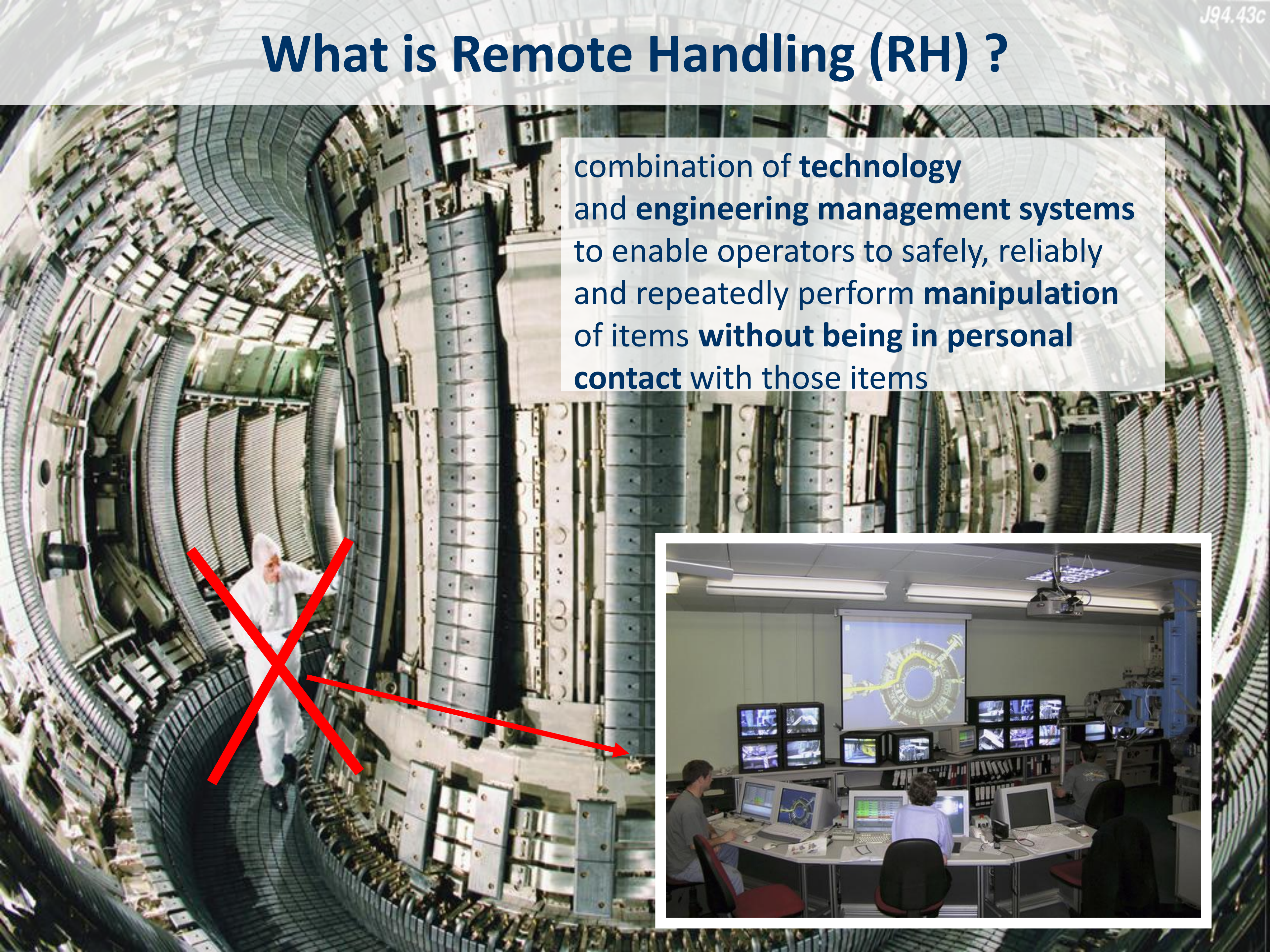
Instituto Superior Técnico / Institute for Systems and Robotics, Portugal

Carlo Damiani, Alessandro Tesini, Satoshi Kakudate, Mikko Siuko, Carlo Neri

F4E , Spain | ITER Organization, France | JAEA, Japan | VTT, Finland | ENEA, Italy

What is Remote Handling (RH) ?

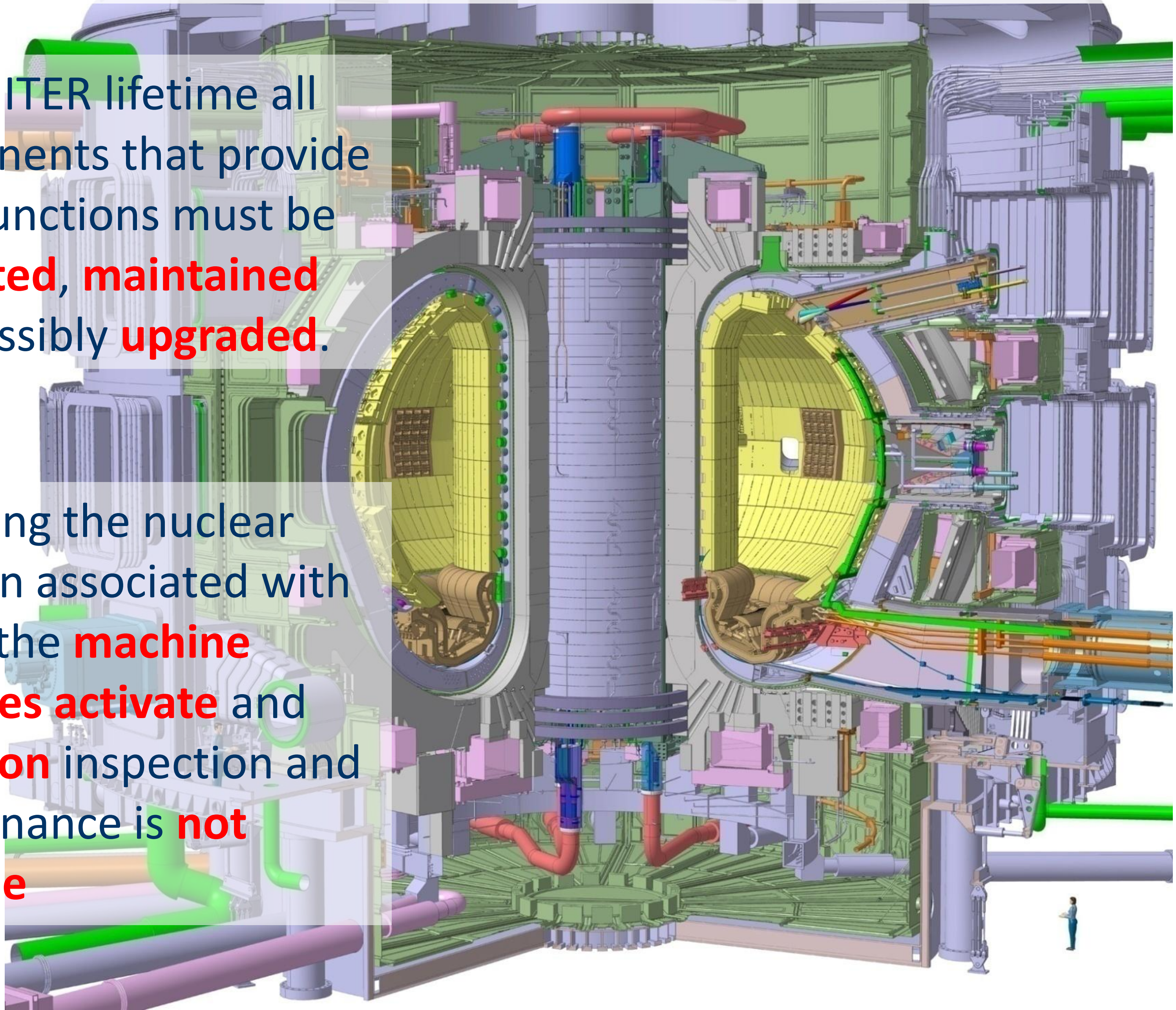
combination of **technology**
and **engineering management systems**
to enable operators to safely, reliably
and repeatedly perform **manipulation**
of items **without being in personal
contact** with those items



Why Remote Handling in ITER?

During ITER lifetime all components that provide basic functions must be **inspected**, **maintained** and possibly **upgraded**.

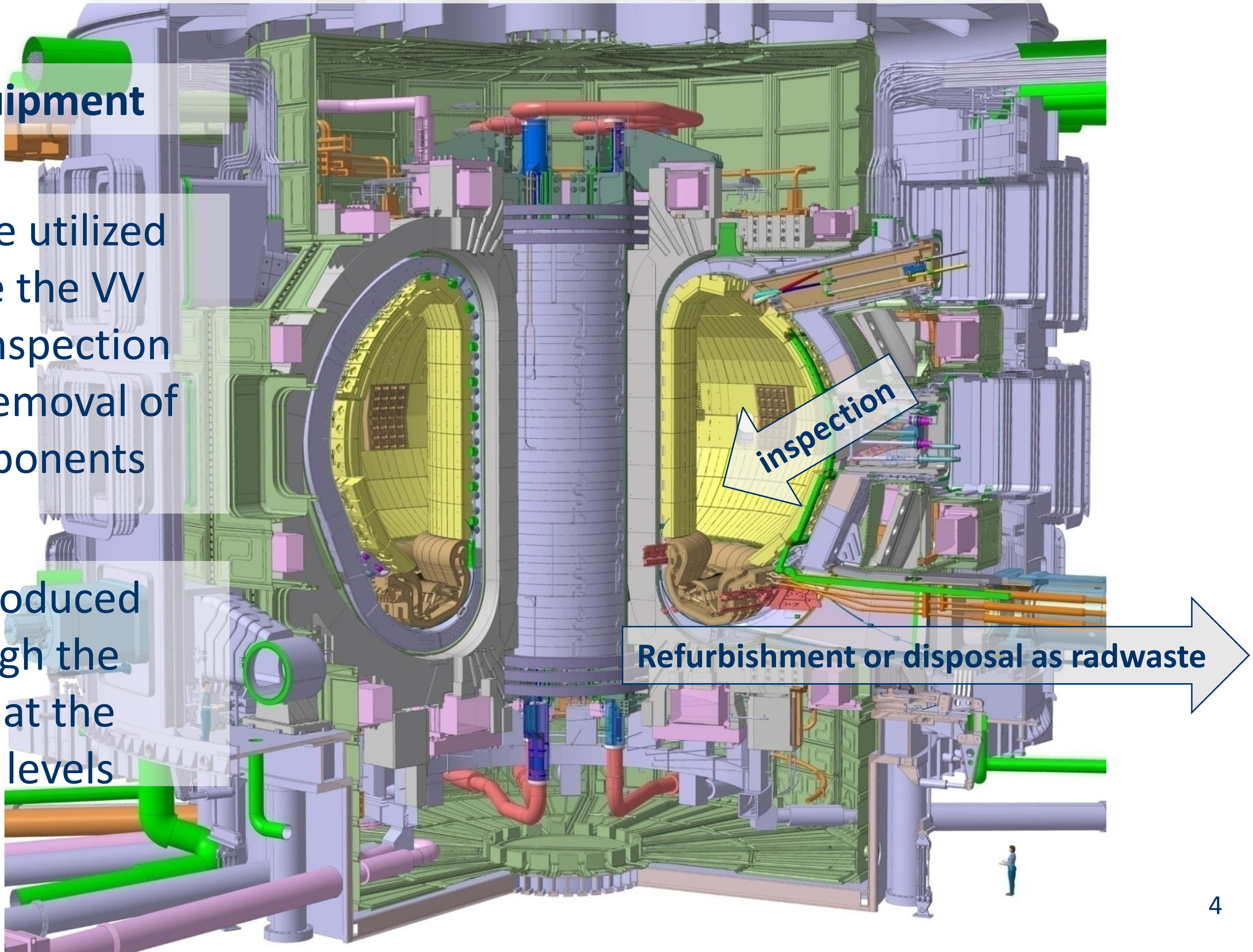
Following the nuclear reaction associated with fusion the **machine becomes activate** and **hands-on** inspection and maintenance is **not possible**



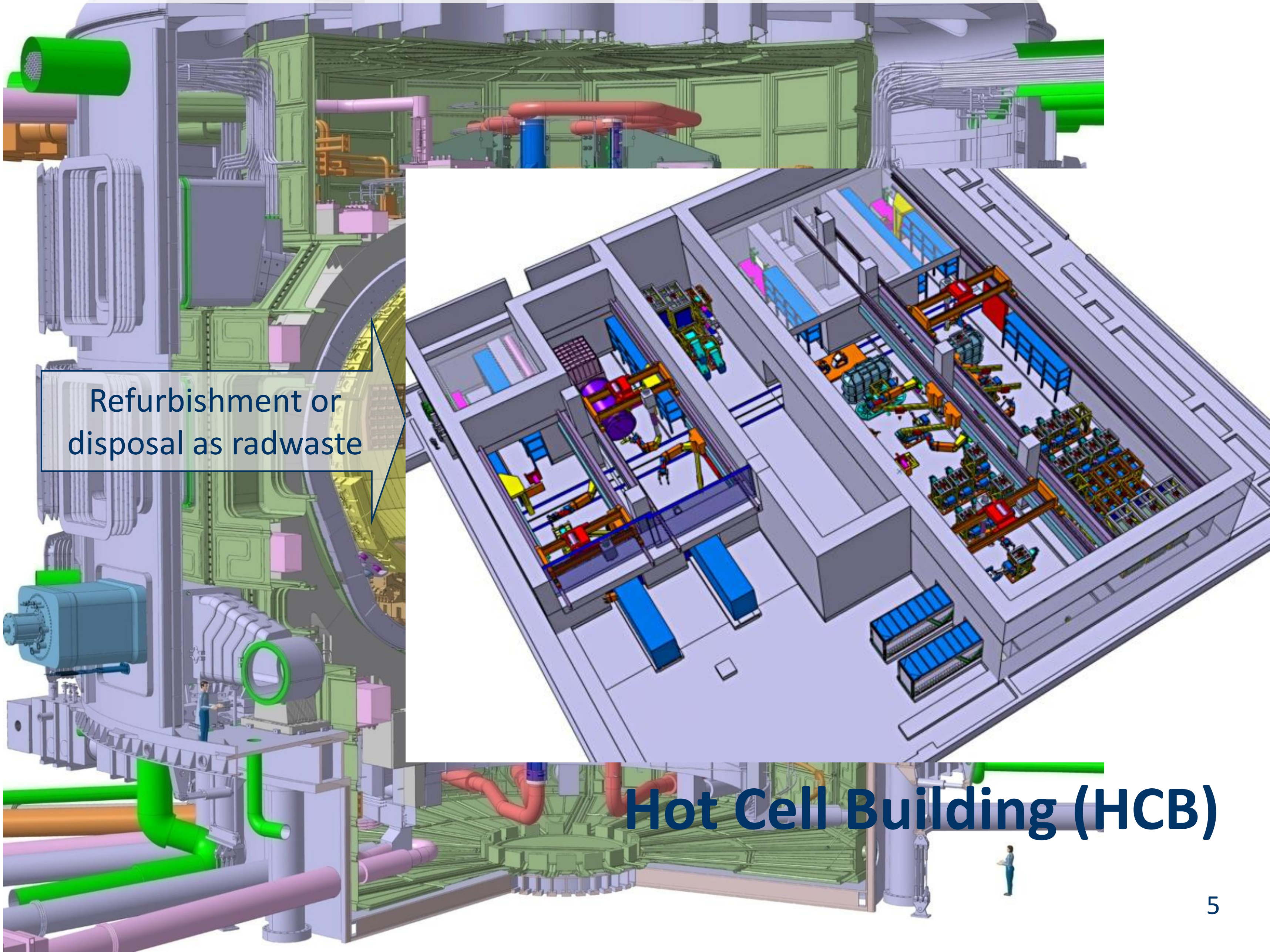
Where Remote Handling in ITER ?

RH Equipment

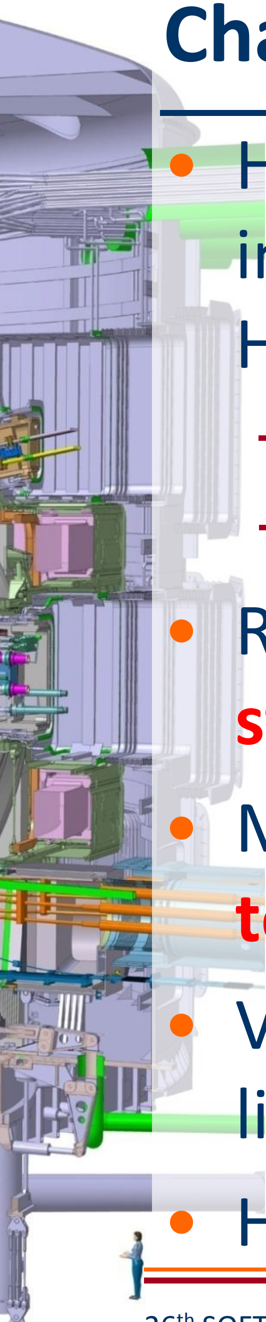
- will be utilized inside the VV
  - for inspection
  - for removal of components
- is introduced through the ports at the three levels



Where Remote Handling in ITER ?



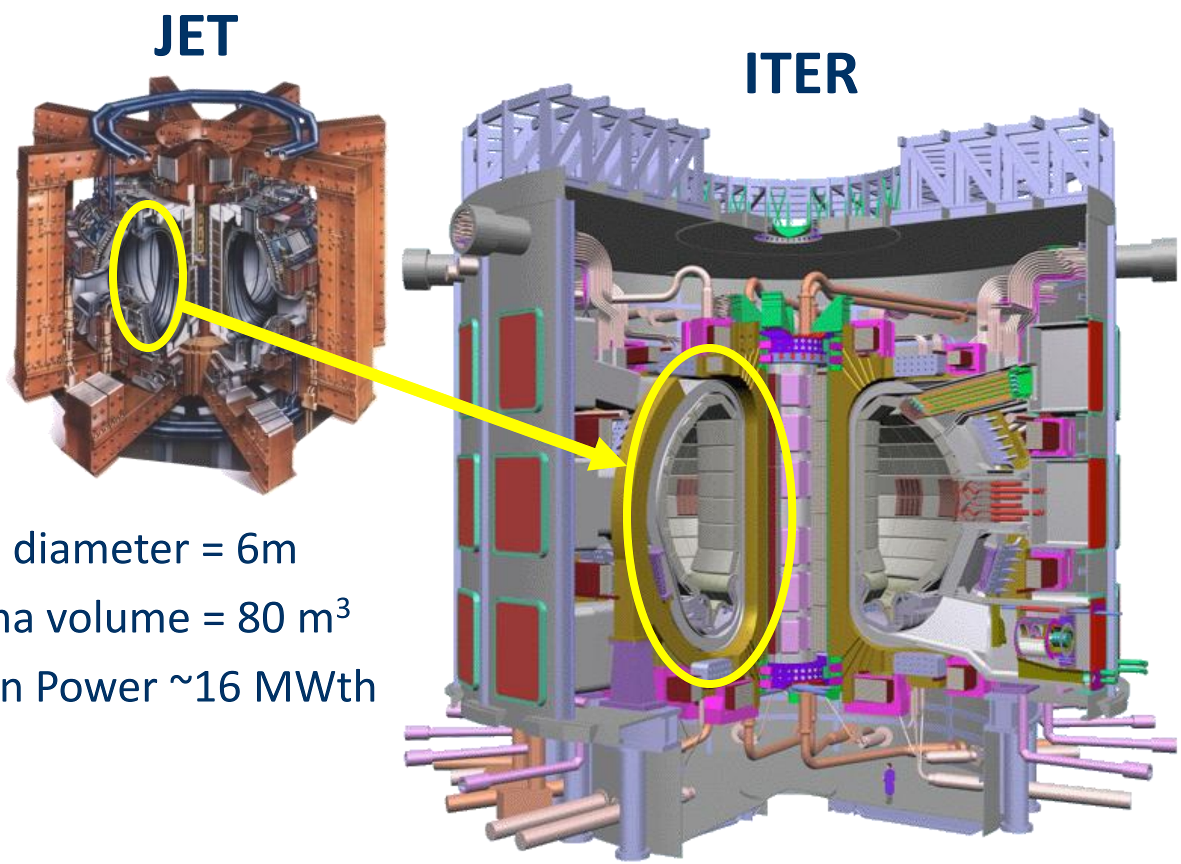
Hot Cell Building (HCB)



Challenges of RH in ITER

- Handle **many** and **very large and heavy components** inside the machine, and transport them from TB to HCB, with
  - **Very high degree of accuracy**
  - **Very high level of reliability**
- RH equipment has to negotiate **narrow gaps** with very **strict tolerances**
- Most RH equipment and tools have to be **radiation tolerant** ← **Key Issue**
- VV is a dark place. RH equipment has to carry lightening systems
- Highly **sophisticated control system**

ITER RH vs JET RH



Torus diameter = 6m

Plasma volume = 80 m^3

Fusion Power ~16 MWth

Torus diameter = 12m

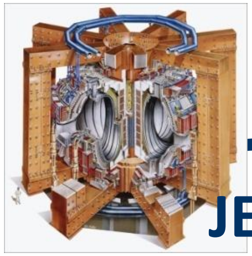
Plasma volume = 800 m^3

Fusion Power ~500 MWth

ITER RH vs JET RH

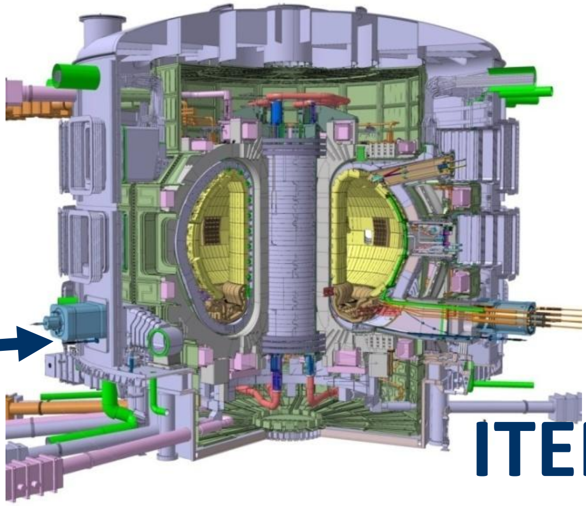
ITER RH overcomes JET RH by orders of magnitude

- **number** of RH components/ devices/ interfaces (~ 10^2)
- **hostile environment** (10^6 times more gammas)
- **size/weight** of the to-be-handled components (up to 10^4) still retaining **millimetric accuracy** requirements
- **complexity of the procurement**/organisational scheme
  - multi-party,
  - world-wide,
  - in-kind design / manufacturing / delivery / integration.



JET

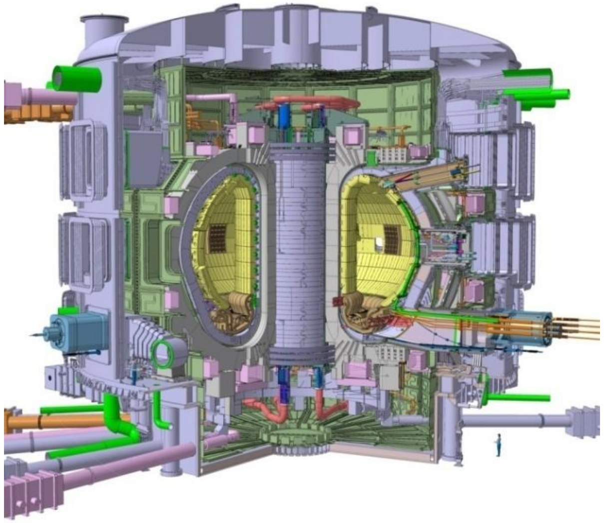
10^n x



ITER

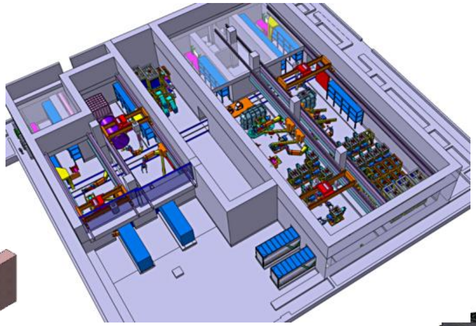
ITER Remote Handling Systems

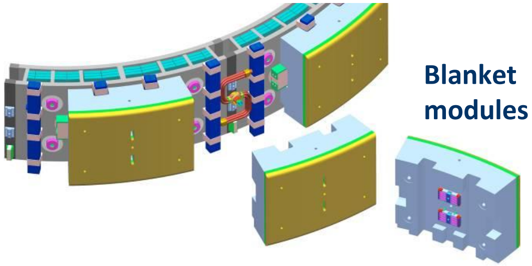
- Blanket RH System
- Divertor RH Systems
- In-Vessel Viewing System
- Multi-Purpose Deployer
- Transfer Cask System
- Neutral Beam RH System
- Hot Cell RH System

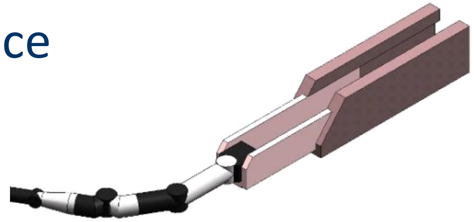


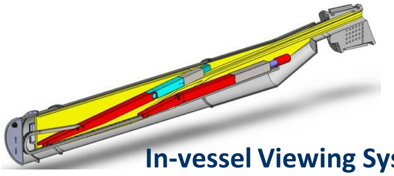
IRMS

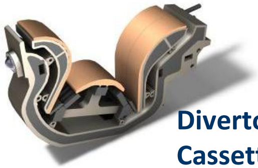
ITER Remote Maintenance System











ITER Remote Handling Systems

- Blanket RH System
- Divertor RH Systems
- In-Vessel Viewing System
- Multi-Purpose Deployer
- Transfer Cask System
- Neutral Beam RH System
- Hot Cell RH System

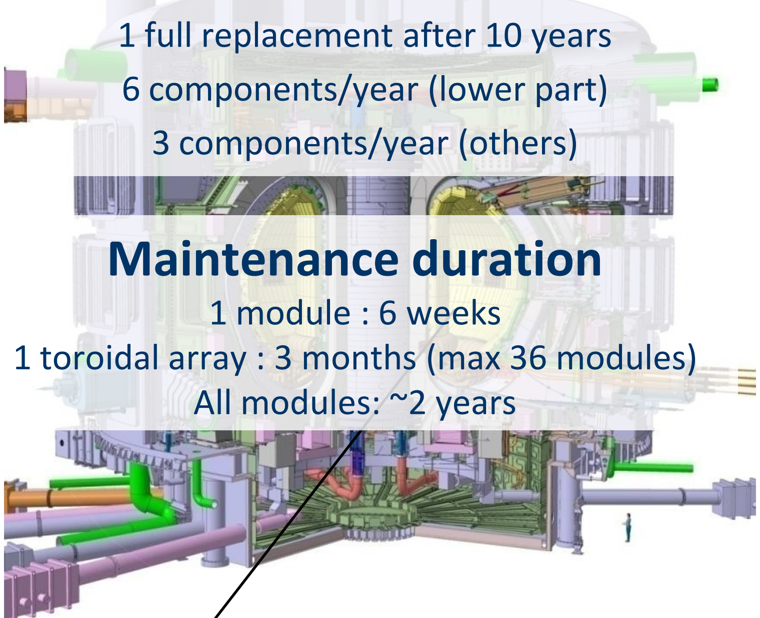
Blanket RH System | Purpose

Maintenance frequency

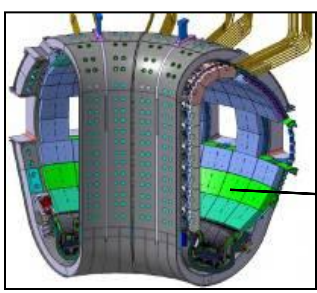
1 full replacement after 10 years
6 components/year (lower part)
3 components/year (others)

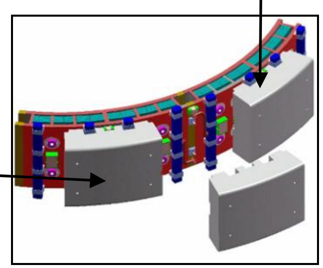
Maintenance duration

1 module : 6 weeks
1 toroidal array : 3 months (max 36 modules)
All modules: ~2 years



440 blanket modules
30 types | 4,5 tons | RH Class 1





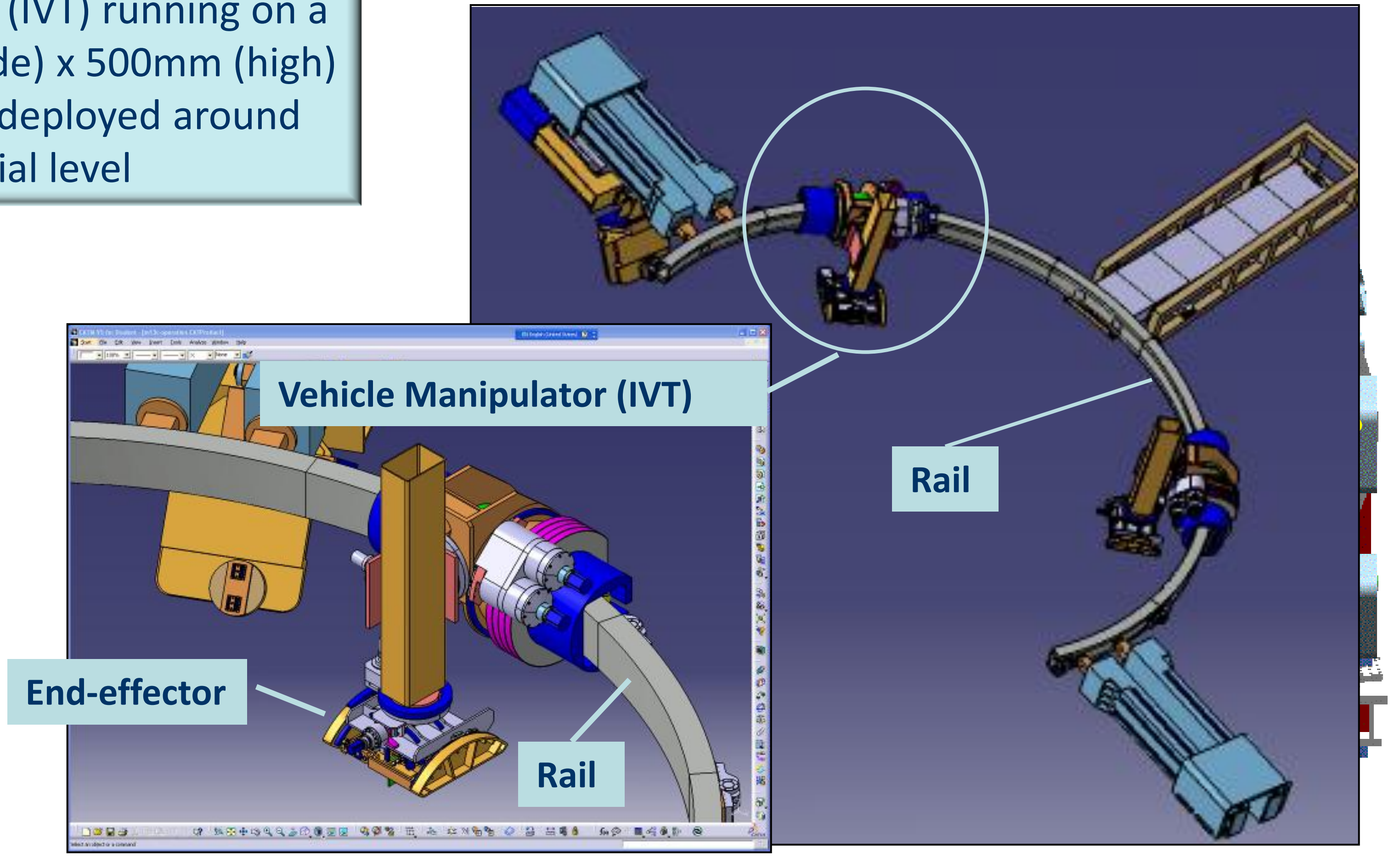
- Blanket modules
  - **plasma facing components**
  - provide **shielding from the high thermal loads** and the 14MeV neutrons produced by fusion reactions
- Remote maintenance
  - **Removal** from and **replacement** to the VV wall
  - **Transportation to HCB** for refurbishment (First Wall exchange) or disposal as radwaste
  - **Bolting/unbolting**
  - Cooling pipes **cutting**, **welding** and **weld inspection**

Blanket RH System | Equipment

Blanket modules are exchanged via an **In-Vessel Transporter** (IVT) running on a 250mm (wide) x 500mm (high) **passive rail** deployed around the equatorial level

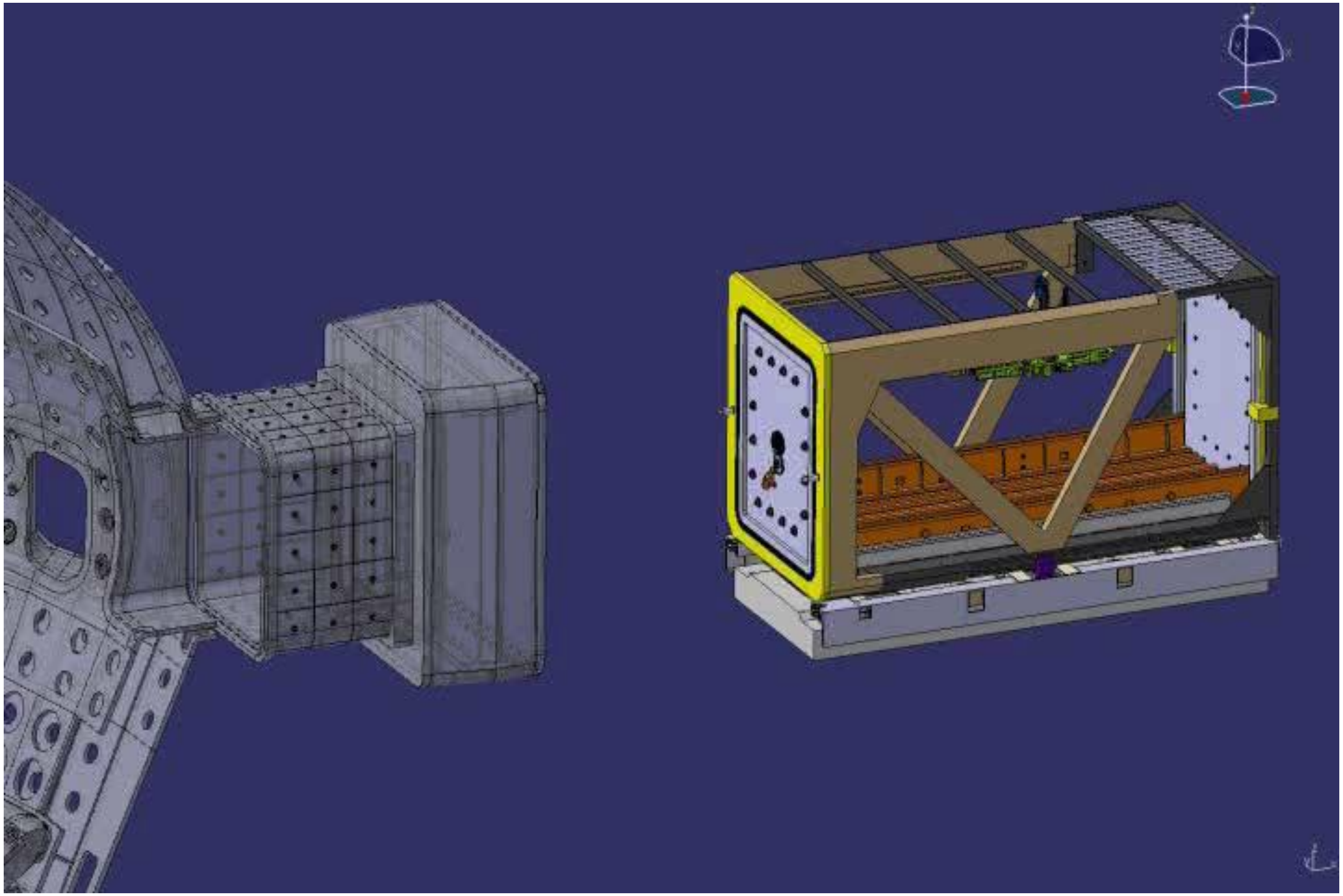
Rail supported through 3 VV ports

Deployment of rail in VV (covered by 180 degrees) with two IVTs



Blanket RH System

Rail deployment and extraction of one blanket module



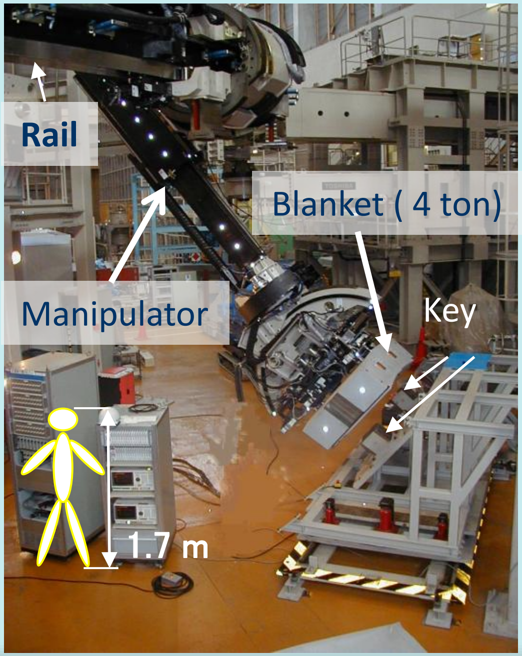
Two Transfer Cask Systems are required for this operation

Blanket RH System | Results

Blanket Handling Technology for High Positioning Accuracy

↓

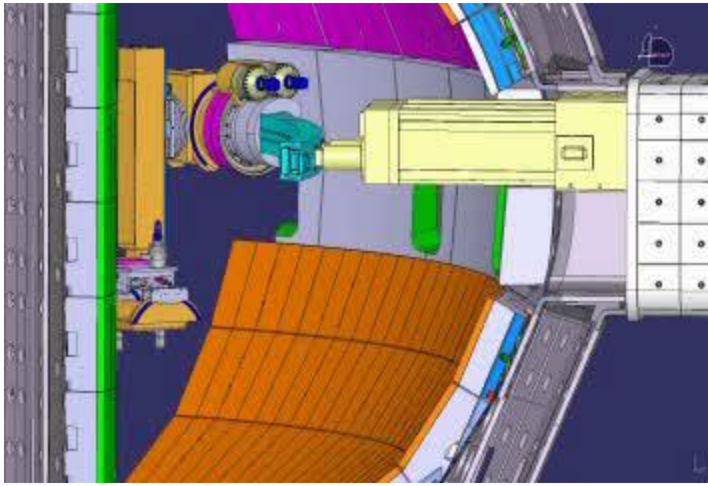
Deployment of Force Sensor



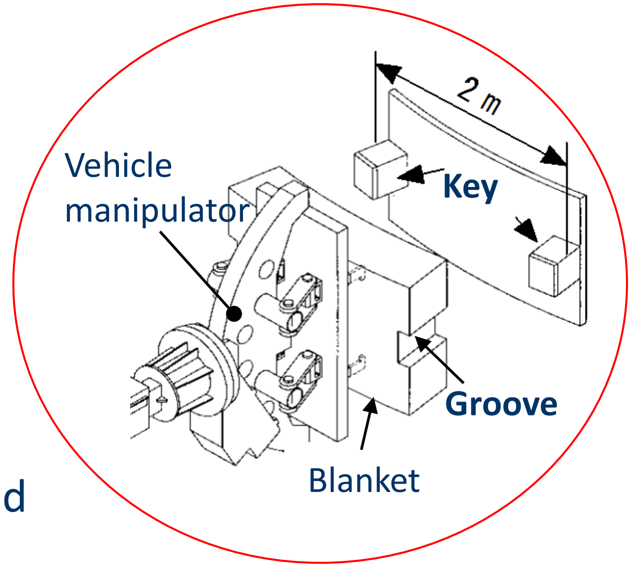
JAPT
Tokai
Japan

Final installation accuracy of Blanket Modules :

- less than 0.5 mm between keys and grooves



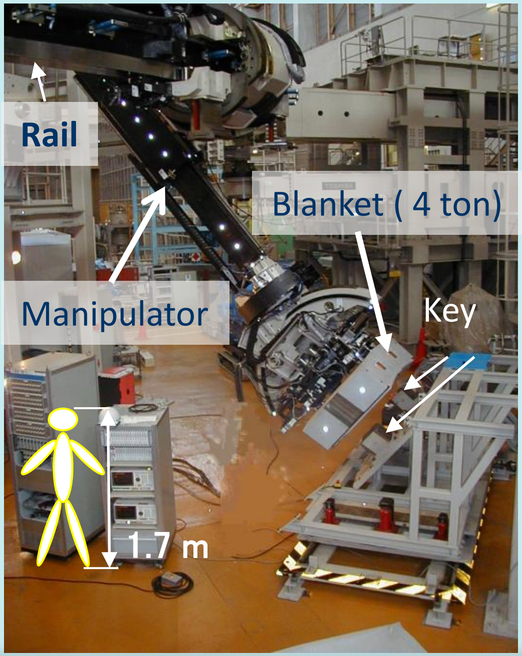
- Sensor-based control system:
  - Rough positioning through robot vision
  - Fine positioning through torque control and force measurements
- Required installation accuracy was demonstrated

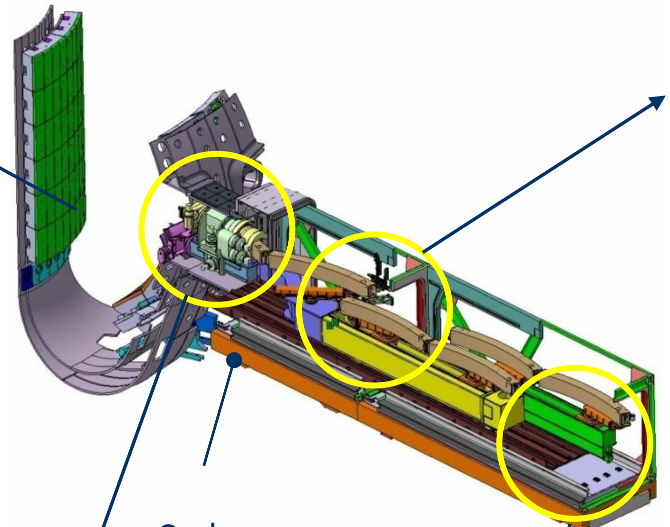


Blanket RH System | Results

Blanket Handling Technology for High Positioning Accuracy

Deployment of Force Sensor



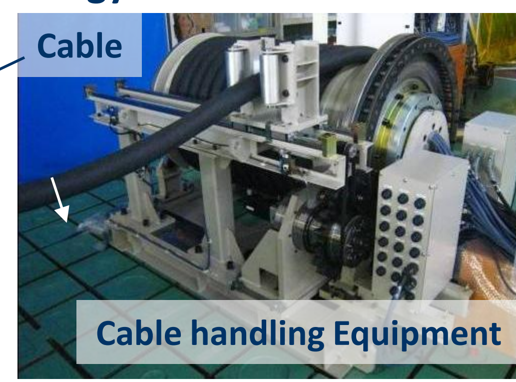


Rail Assembly Technology

Rail Connection/ disconnection Mechanism

Cable Handling Technology

Cross-section



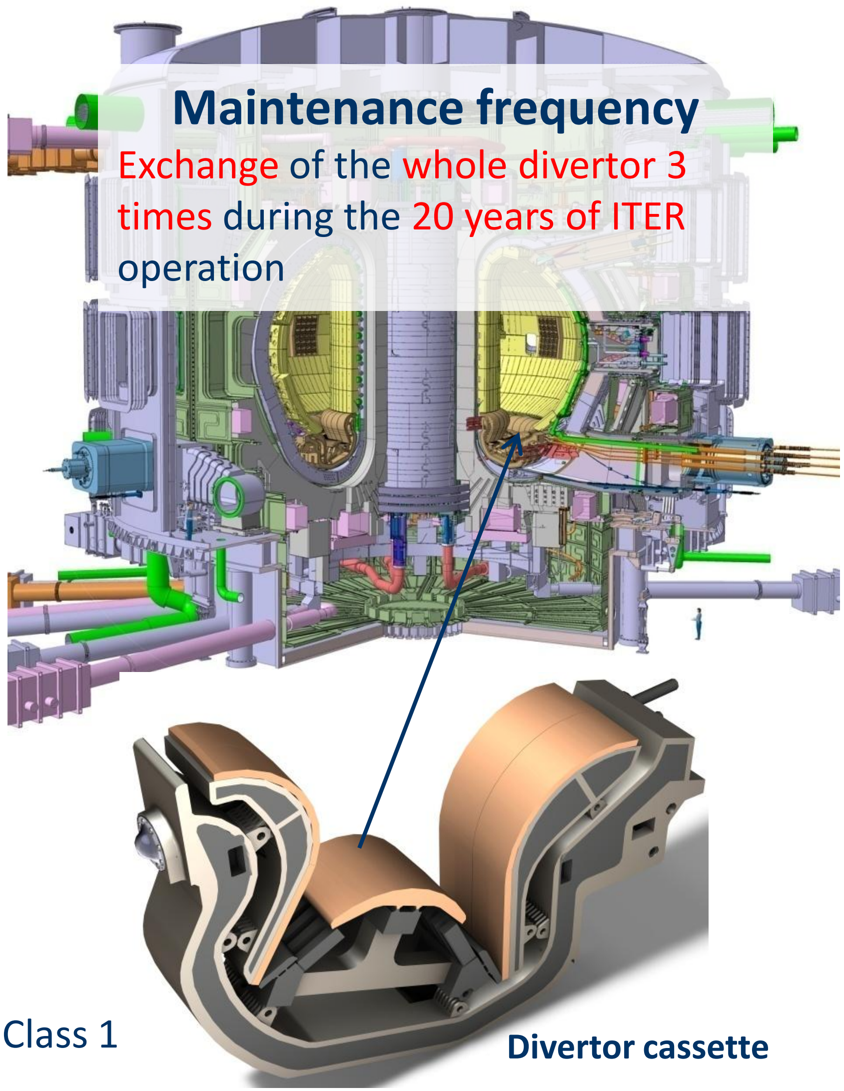
Cable handling Equipment

Dry Lubricant Technology using DLC (Diamond Like Carbon) for compatibility with the gamma irradiation

ITER Remote Handling Systems

- Blanket RH System
- Divertor RH Systems
- In-Vessel Viewing System
- Multi-Purpose Deployer
- Transfer Cask System
- Neutral Beam RH System
- Hot Cell RH System

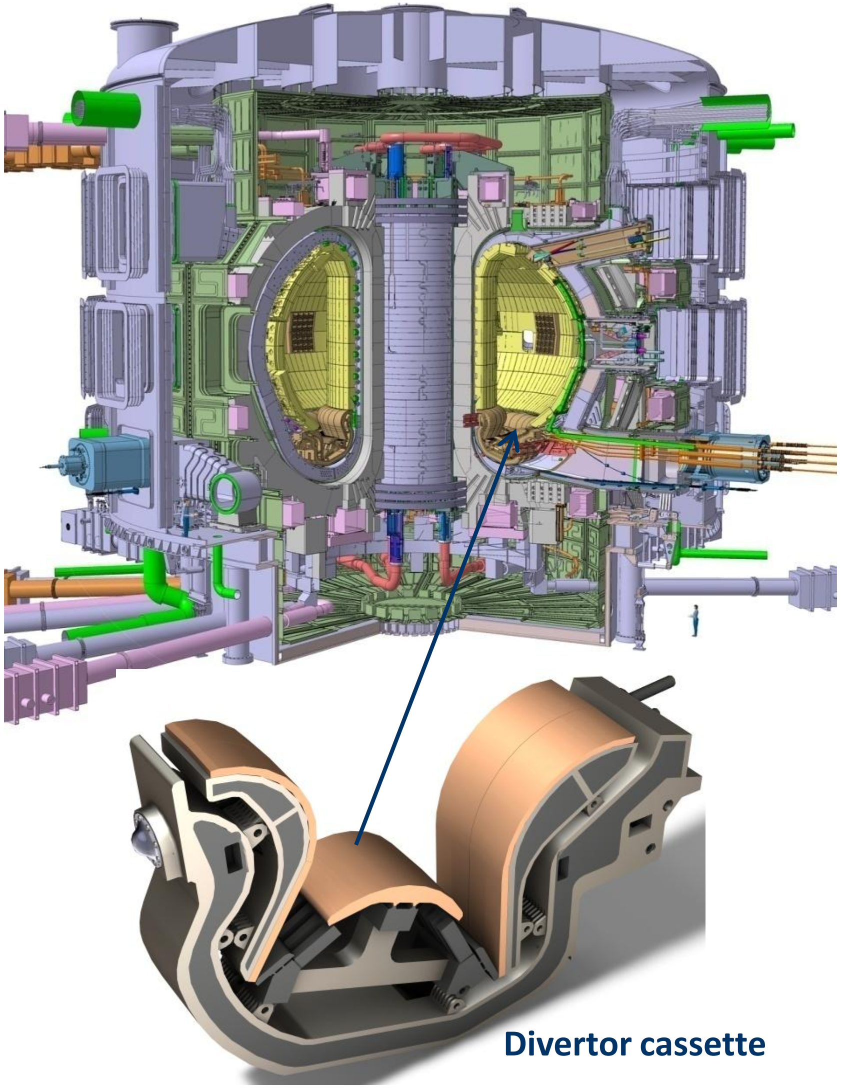
Divertor RH System

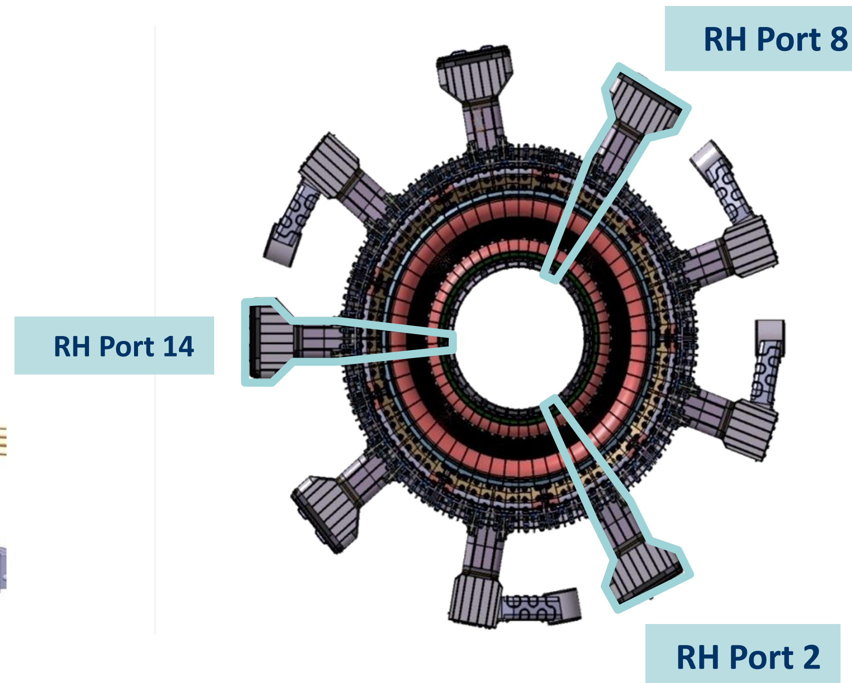


RH Class 1

- Lower part of ITER is fitted with 54 divertor cassettes
  - Dimensions 3.4 x 1.2 x 0.6 m
  - Weight up to 10 tons
- Divertor
  - extract heat and Helium ash and other impurities from the plasma.
  - sustains loads in the range of several MW/m^2
- Divertor cassettes are refurbished or disposed as radwaste at the HCB

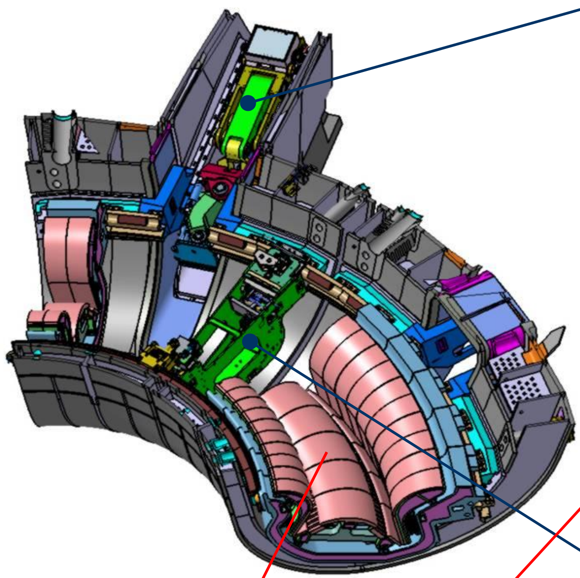
Divertor RH System





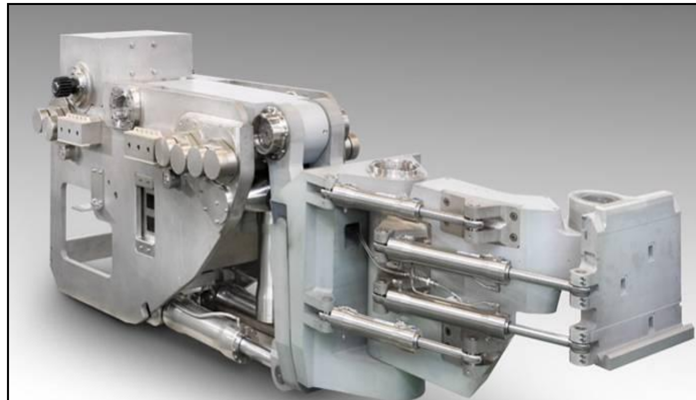
- **54 divertor cassettes**
- **18 divertor cassettes** are removed/installed **from each port**

Divertor RH System | Components



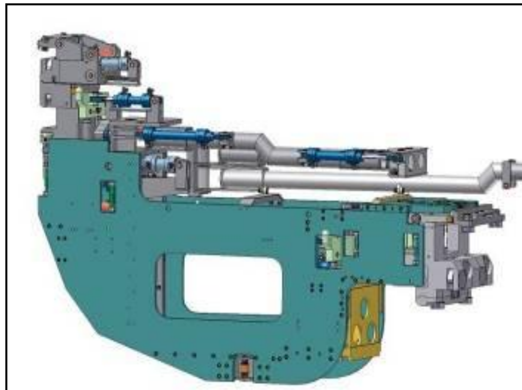
CMM

CTM



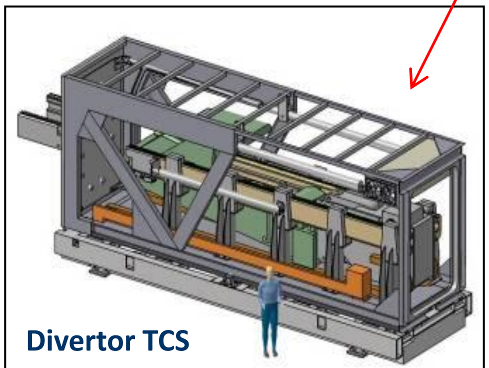
Cassette Multifunctional Mover (CMM)

Tractor **moving radially** along the port and equipped with 4 different end-effectors for cassette transportation



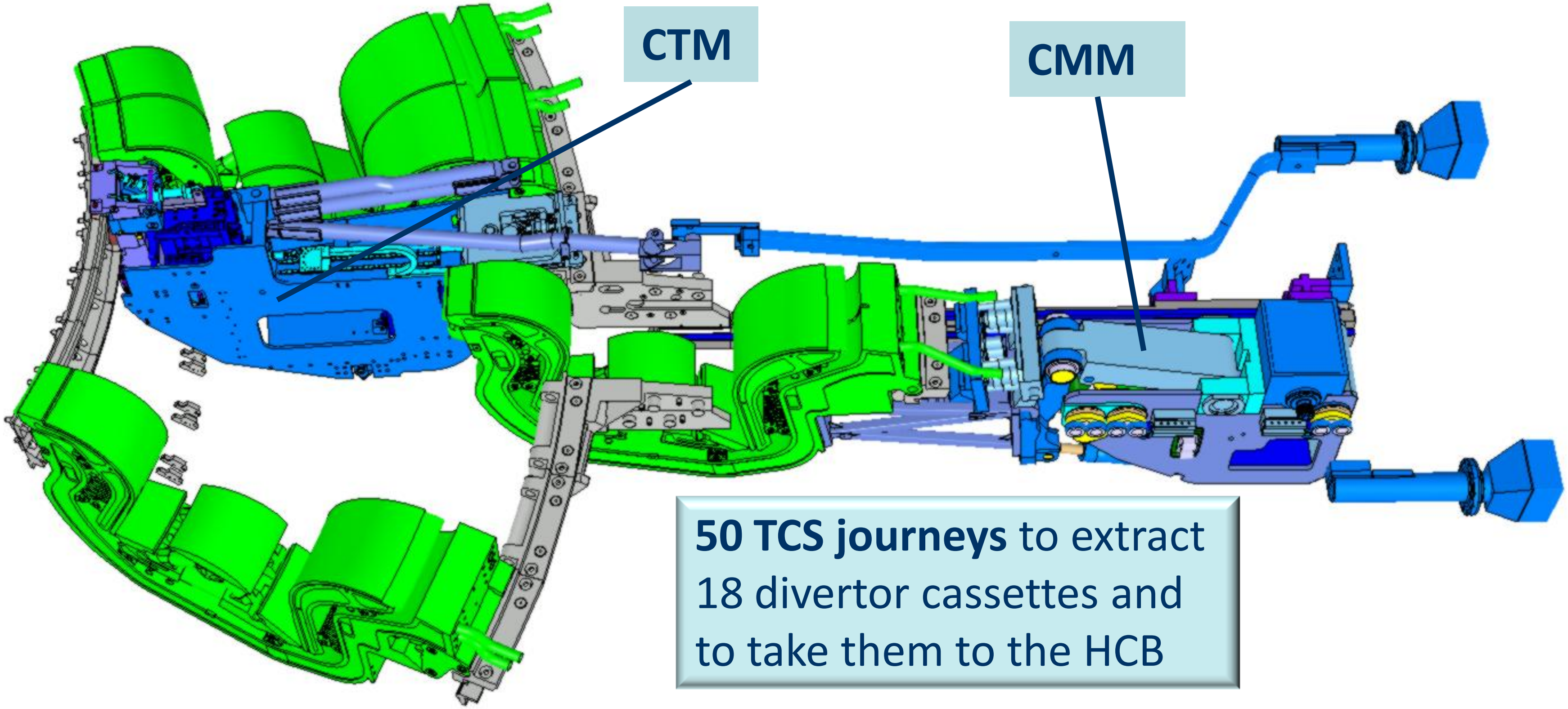
Cassette Toroidal Mover (CTM)

- Delivered into the VV by the CMM
- **Moves toroidally** to transport the cassettes from its location to the entry port
- 2 CTM (1 right-hand-side + 1 left-hand-side CTM

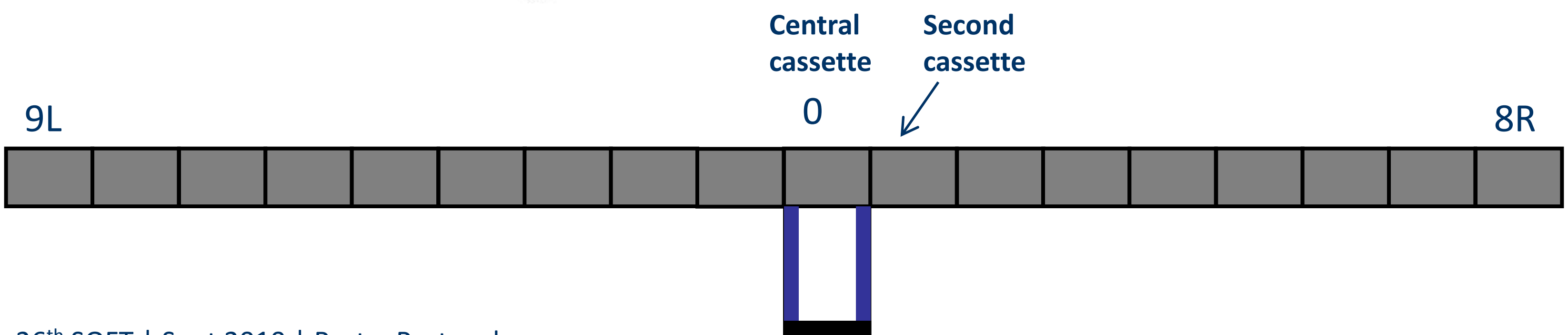


Divertor TCS

Divertor RH System | Cassette Extraction



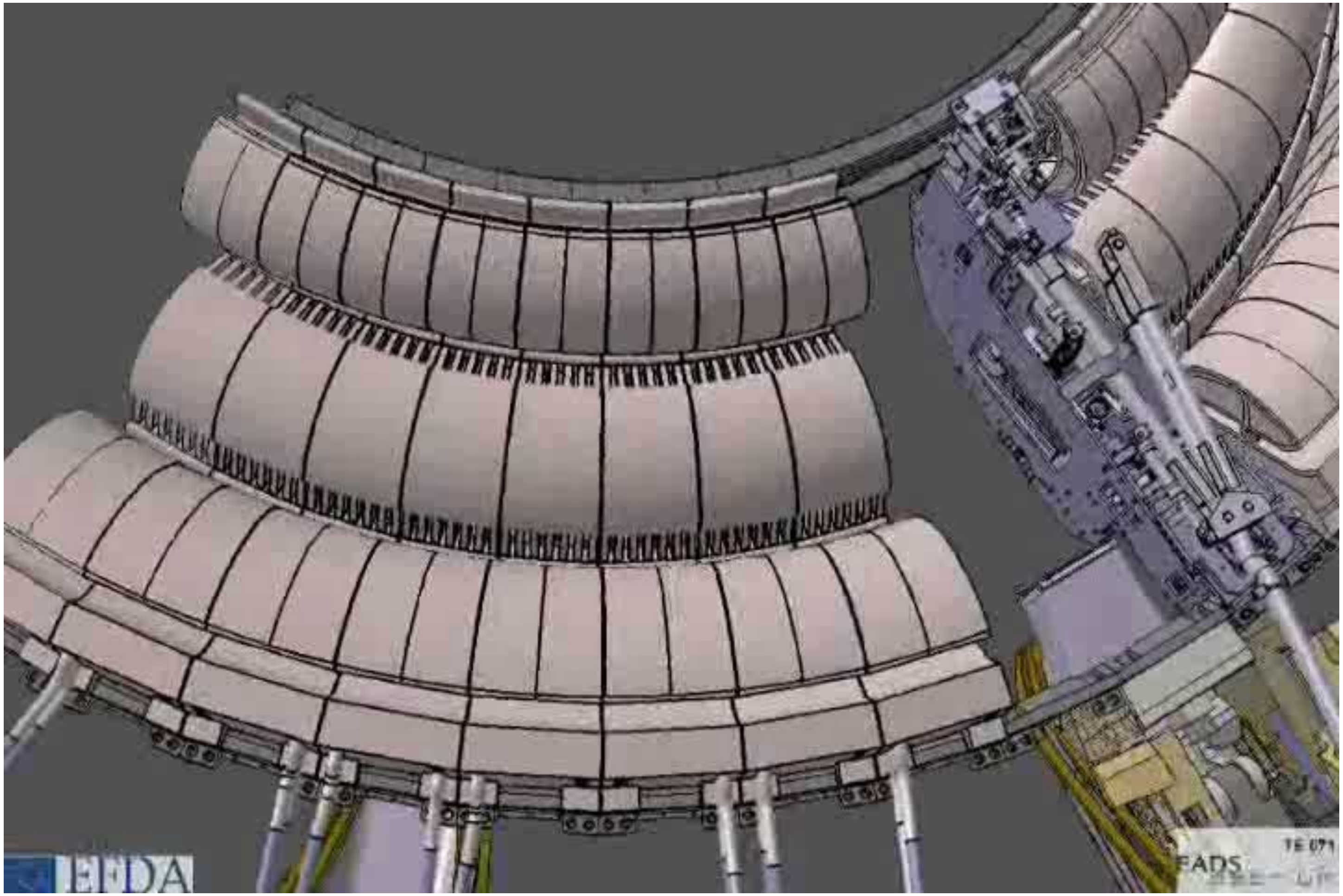
50 TCS journeys to extract 18 divertor cassettes and to take them to the HCB



Courtesy: C González

Divertor RH System

Extraction of standard cassette



Central cassette

Second cassette

Divertor Test Platform 2 (DTP2)

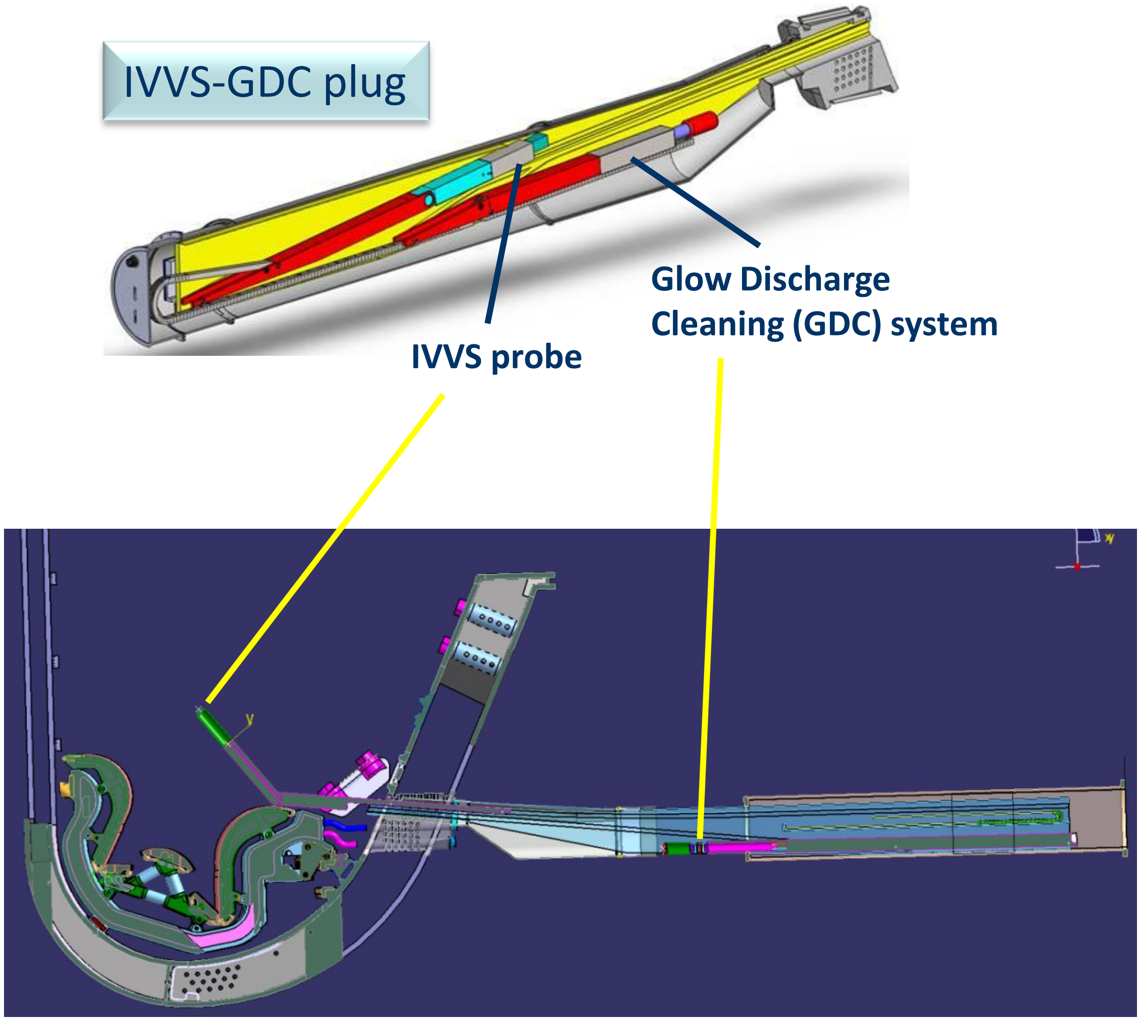
CMM | Divertor Cassette Instalattion

VTT Tampere Finland

ITER Remote Handling Systems

- Blanket RH System
- Divertor RH Systems
- In-Vessel Viewing System
- Multi-Purpose Deployer
- Transfer Cask System
- Neutral Beam RH System
- Hot Cell RH System

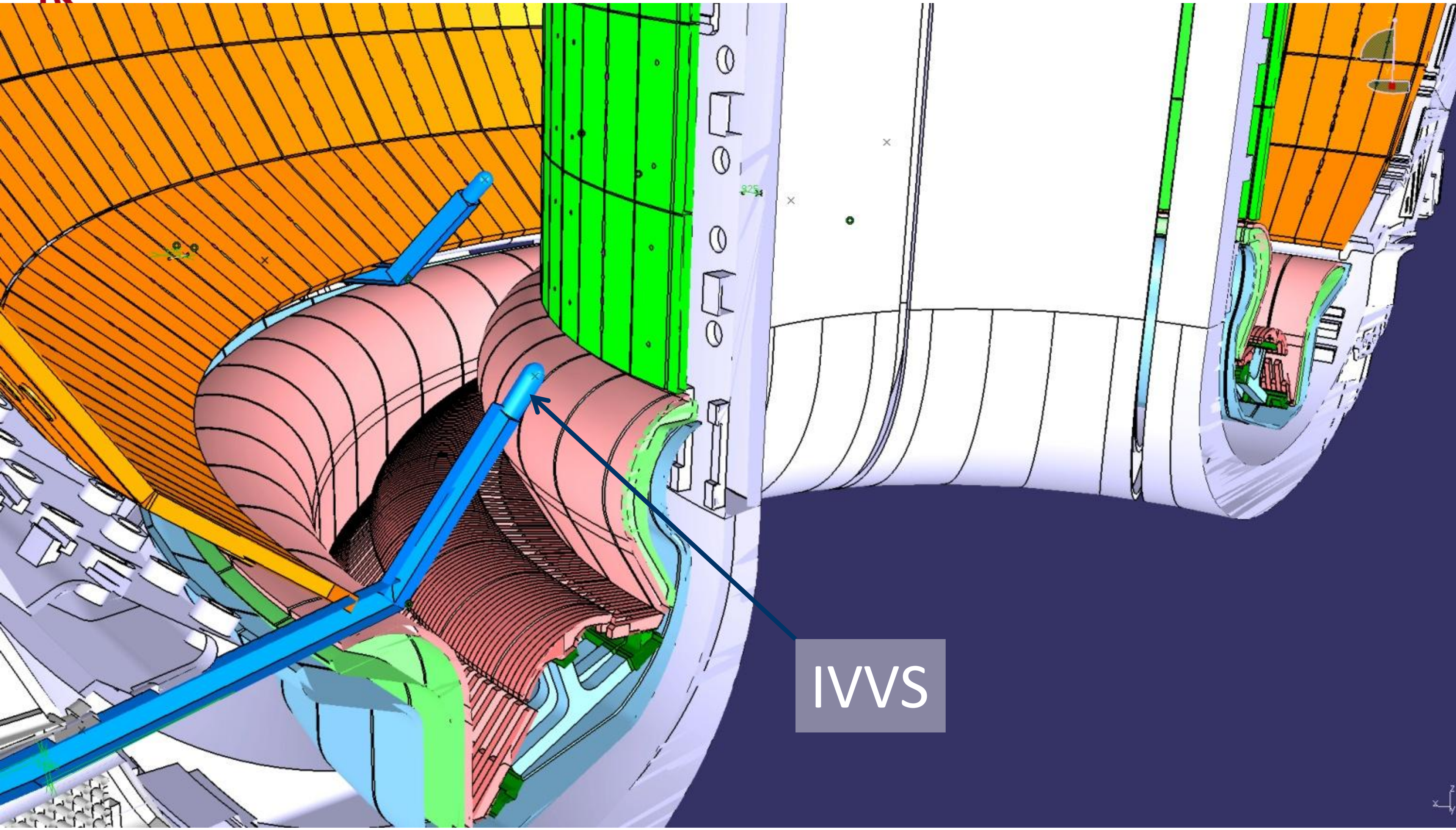
In-Vessel Viewing System | Where



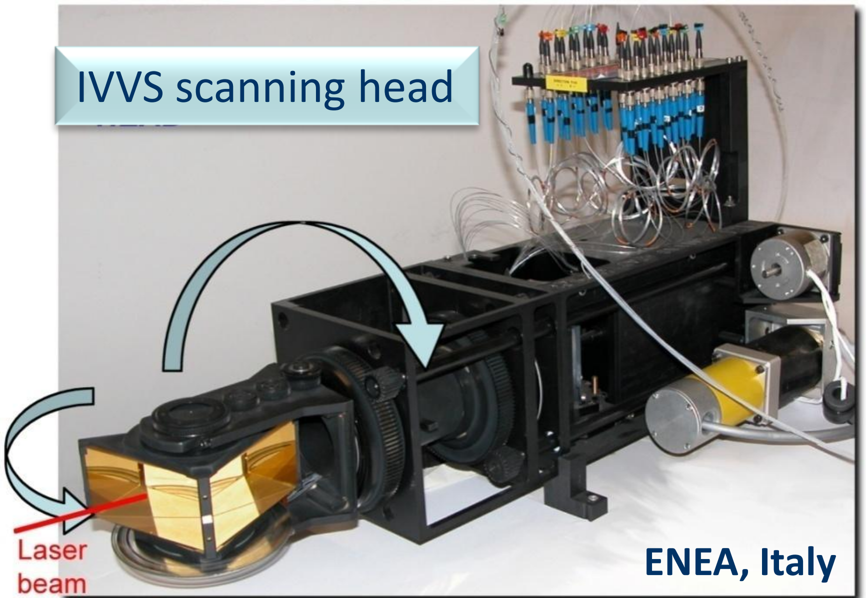
- In-vessel **inspection** (viewing and metrology) of plasma-facing surfaces (blanket, divertor, limiters) :
  - to look for **possible damage** occurred during plasma operations
  - To provide information in support of scheduled or unscheduled **maintenance** activities

- Visual Inspection per ITER sector: < 2 hrs
- 3D survey per ITER sector: < 8 hrs

In-Vessel Viewing System (IVVS) | Purpose



In-Vessel Viewing System | Mock-up



- Viewing and metrology system
- Amplitude modulated laser radar concept
- Sub-milimetric, real 3D data (viewing + metrology)

Target specifications

- Metrology accuracy: 0.5mm @ 5m
- Viewing spatial resolution
  - ≤ 1mm @ 0.5m-4m
  - ≤ 3mm @ up to 10m
  - Self-illumination (no external light source)

Environmental conditions

- Pressure in Ultra High Vaccuum conditions
- High temperature ≤ 240º
- Gamma Radiation dose rate up to 5KGy/hour
- Total radiation dose up to 10MGy
- Total neutron fluence up to 5 10^{13} n/cm^2
- Magnetic field up to 8 Tesla

In-Vessel Viewing System | Results

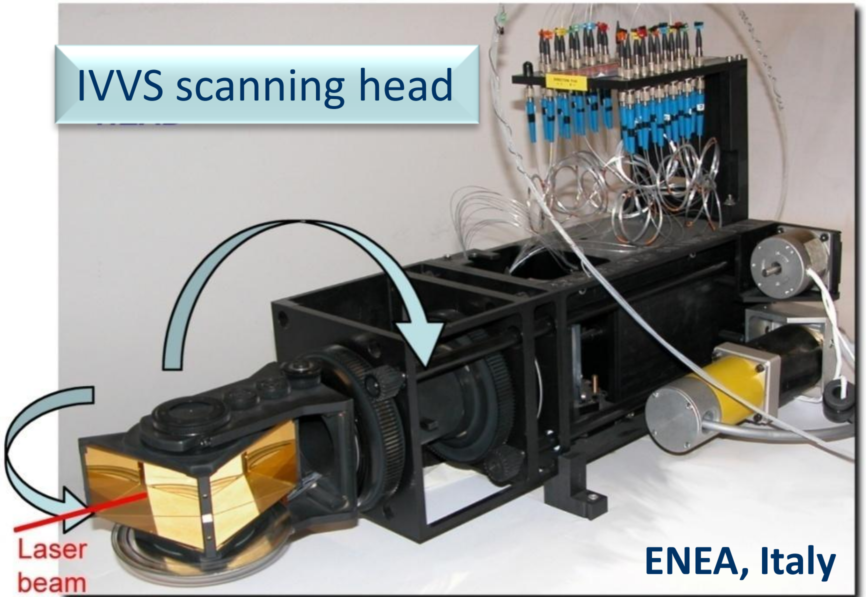
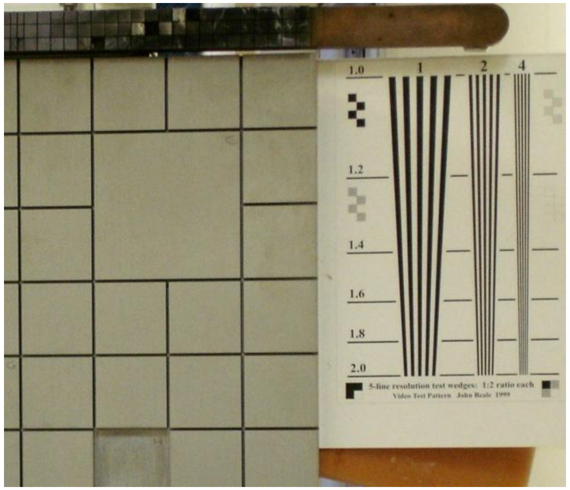
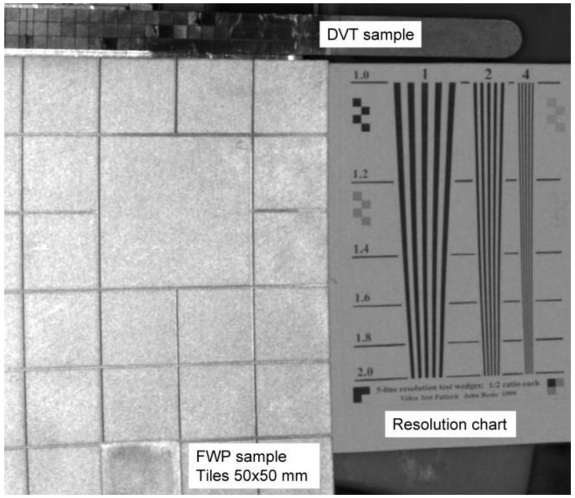


image from camera



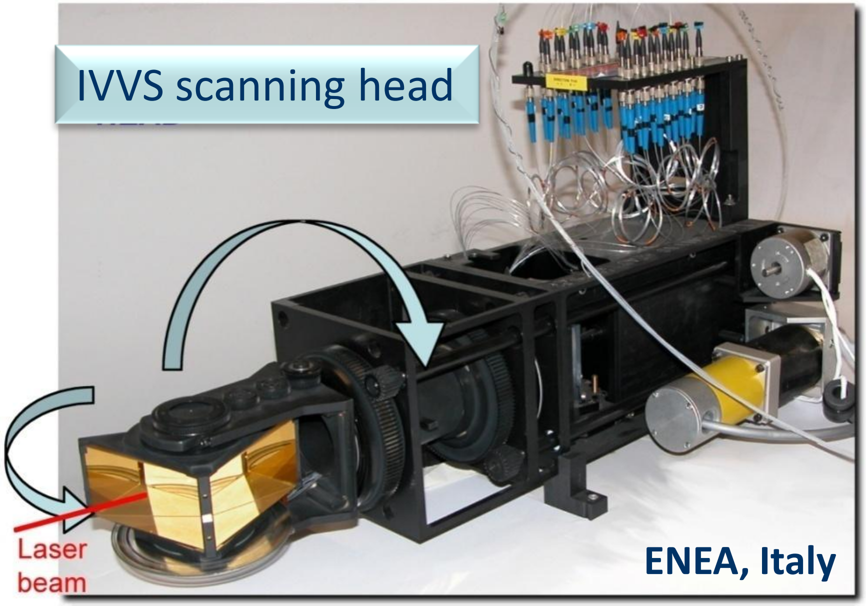
IVVS viewing



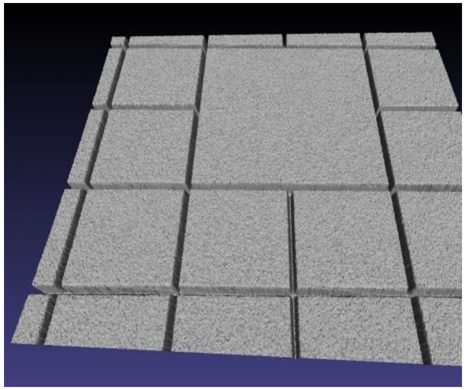
Target specifications

- Metrology accuracy: 0.5mm @ 5m
- Viewing spatial resolution
  - ≤ 1mm @ 0.5m-4m
  - ≤ 3mm @ up to 10m
  - Self-illumination (no external light source)

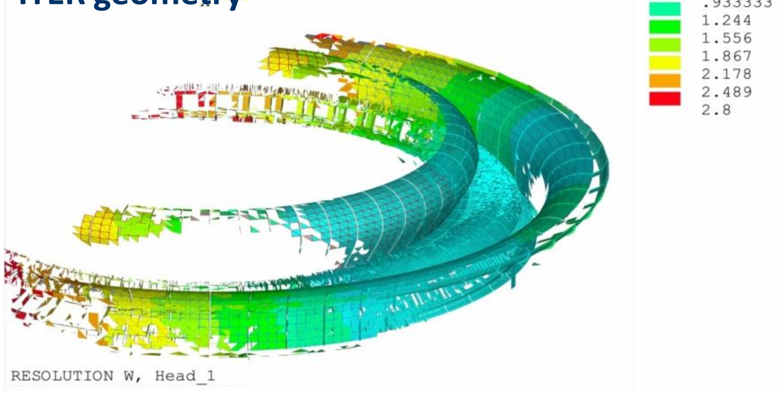
In-Vessel Viewing System | Results



3D image produced with IVVS data on a first wall panel mock-up



Resolution map obtained on divertor ITER geometry



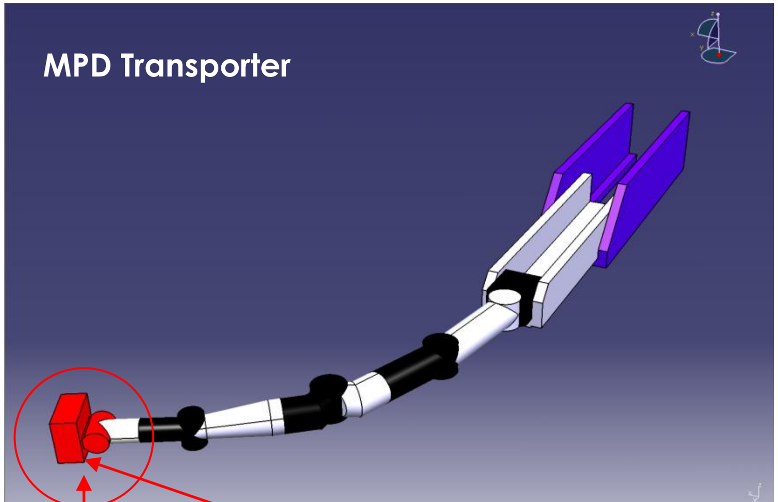
Other on-going activities

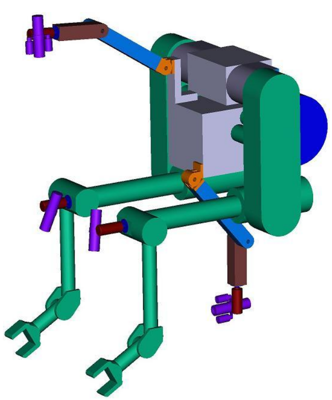
- Study on vibration effects on IVVS images and **vibration correction** method
- **Conceptual design** of an IVVS probe compliant with the ITER environmental conditions
- Preliminary study of an **IVVS plug test facility**

ITER Remote Handling Systems

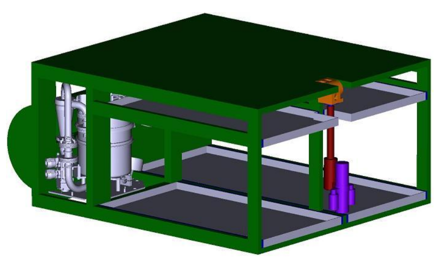
- Blanket RH System
- Divertor RH Systems
- In-Vessel Viewing System
- Multi-Purpose Deployer
- Transfer Cask System
- Neutral Beam RH System
- Hot Cell RH System

Multi-Purpose Deployer (MPD) | Purpose





Manipulator

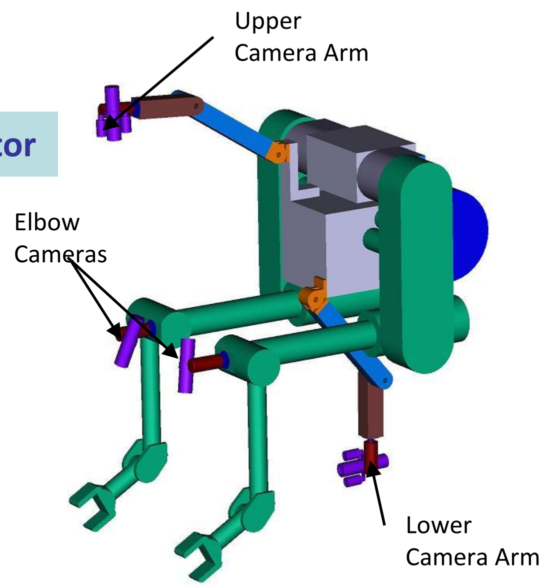


Task Module

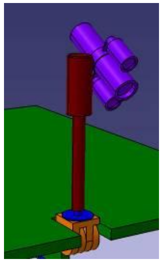
- In-vessel maintenance tasks
  - Dust accumulation monitoring and removal 16 months
  - Tritium inventory monitoring
  - VV inspection 16 months
  - VV leak identification 40 months
  - VV diagnostics maintenance (calibration, alignment, inspection, replacement, cleaning) 16 months
  - Assistive and contingent RH operations
- Various frequencies of operation

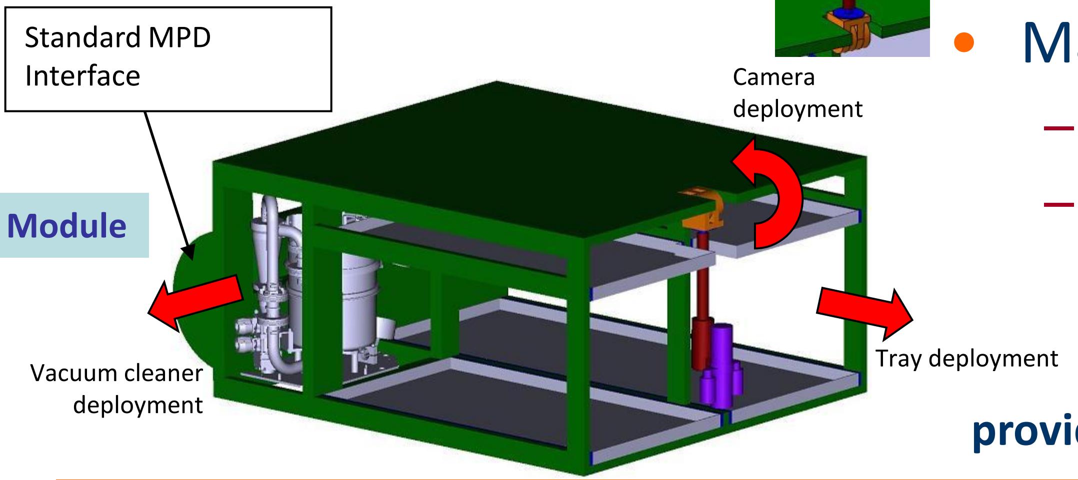
Multi-Purpose Deployer | Components

MPD Manipulator



Task Module



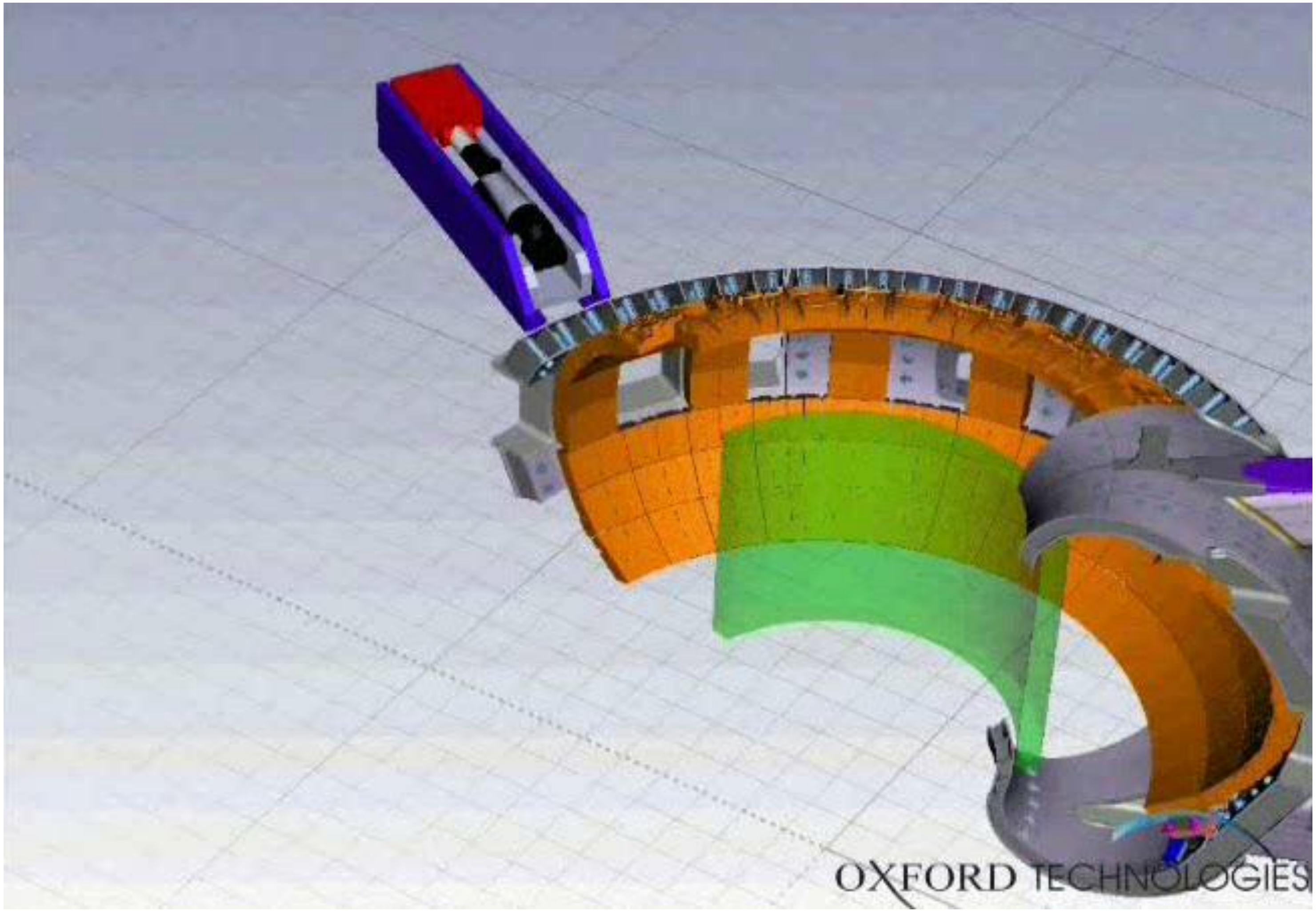


- Deployment from:
  - Main IVT and intermediate IVT TCS
  - through 4 IVT entry ports (Nº 3,8,12, 17) at equatorial level
- Reach over a segment of VV of ± 50º
- Payload capacity 2.0 tons
- Maxium Point of reference
  - Speed 100mm/s
  - Positional accuracy ± 10mm

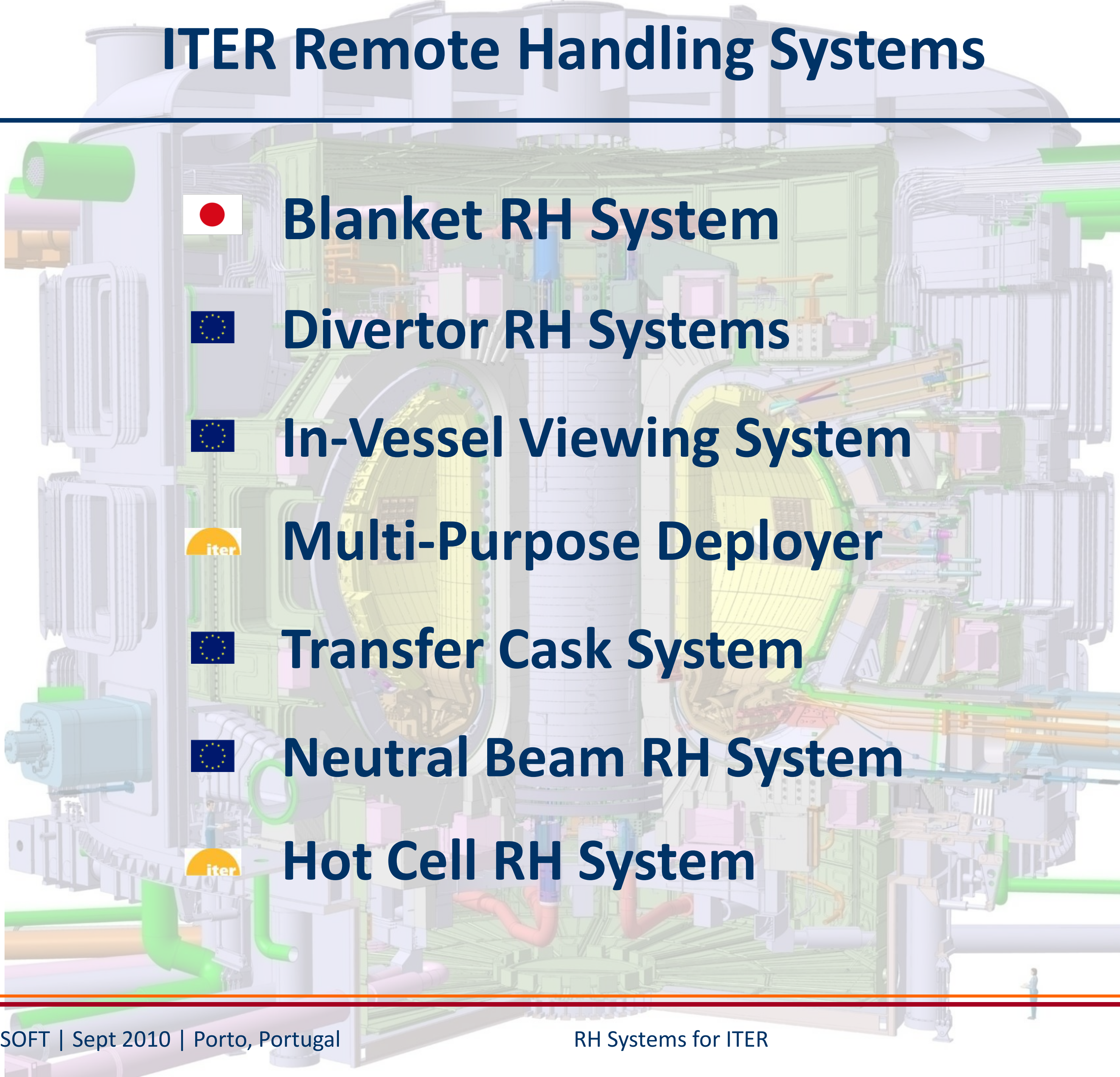
provides tools anywhere in the VV

Multi-Purpose Deployer (MPD)

Collaborative work of two MPDs

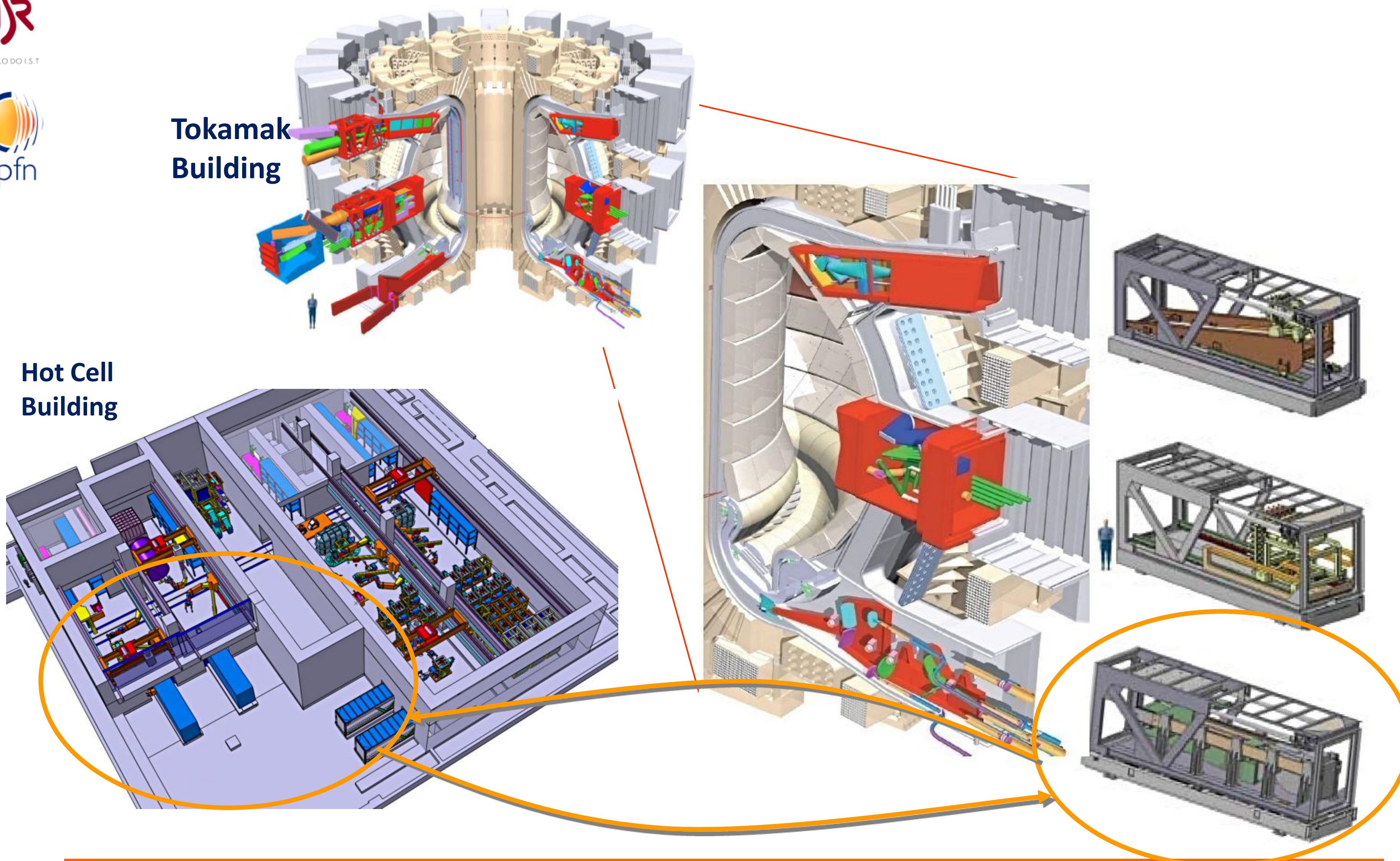


ITER Remote Handling Systems

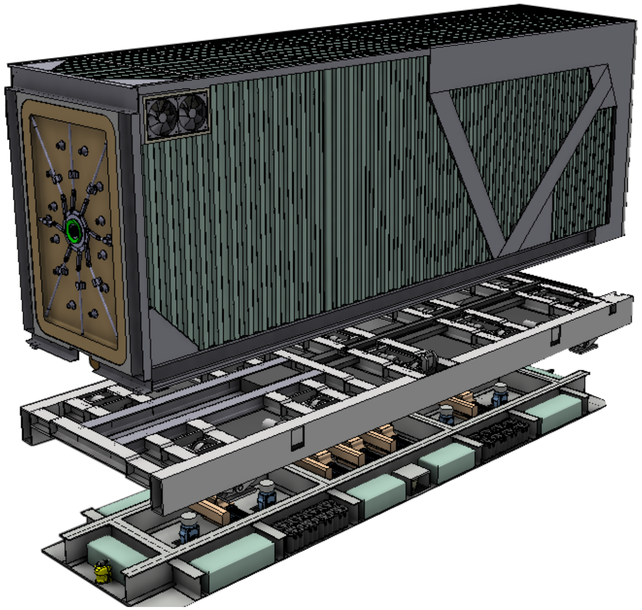


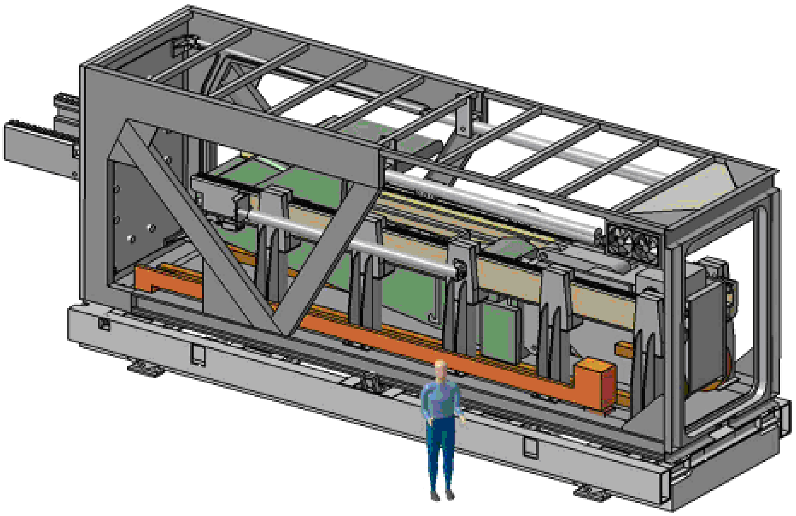
- Blanket RH System
- Divertor RH Systems
- In-Vessel Viewing System
- Multi-Purpose Deployer
- Transfer Cask System
- Neutral Beam RH System
- Hot Cell RH System

Transfer Cask System (TCS)



Transfer Cask Systems (TCS)





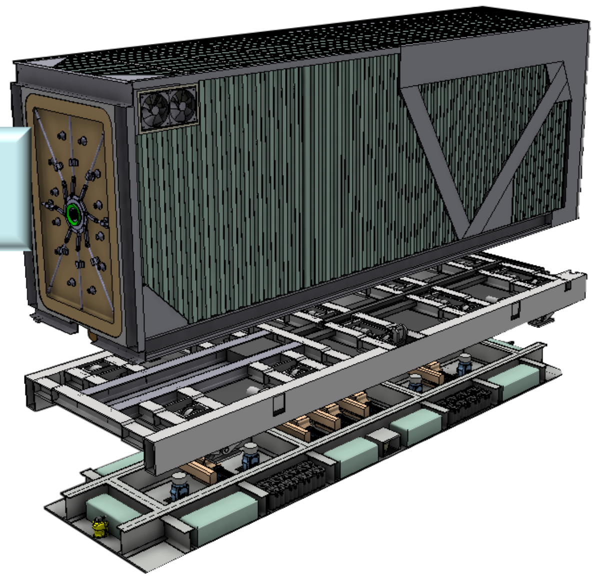
- **Transportation** of heavy loads (max 45 tons) and highly activated components
  - Divertor cassettes, blanket modules, heating and diagnostic plugs, cryopumps, IVVS probes, in-cask equipment and handling tools
  - From/to the VV port cells in TB to/from HCB
- TCS **max weight at full load (100 tons)**
- TCS itself has no radiation shielding capabilities

TCS has to be **remotely operated** withouth hands-on assistance

Transfer Cask System (TCS) | components

Cask Envelope

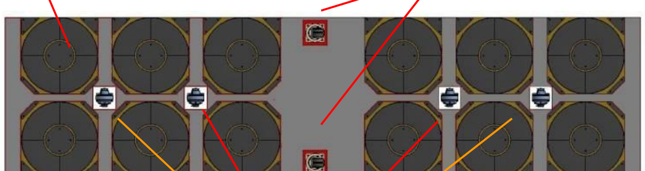
Pallet



ATS=Air Transfer System

air casters

swivel wheels



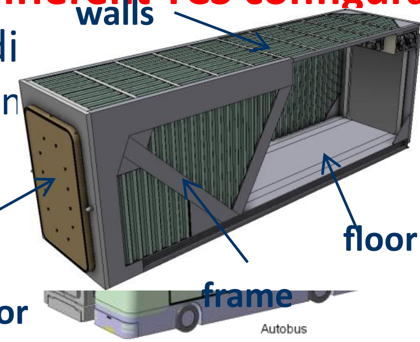
drive/steering wheels

Cask envelope

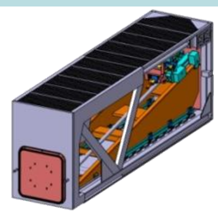
different TCS configurations

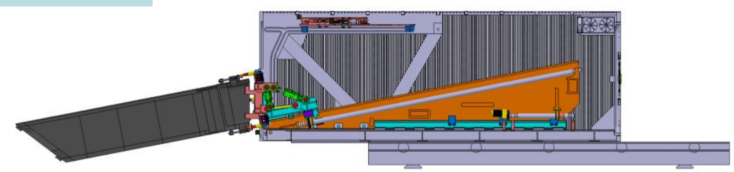
di

8.5m (len … .62 (height)

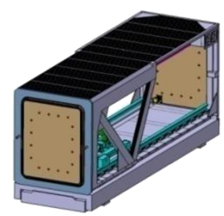


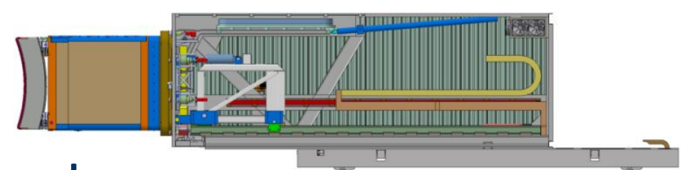
In-cask equipment



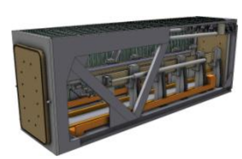


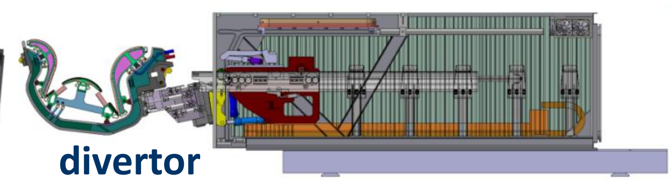
upper plug





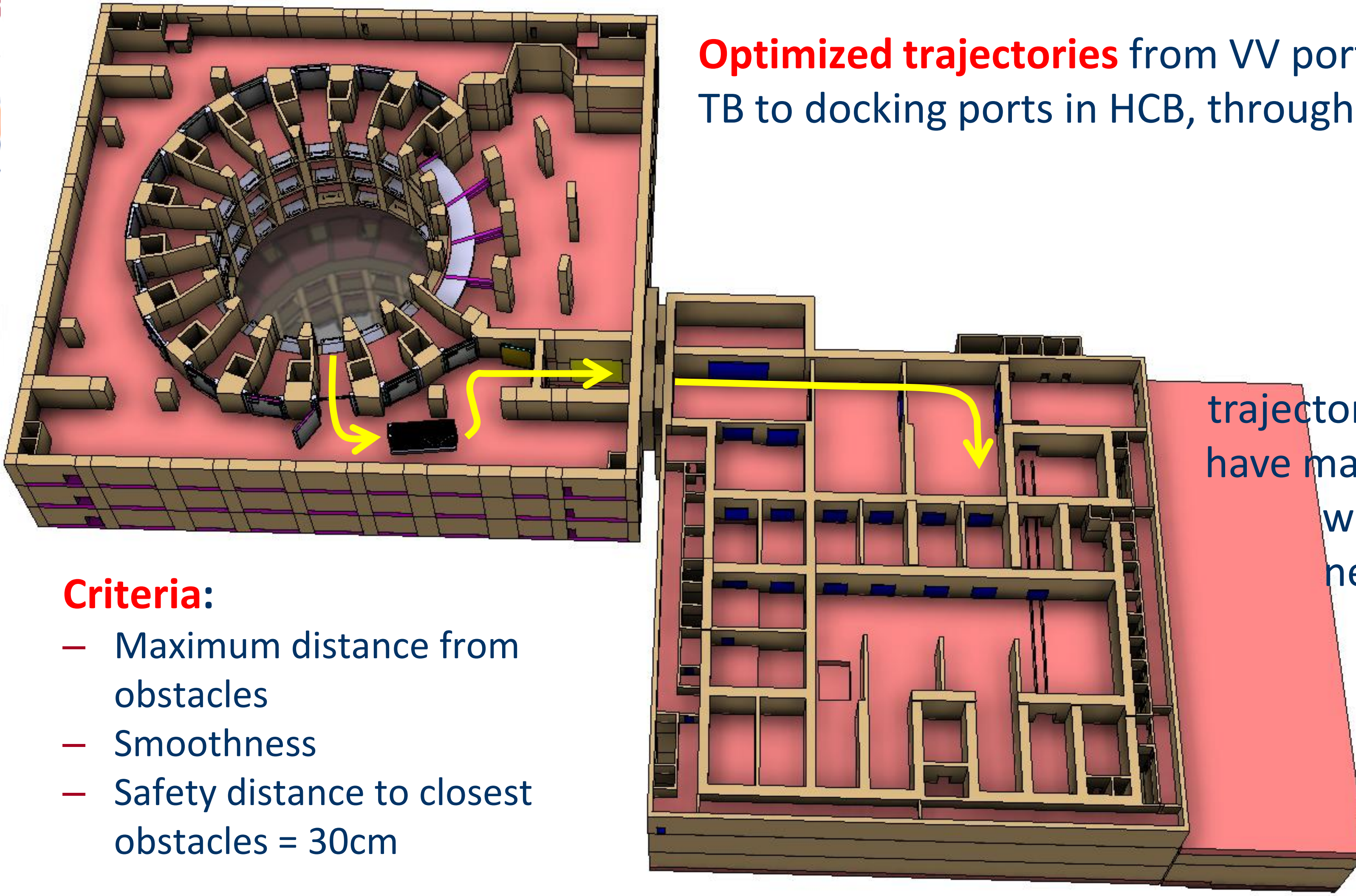
eq plug





divertor

Transfer Cask System (TCS) | Trajectories



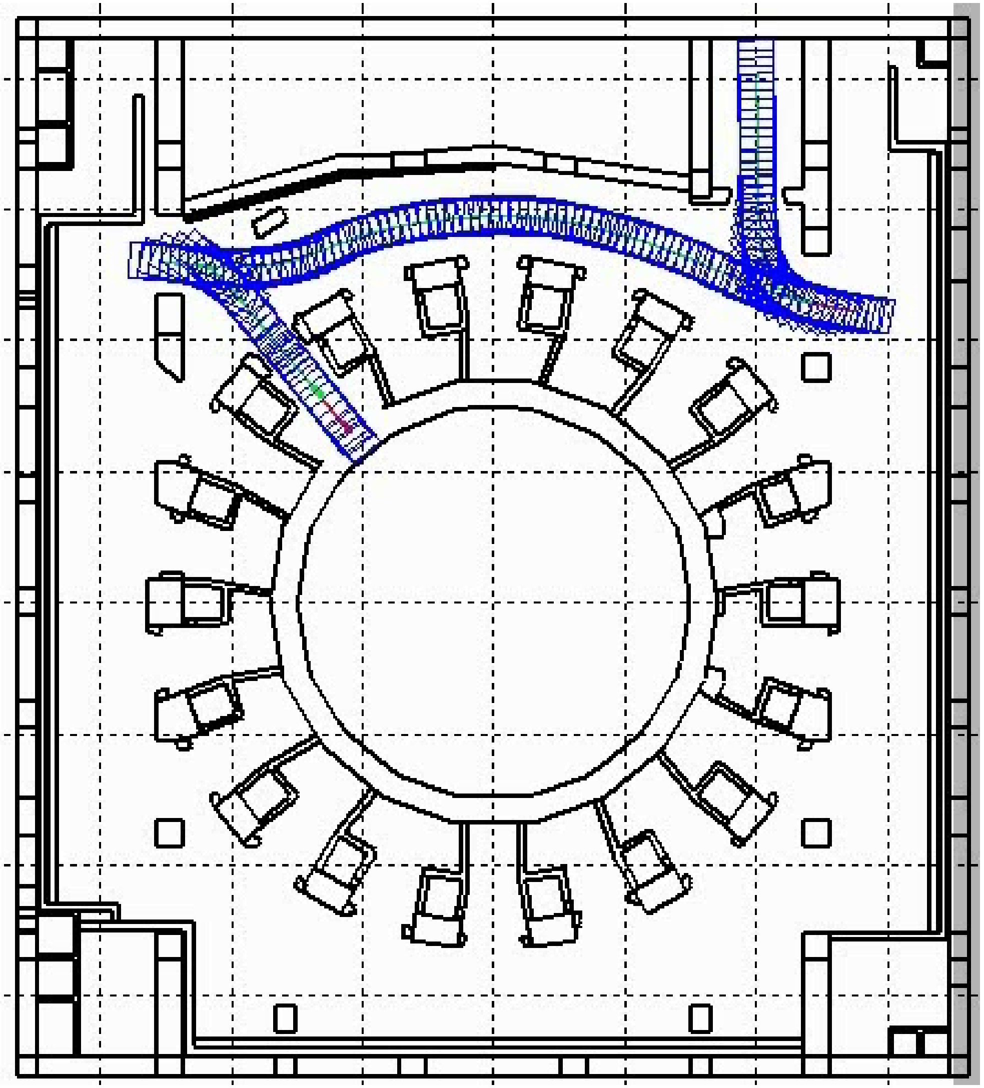
Optimized trajectories from VV port cells in TB to docking ports in HCB, through the lift

trajectories may have maneuvers whenever necessary

Criteria:

– Maximum distance from obstacles
– Smoothness
– Safety distance to closest obstacles = 30cm

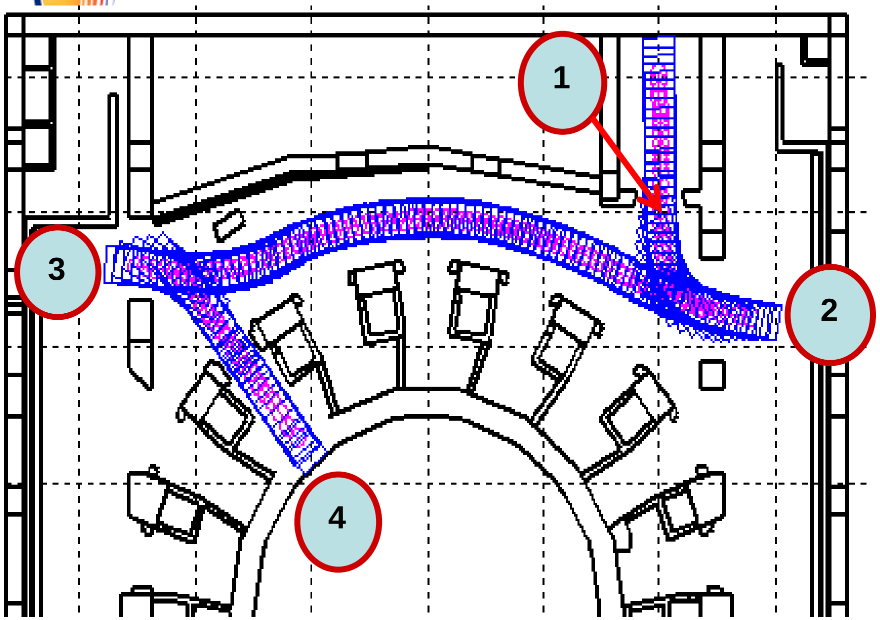
Transfer Cask System (TCS) | trajectories



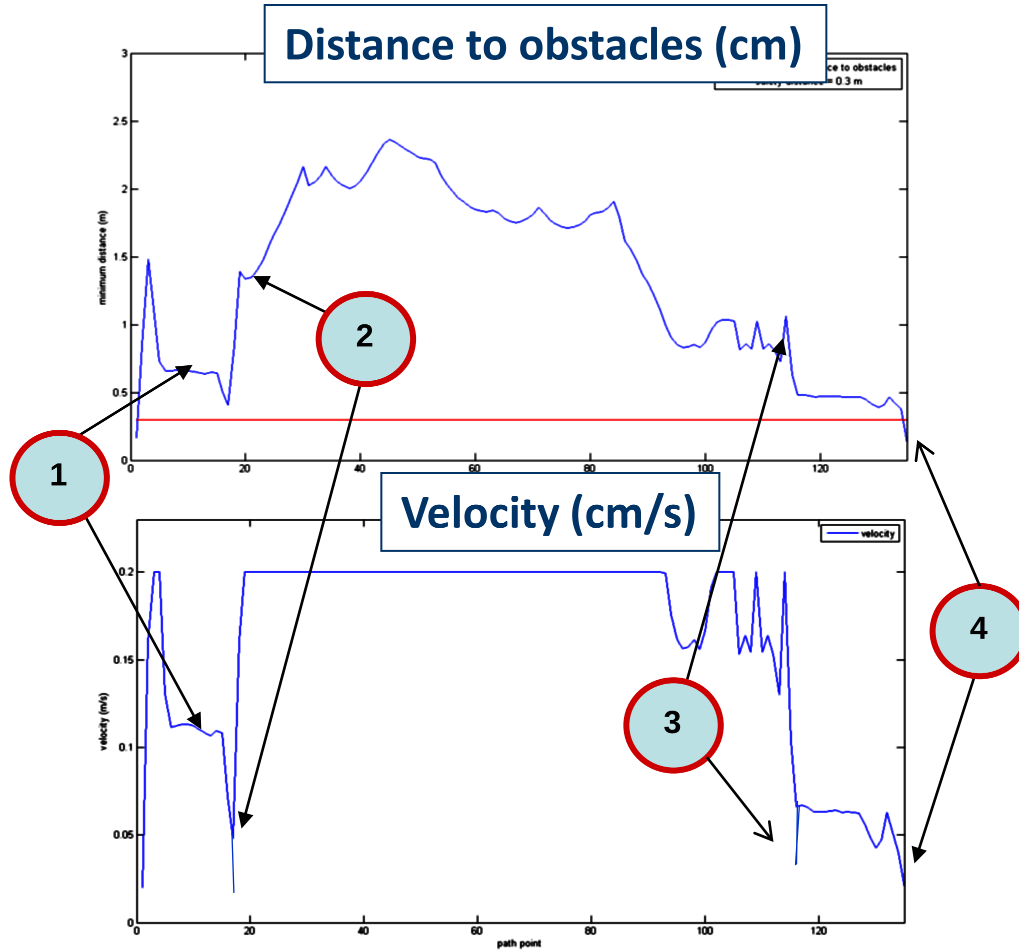
TB Divertor Level from lift to VV port # 7

IST

Transfer Cask System (TCS) | trajectories



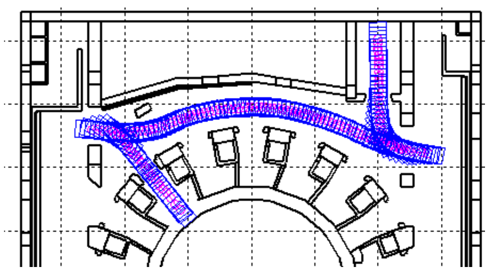
TB Divertor Level from lift to VV port # 7

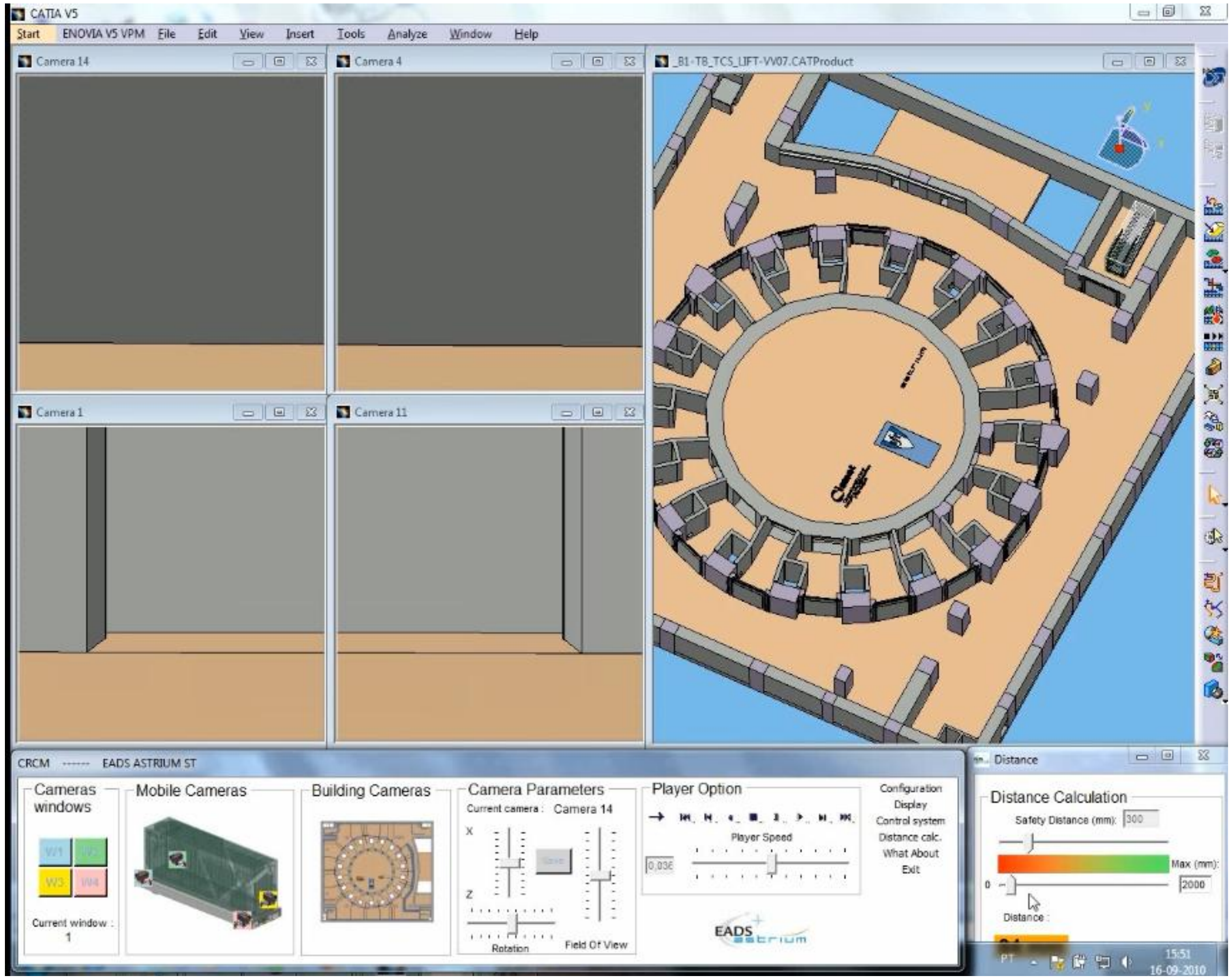


IST

Transfer Cask System (TCS) | VR model

3D Virtual Reality model, with HMI functionalities
- TCS operating mode
- Virtual cameras (in TCS and environment)

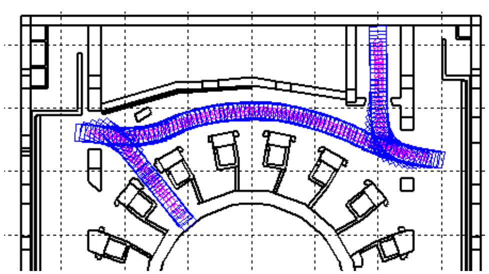


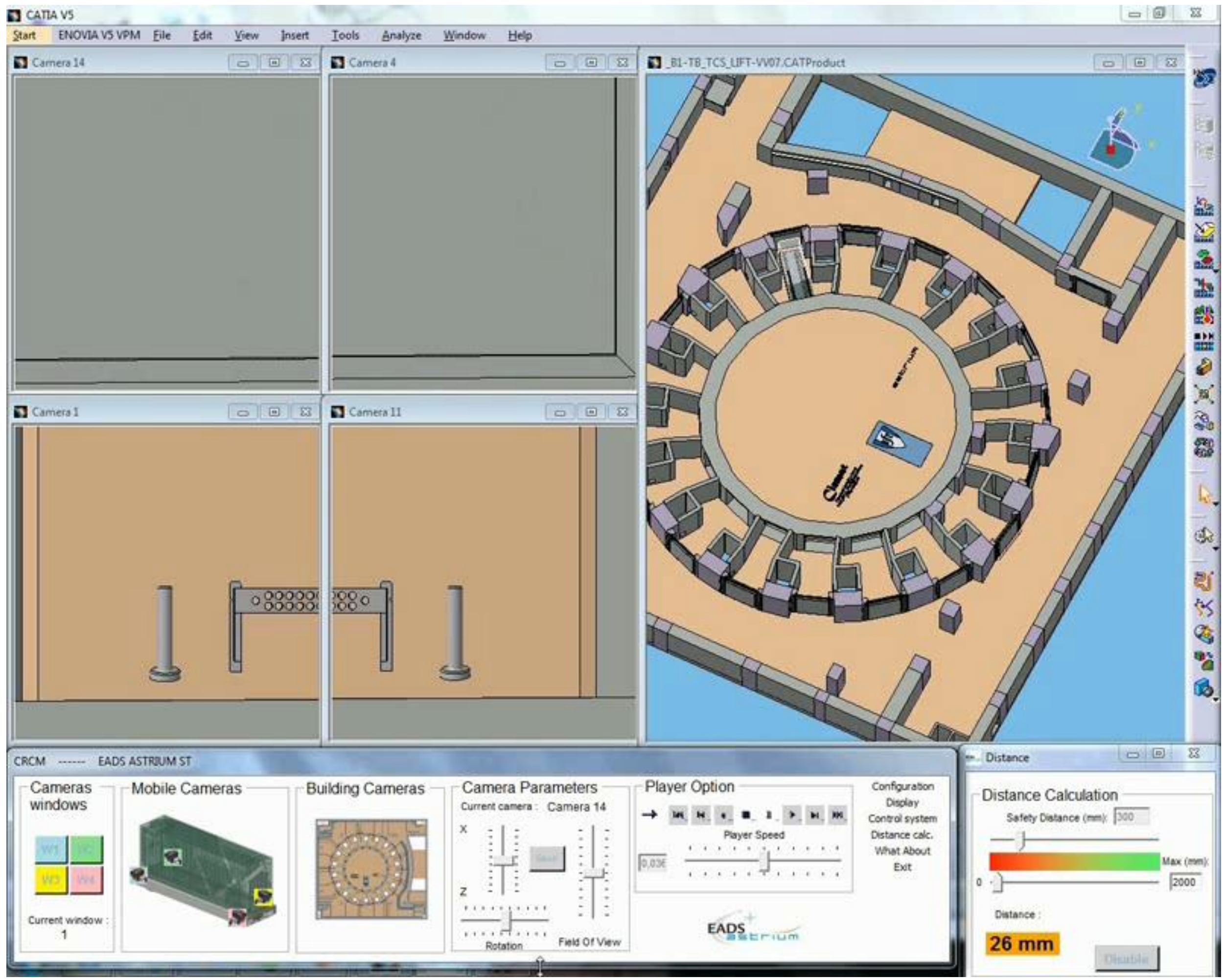


EADS, Astrium

Transfer Cask System (TCS) | VR model

3D Virtual Reality model, with HMI functionalities
- TCS operating mode
- Virtual cameras (in TCS and environment)

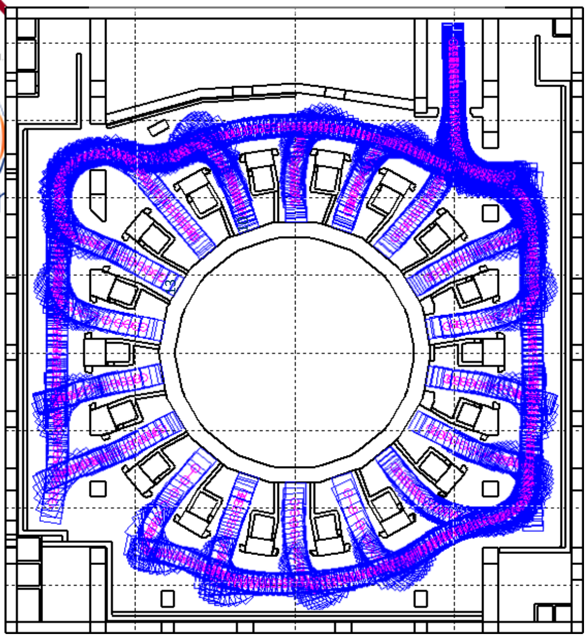




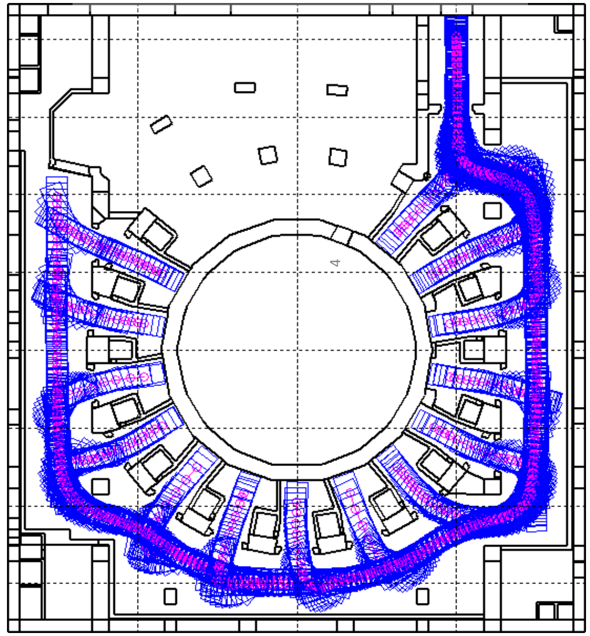
EADS, Astrium

Transfer Cask System (TCS) | trajectories

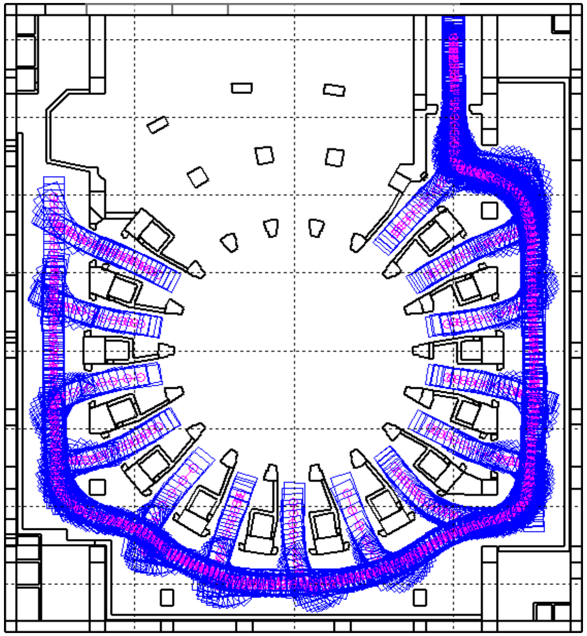
Divertor level @TB

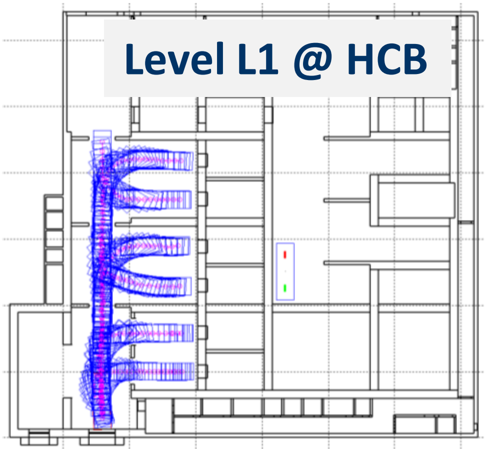


Equatorial level @TB



Upper level @TB



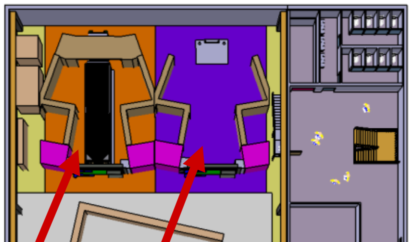


IST

- 63 trajectories were evaluated
- recommendations were made to modify the building design

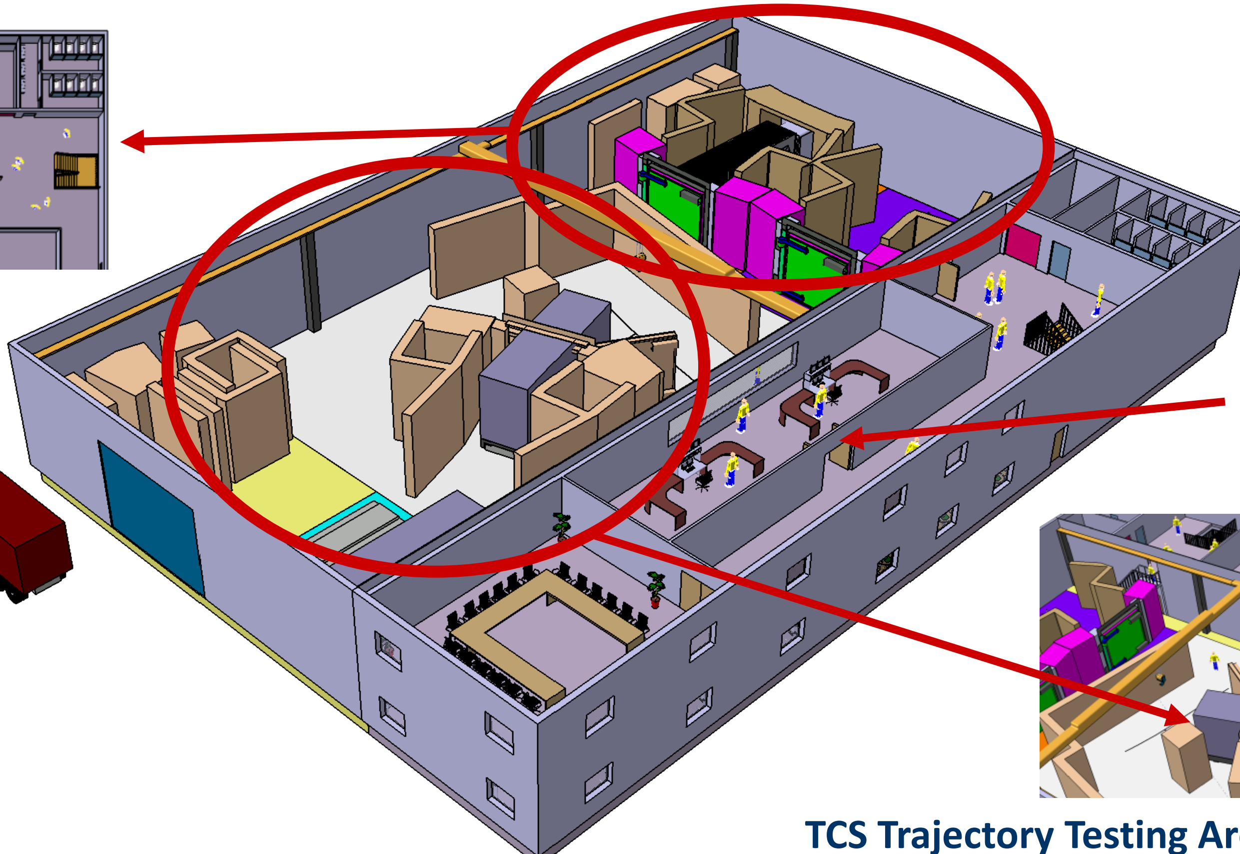
Transfer Cask Systems (TCS) | Test facility

- TCS operation is RH class 1 or 2 operation
  - Design and test of the TCS require a full scale prototyping
- Test facility: 1200 m2, three main areas

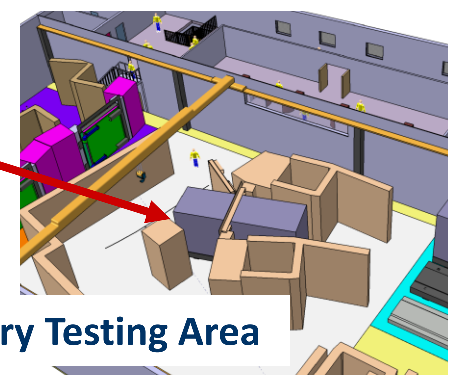


Transfer Testing Area

Docking Testing Area



Offices



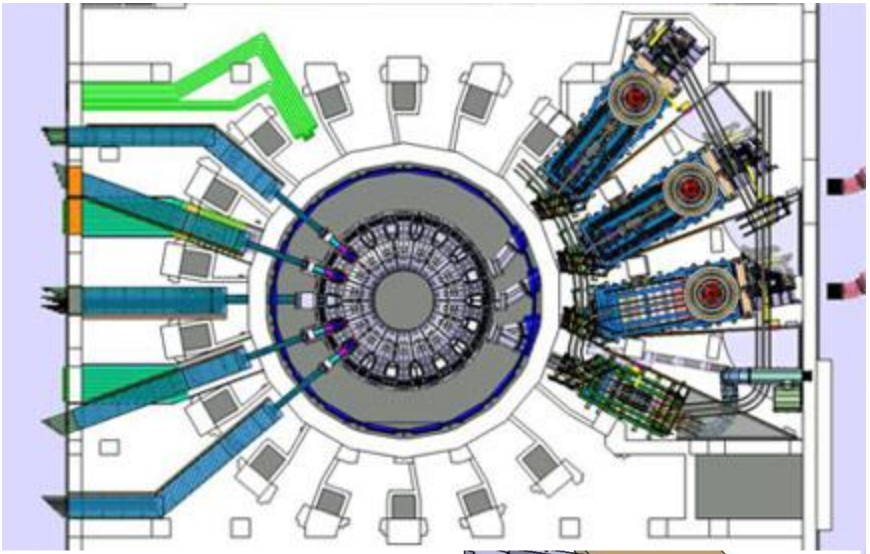
TCS Trajectory Testing Area

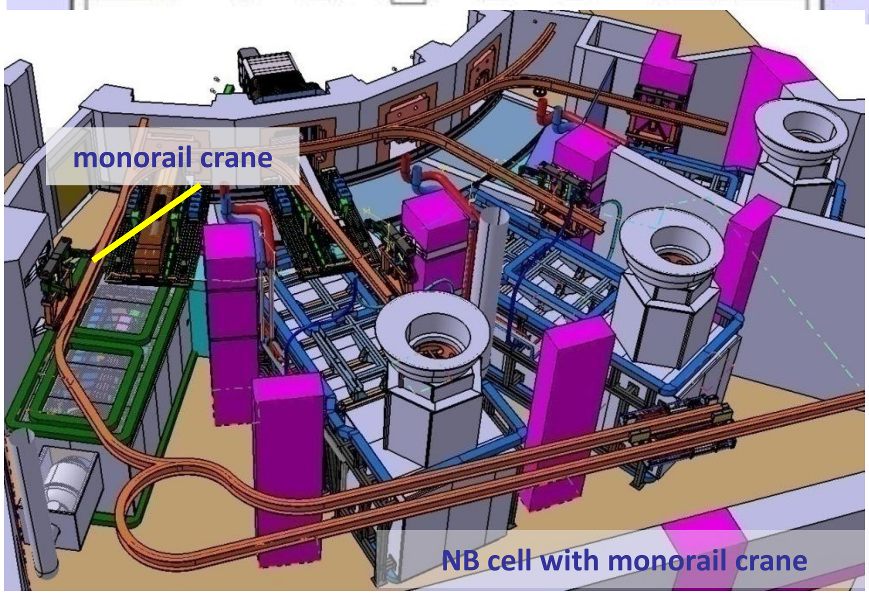
IST, CIEMAT

ITER Remote Handling Systems

- Blanket RH System
- Divertor RH Systems
- In-Vessel Viewing System
- Multi-Purpose Deployer
- Transfer Cask System
- Neutral Beam RH System
- Hot Cell RH System

Neutral Beam RH System

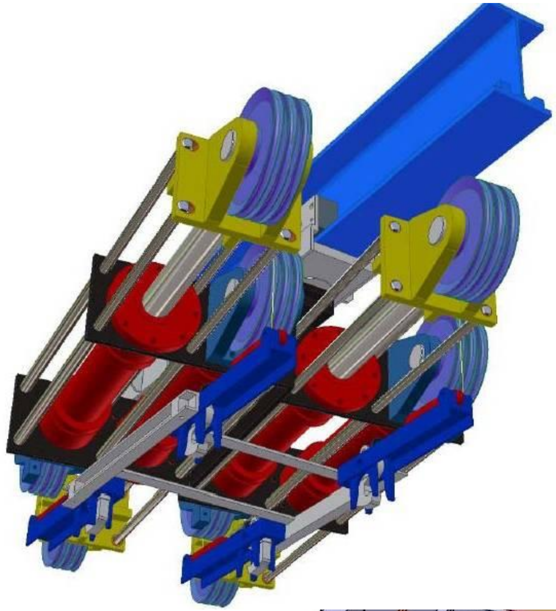


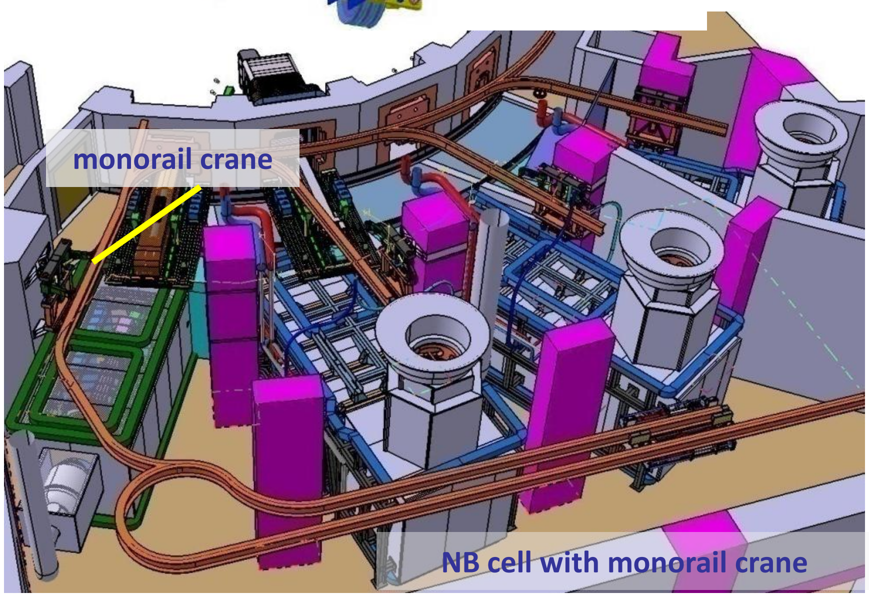


RH Requirements

- Removal and replacement of the
  - caesium oven fuelling system
  - beam source and accelerator
  - beam line components
  - Front components
  - Upper plug diagnostic tubes

Neutral Beam RH System

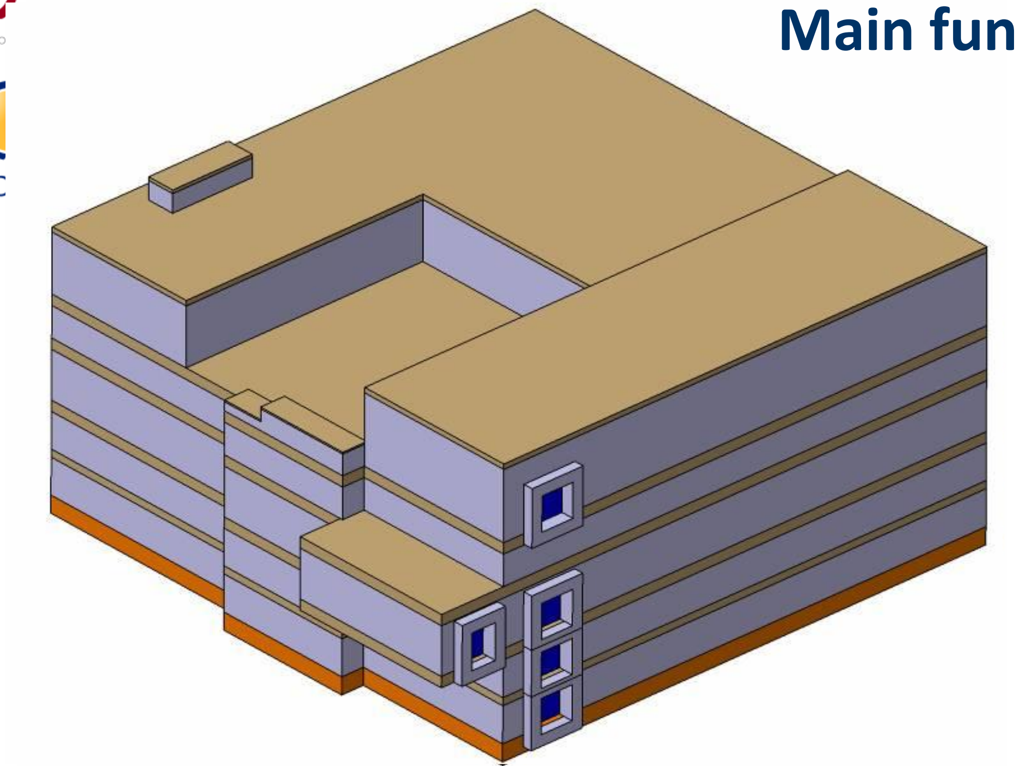




RH Equipment

- **50-tons monorail crane**, equipped with special lifting interfaces,
  - Transportation of the various components to a specific transfer area (to get out of the NB cell towards the HCB)
- **transport cradle**
  - specifically designed for the 26-tons NB source/accelerator
- **force feedback manipulator arm** and various tooling;
- **special end-effectors/devices**
  - for the installation and removal of the diagnostic tubes located in the upper level
- **auxiliary devices**
  - for temporary storage and transportation

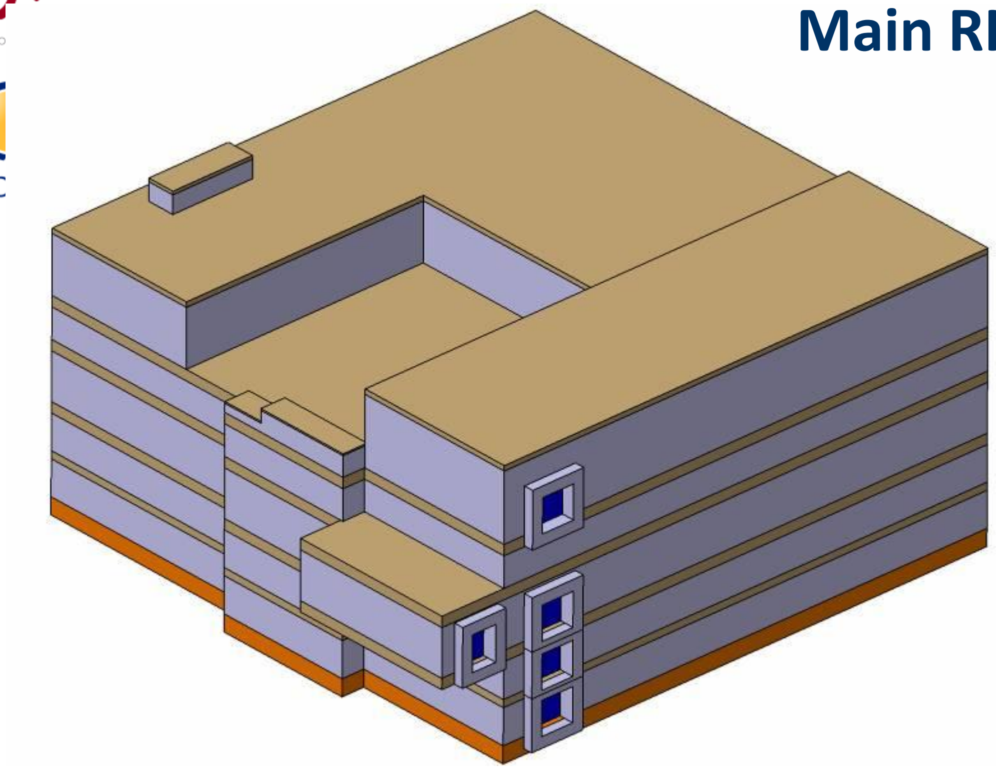
Hot Cell RH System



Main functions to be perfomed in HCB

- Cleaning and dust removal
- Repair / refurbishment/ testing of machine components which may be returned to service
- Inspection of components
- Processing of machine components which may be discarded as radwaste

Hot Cell RH System



Main RH Equipment

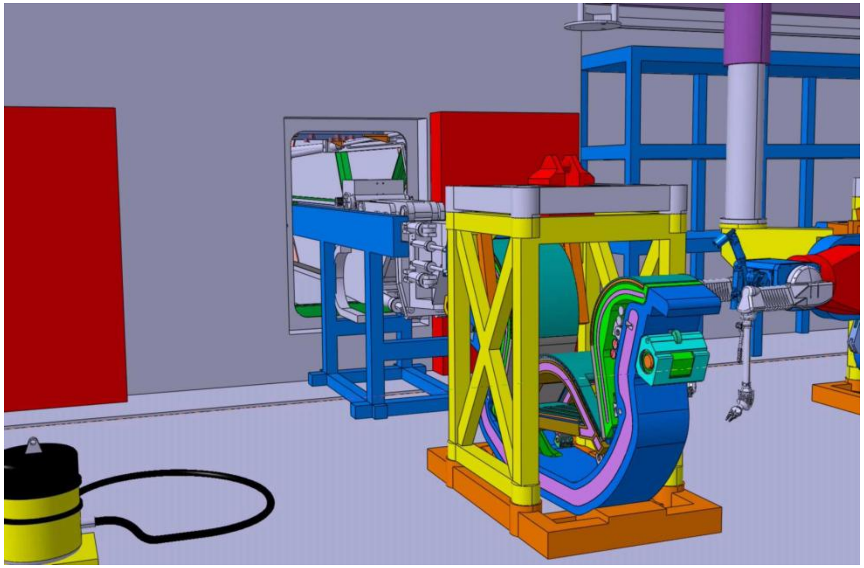
- Boom-style RH transporters
- Jib cranes transporters
- Lifting jigs
- Dexterous telemanipulators
- Viewing systems
- Inspection systems
- Cleaning equipment

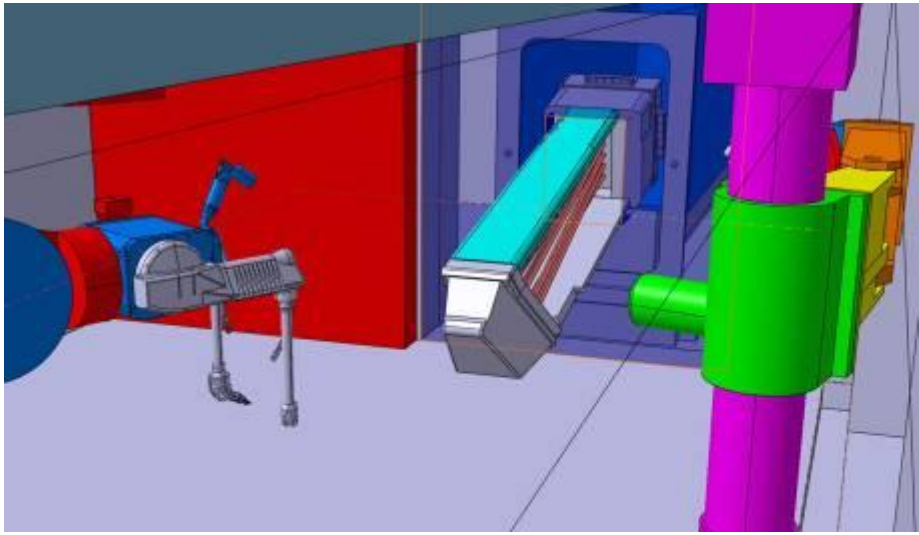
Hot Cell RH System

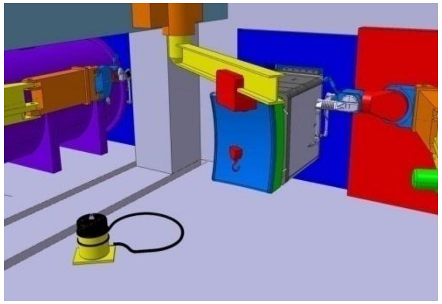
Plugs Refurbishment

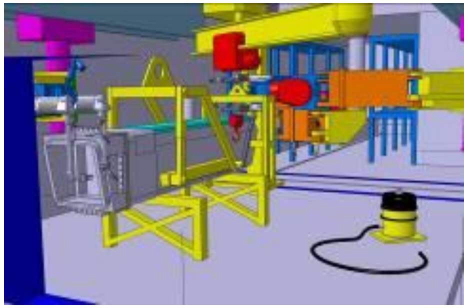
Divertor Cassette Refurbishment

Cassette Reception









Conclusions

- RH in ITER is **a key technology**
- RH in ITER is **very complex**
- RH in ITER is **required since the preparation of the D-T phase** and during the entire machine lifetime
- ITER cannot operate without a **fully operational Remote Maintenance System**
- There is still a massive amount of work to move from the present status to the final design, procurement and delivery to site.

Acknowlegments

We acknowledge

- the work of all the colleagues that contributed to the developments presented
- the colleagues that provided material for this presentation

THANK YOU FOR YOUR ATTENTION