

The ITER Hot Cell

Current situation and main issues

Magali Benchikhoun, ITER Organization

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- About ITER project and organization
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- ITER Hot Cell Facility
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- Back-up slides

The Way to Fusion Power – The ITER (Hi-)story



"For the benefit of mankind"

The idea for ITER originated from the Geneva Superpower Summit in 1985 where Gorbachev and Reagan proposed international effort to develop fusion energy...

"as an inexhaustible source of energy for the benefit of mankind".

On November 21, 2006, in the Elysée Palace in Paris, the seven ITER Parties China, Europe, India, Japan, Korea, Russian Federation and the United States of America signed the ITER Agreement.

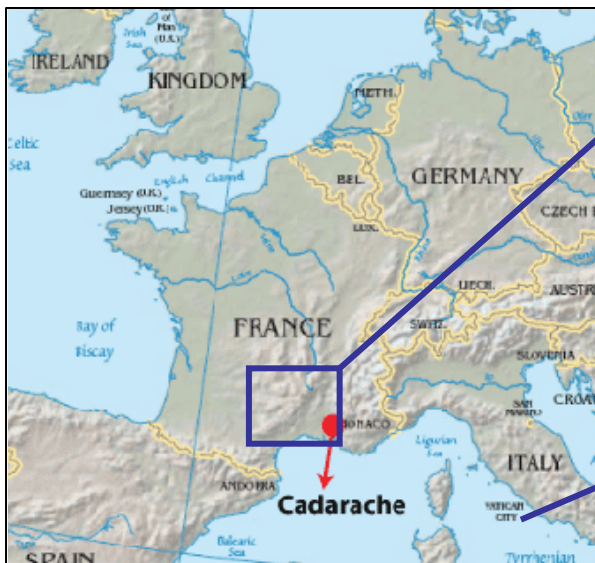


On 24 October 2007, the ITER Organization celebrated its "birthday".



Location: Cadarache, France

= Itinerary ITER components



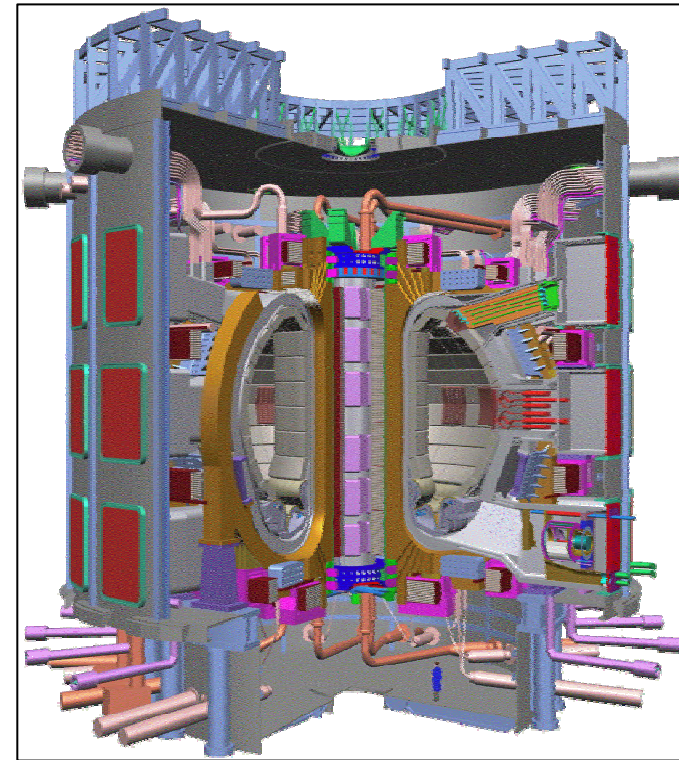
ITER Key Facts

- The overall programmatic objective:

to demonstrate the scientific and technological feasibility of fusion energy for peaceful purposes
- The principal goal: $Q > 10$

to produce a significant fusion power amplification (tenfold the energy input):
 - input power 50 MW
 - output power 500 MW
- The Costs:

5 billion € for ten years of construction and 5 billion € for 20 years of operation and decommissioning
- The execution: ~90% of the contributions are in kind.



ITER is one of the most innovative and challenging scientific projects in the world today.

Central Solenoid
Nb₃Sn, 6 modules

The core of ITER

Toroidal Field Coil
Nb₃Sn, 18, wedged

Poloidal Field Coil
Nb-Ti, 6

Cryostat
24 m high x 28 m dia.

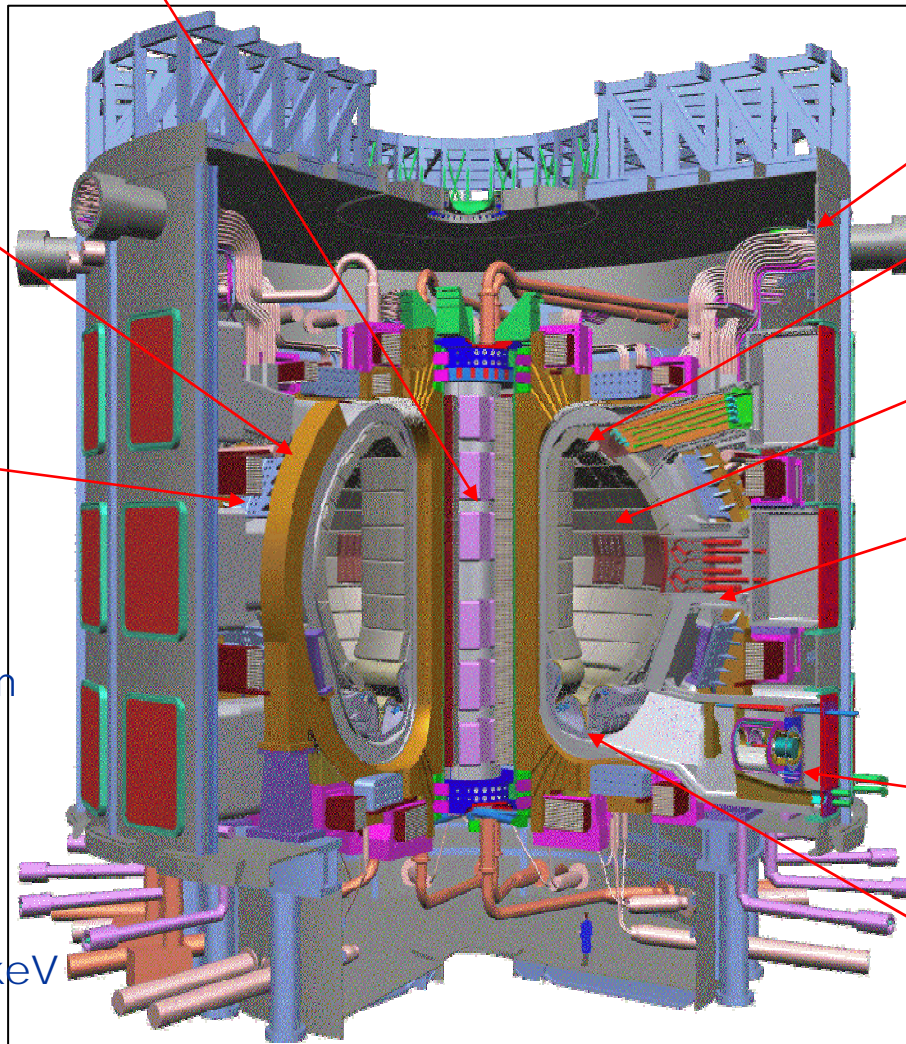
Vacuum Vessel
9 sectors

Blanket
440 modules

Port Plug
heating/current
drive, test blankets
limiters/RH
diagnostics

**Torus
Cryopumps**, 8

Divertor
54 cassettes



Major plasma radius 6.2 m

Plasma Volume: 840 m³

Plasma Current: 15 MA

Typical Density: 10²⁰ m⁻³

Typical Temperature: 20 keV

Fusion Power: 500 MW

Machine mass: 23350 t (cryostat + VV + magnets)

- shielding, divertor and manifolds: 7945 t + 1060 port plugs

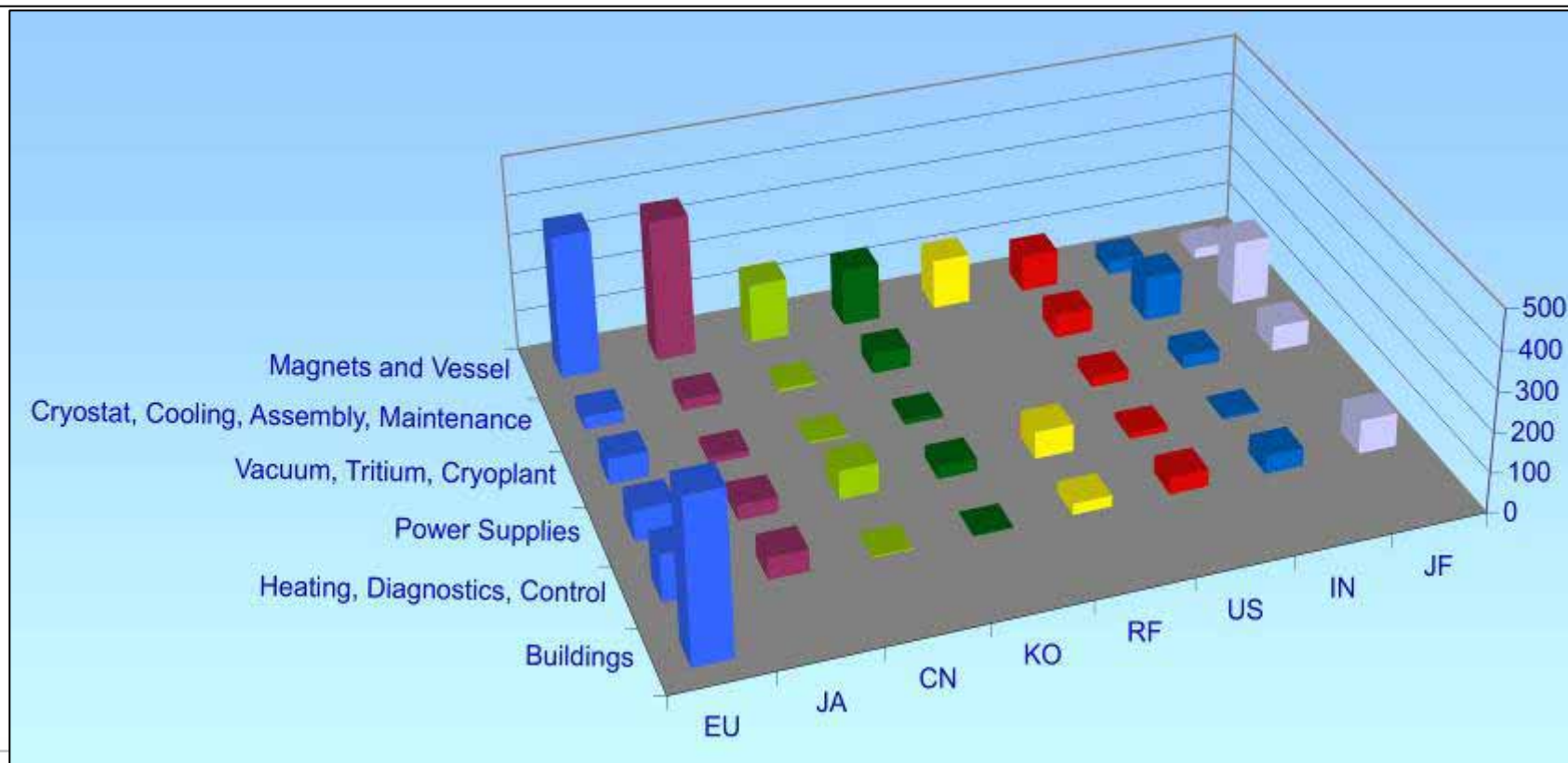
- magnet systems: 10150 t; cryostat: 820 t

Procurement Sharing

A unique feature of ITER is that almost all of the machine will be constructed through *in kind* procurement from the Parties

How the overall costs are shared:

EU 5/11, other six parties 1/11 each. Overall contingency of 10% of total. Total amount: 3577 kIUA (5.365 Mil € / 2008)

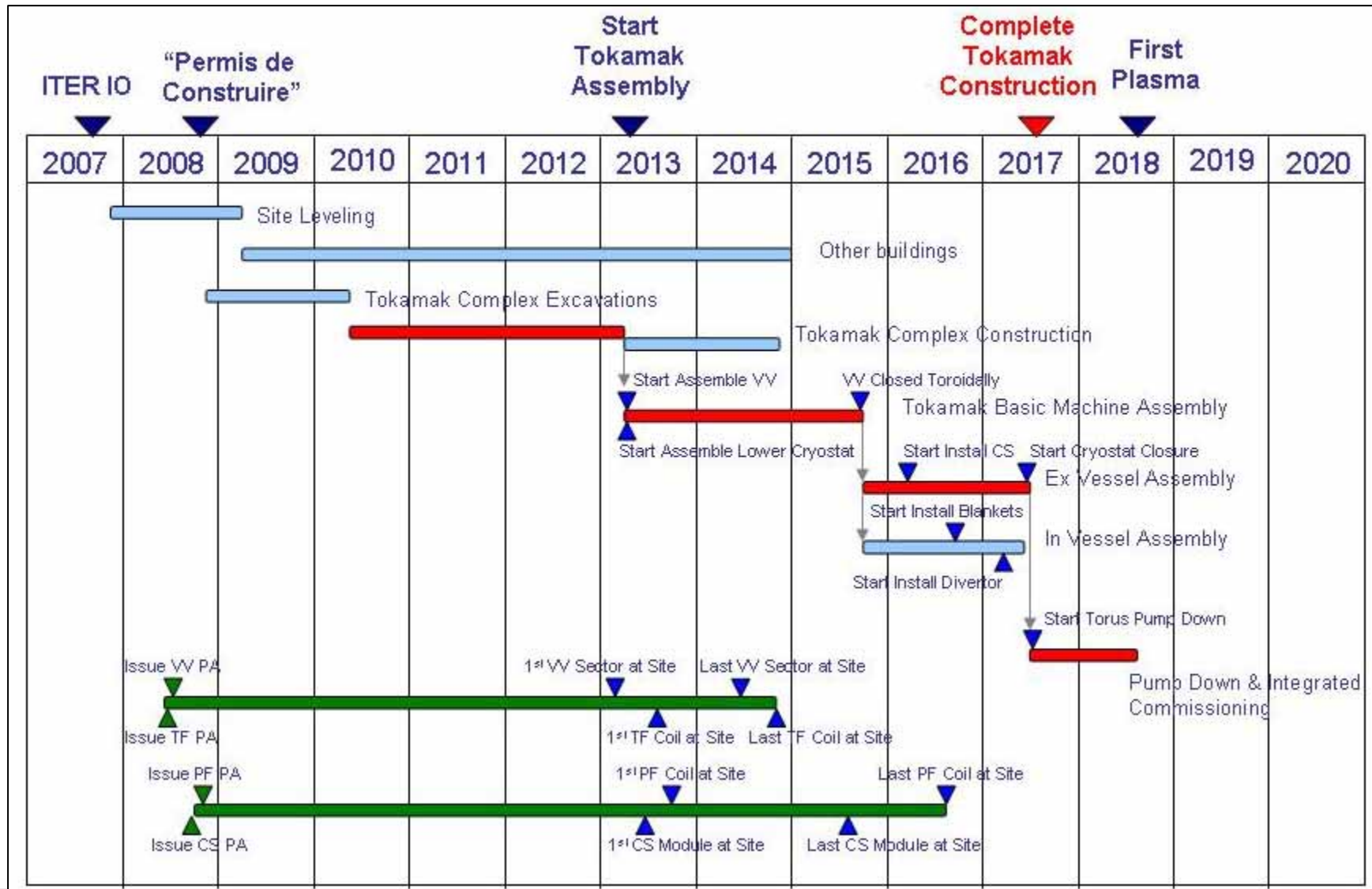




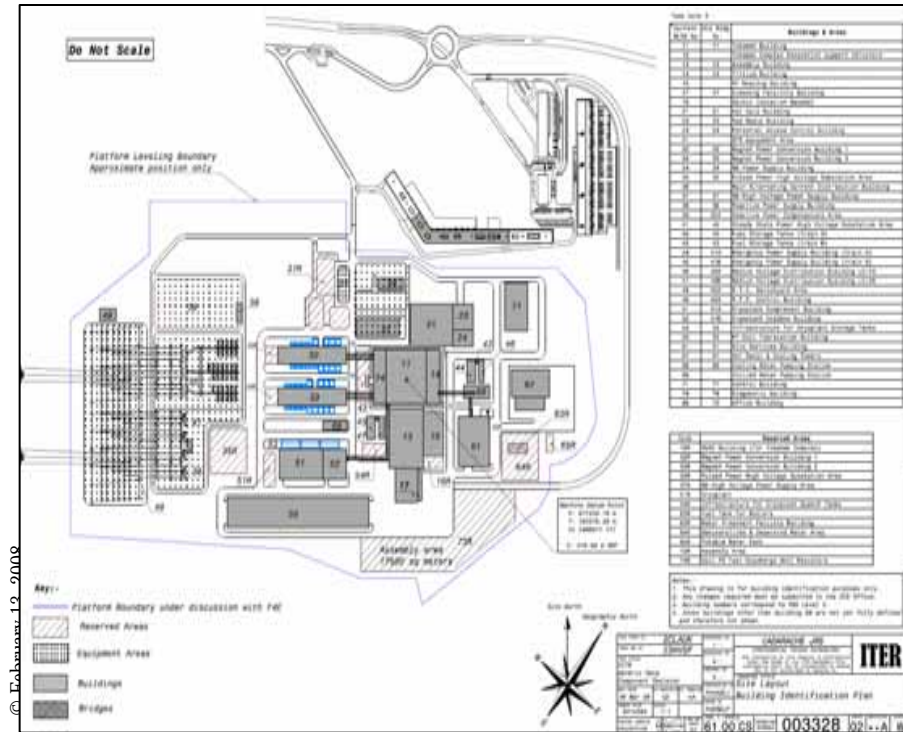
ITER...
...on its way



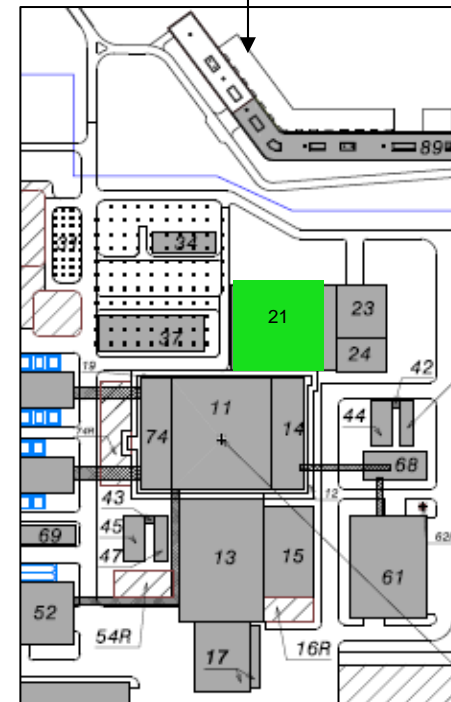
Integrated Planning Schedule



Where is the Hot Cell Facility on ITER site?



The Hot Cell Facility (bldg 21) is located to the North of the Tokamak, and to the West of the Tritium building complex.



Some dates to share for Hot Cell Facility

2008

- Reference Hot Cell design.
- Pre A&E activities.

2009 – 2013

- A&E, preparation and construction.
- December 2013, building ready for equipment.



2014 – Remote handling test stand ready.

2015 – Remote handling equipments and casks ready.

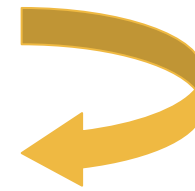
2016 - Blankets modules before installation in torus.

2018 -First plasma.

After first plasma:

- 2.5 years for HH phase;
- 0.5 year for possible upgrade;
- 1 year for DD phase with limited T (max. 5 g?)
- Then DT phases
- And then a planned shutdown after 10 years operations.
- Again 10 years operations.

nuclear
phase



What are the functions of hot cell facility?

- **ITER Hot Cell Facility (HCF) (building 21)** is designed to support the Tokamak during the assembly, commissioning, operation, de-activation and dismantling phases.
- It is classified as a nuclear facility and has to meet safety French regulation. The main drivers for the design: tritium (+ beryllium) confinement, radiation shielding, machine availability & remote handling.

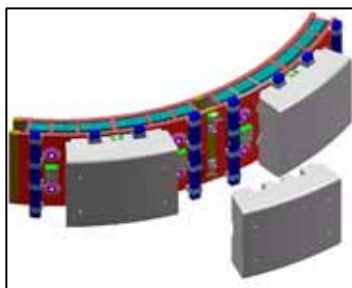
The current design comprises a substantial concrete, stand-alone building of four floors above ground and one basement.

Main characteristics: 70 m*62 m. High about 22 m. Current volume is about 91 000 m³ above ground. Total volume is about 130 000 m³.

What are the functions of hot cell facility?

1. **Diagnose, repair or refurbish** components, tools, and equipment which have become activated by neutron exposure and/or contaminated with tritium or covered with activated dust, this in order to meet the requirements of the maintenance/upgrade plan of the ITER machine. **Test** them before re-installation in the vacuum vessel.
2. **Store** full spare set of divertor cassettes (off line refurbishment).
3. **Process** components or parts of them as radwaste. Temporarily store them after proper conditioning till the end of the de activation phase, prior handover to Host Country. Process includes detritiation for tritium recovery.
4. Contribute to tritium mass balance inventory. **Provide confinement** for tritium (or beryllium) operations.
5. All operations will be performed by remote handling (RH) systems. **Remote handling simulation and rehearsal test stand** are also housed in the HCF.
6. **Provide a nuclear controlled area** to :
 - Park, maintain and recharge transfer casks
 - TBM program
 - Decontaminate, maintain and repair tools and equipments
 - Store radioactive sources (instruments calibration).

Main ITER In-VV Components to be Remotely Handled and transferred to Hot Cell Facility



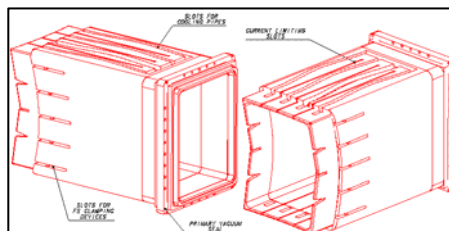
BLANKET MODULES

Design features

- ✓ ~ 400 modules (4.5 ton each)
- ✓ Mechanical connection to vessel via bolts
- ✓ Independent hydraulic connection to cooling circuit

Maintenance features

- ✓ 4 access ports
- ✓ Handling with special robotic vehicle & manipulator
- ✓ TRANSFER CASKS



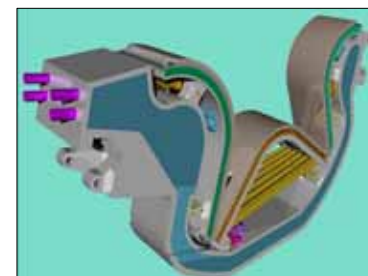
PORT PLUGS

Design features

- ✓ 45 ton (equator plugs)
- ✓ 20 ton (upper plugs)

Maintenance features

- ✓ 18 upper ports
- ✓ 15 equatorial ports
- ✓ Handling with special robotic vehicle & manipulator
- ✓ TRANSFER CASKS



DIVERTOR CASSETTES

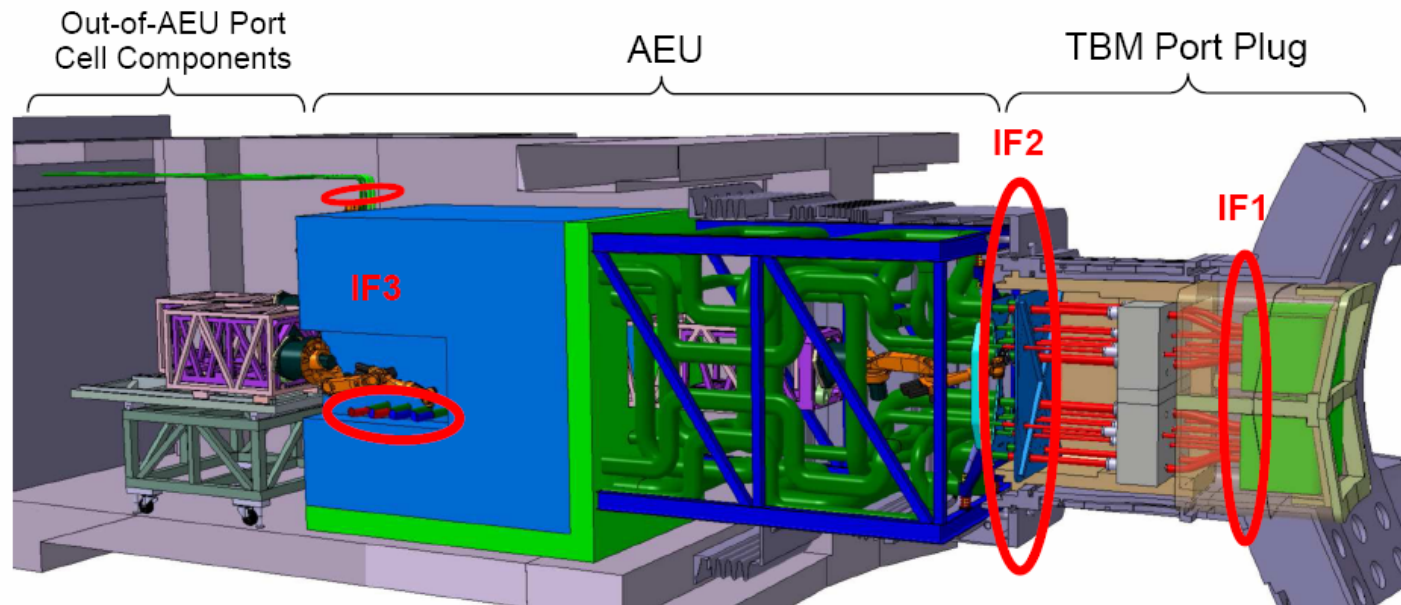
Design features

- ✓ 54 cassettes (~11 ton) with removable PFC's
- ✓ Mechanical connection to vessel via toroidal rails
- ✓ Independent hydraulic connection to cooling circuit

Maintenance features

- ✓ 3 access ports
- ✓ Handling by robotic movers & manipulator
- ✓ TRANSFER CASKS

Main ITER In-VV Components to be Remotely Handled and transferred to Hot Cell Facility



About TBM ...

The Test Blanket Modules (TBMs) are being developed and proposed by ITER Parties. Six independent TBM systems will be tested simultaneously in the three ITER Test Port (2 TBMs per port).

What are Hot Cell Facility main contributions?

TBMs replacements will have to be performed (for each TBM, one each 2-3 years in average), in synchronization with the ITER planned shutdowns.

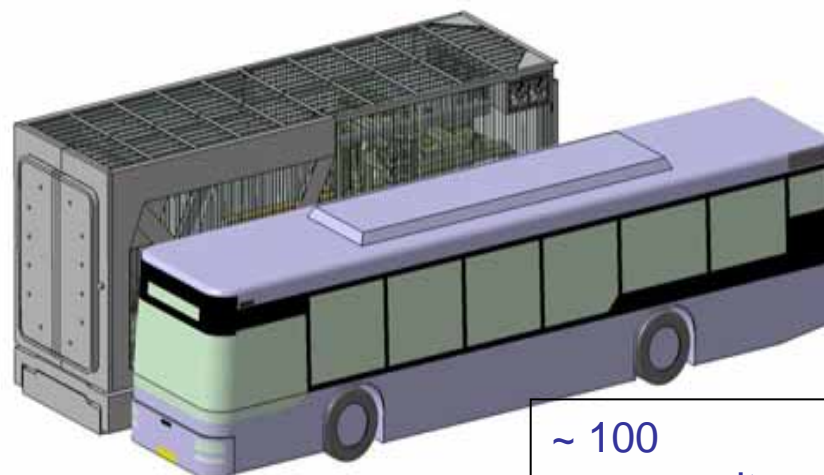
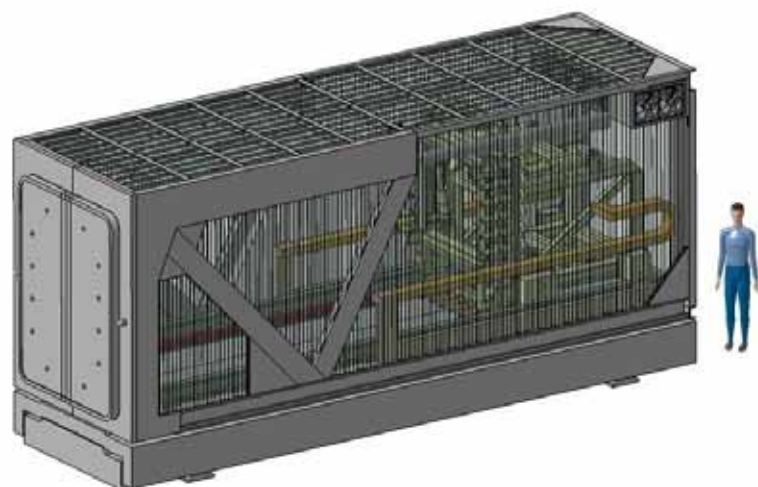
These operations (refurbishments, preparation of the post-irradiation examination, etc.) will be performed in the Hot Cell Facility.

About the transfer casks ...

- A system of 21 dedicated transfer casks is used to move in-vessel components and tools remotely between the Tokamak vacuum vessel and the Hot Cell Facility through dedicated galleries in the ITER buildings.
- These casks are remotely controlled; floating using an air cushion system; driven by motorised wheels; equipped with a tritium confinement system; not shielded;
- docking to the Tokamak machine and the Hot Cell port using a double door system.
- Main functions for the transfer cask:
 - Transfer of the remote handling equipment between the Tokamak vacuum vessel and the Hot Cell Facility;
 - Transportation along the building floor (which has specific requirements e.g. flatness, etc.)
 - Docking/un-docking onto the Tokamak vacuum vessel or the Hot Cell Facility double door docking flange.
 - Provide & maintain confinement onto the Hot Cell Facility or the Tokamak vacuum vessel docking flange during connection.
 - Opening/closing the Hot Cell Facility or the Tokamak vacuum vessel access without breaking confinement.
- *Main features as follows: 3.7m x 2.7m x 8.5m; total mass about 60 t (empty).*

Transfer casks

3.7m x 2.7m x 8.5m
Total Mass about 60 t



~ 100
persons city
bus

21 transfer casks
(14 for RH tools, 7
for in VV
components)

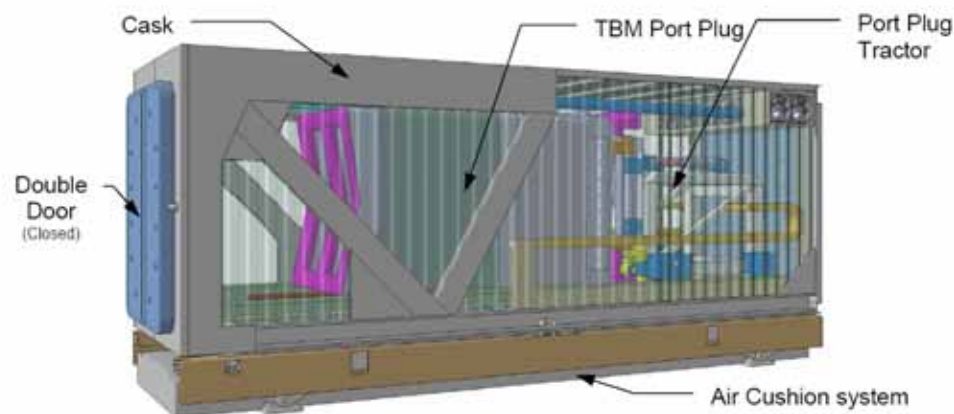
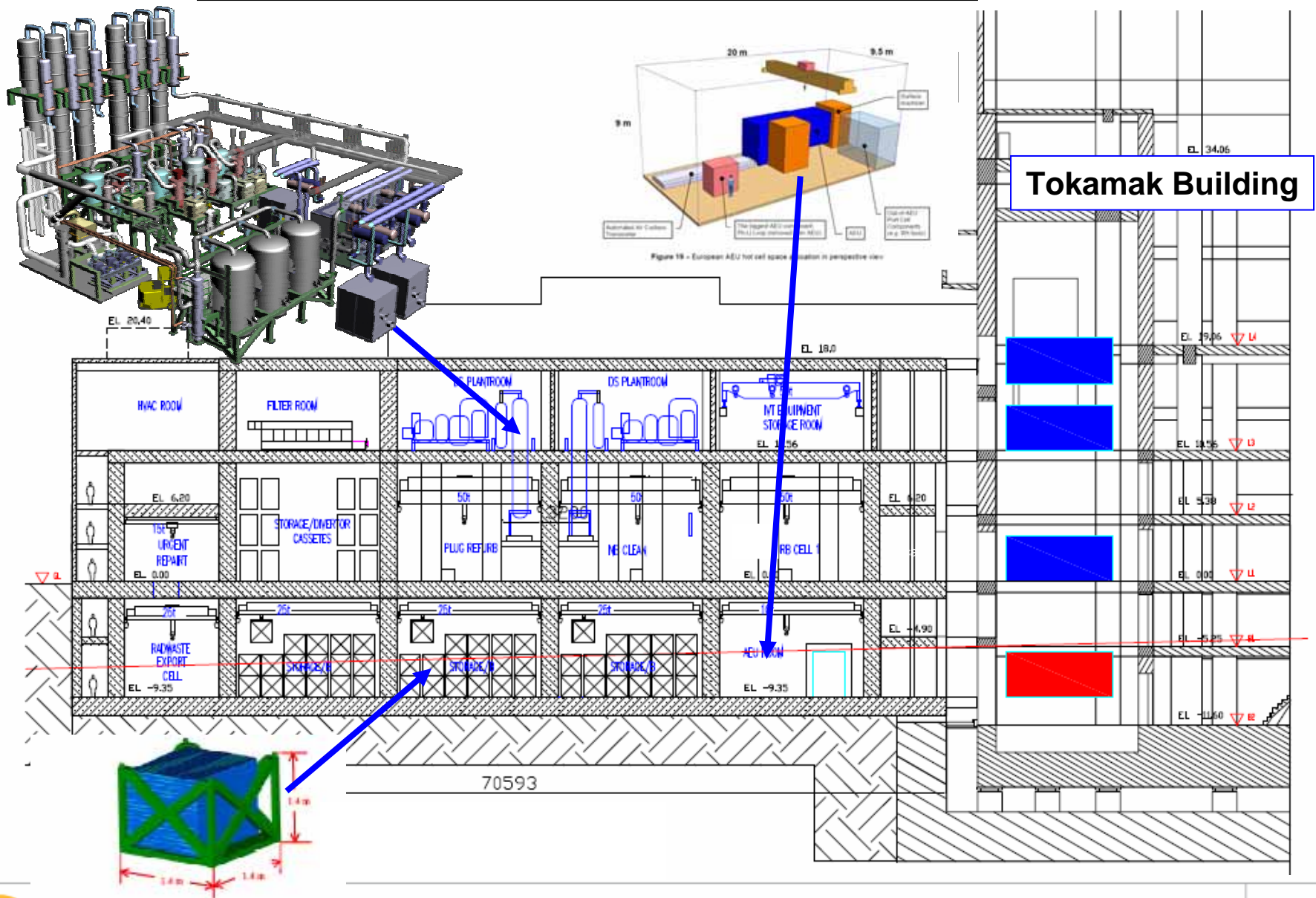


Figure 12 – Transfer Cask "In operation"

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Hot Cell Building. Section view 2



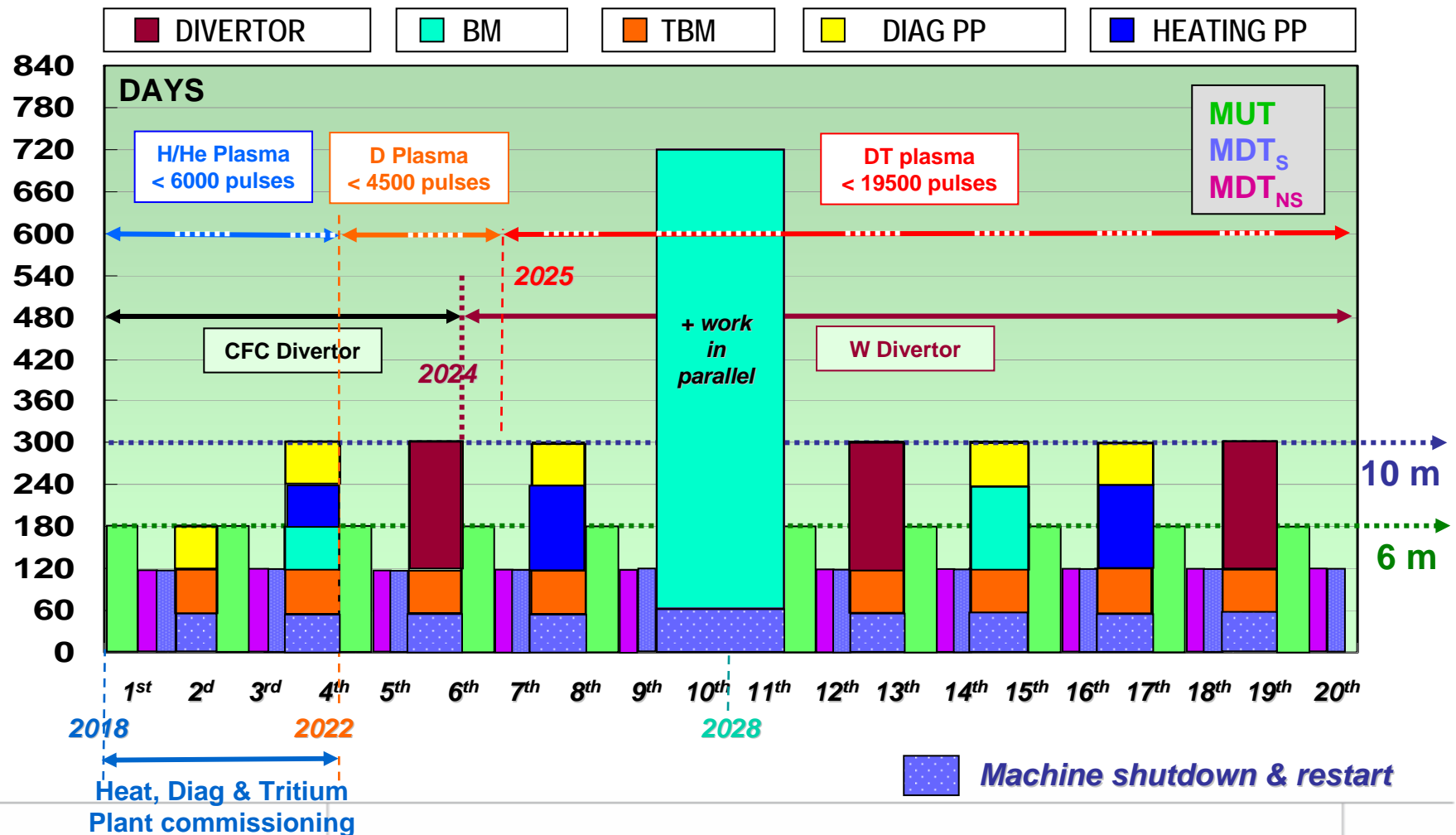
About the Tokamak lift ...

- All ports allocated for remote handling in the Tokamak building can be accessed by transfer casks.
- They are able to be transported via the galleries to the building with a 100 t capacity lift in the north east corner of the Tokamak building.
- The Hot Cell building is functionally linked to the Tokamak building via a lift shaft with an elevator connecting four Tokamak building levels. The lift opens into four passageways to the Hot Cell building:
 - At the equatorial level (i.e. to the Hot Cell level 1) for the hot cell processing,
 - And to the test stand areas in the Hot Cell building at elevations +10,56 m and +15,81 m.
 - One additional connection located at the Hot Cell building basement level – 9,35 m, for transfer casks park.
- **Main features for the 100 t lift motor capacity:**
 - Live load $W=100$ t
 - Dead load of Lift frame $G=120$ t
 - Lifting speed $V=0.5\text{m/min}$
- **Civil engineering of interfaces between the buildings is an issue, as the Tokamak building stands on seismic pads and not the Hot Cell building.**

OPERATION PLAN WITH A MAJOR SHUTDOWN EACH 2 YRS

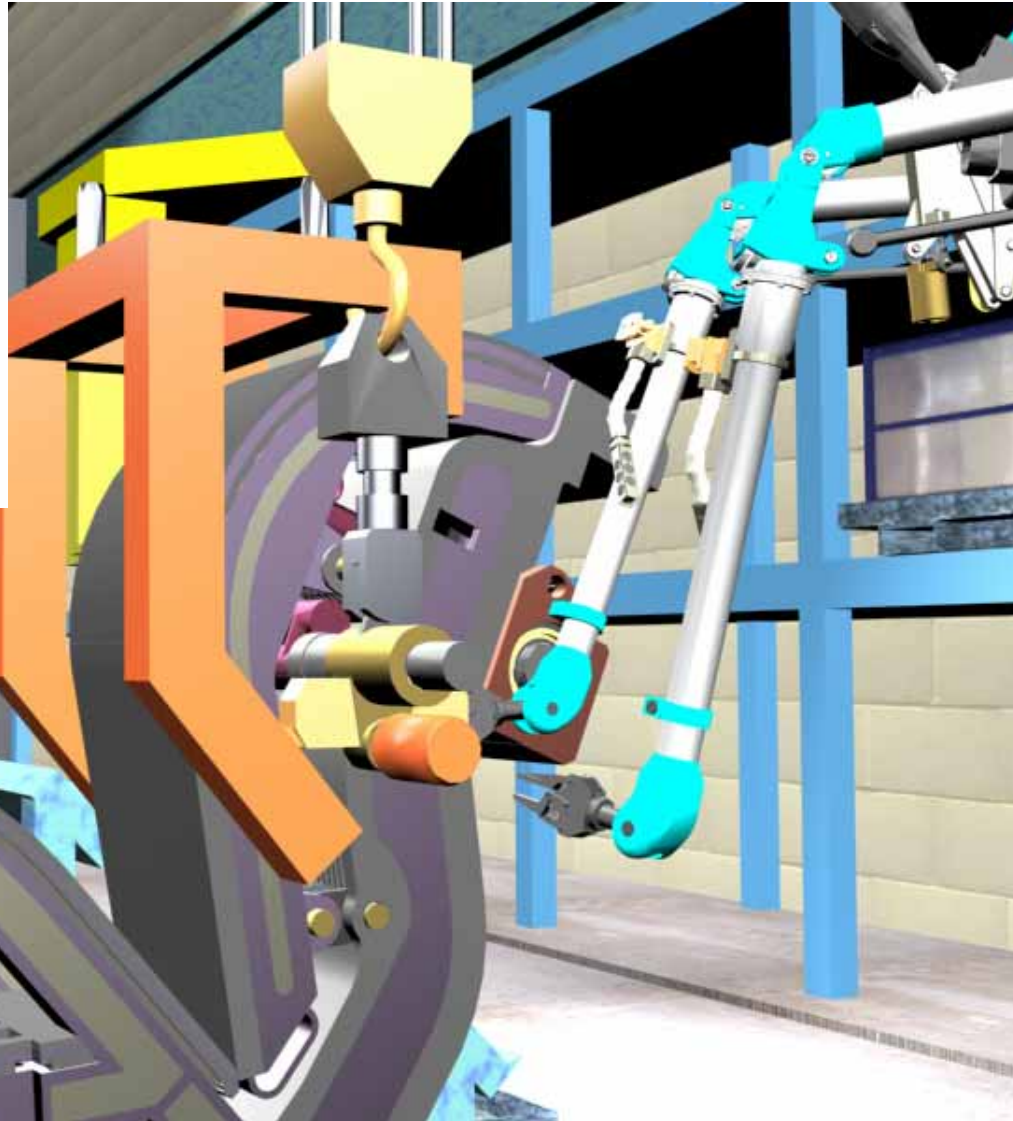
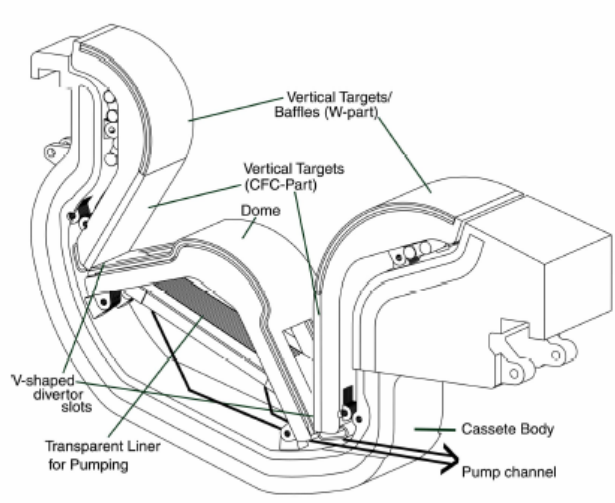
For information only

ITER remote maintenance is based on the removal of relatively large modular systems followed by refurbishment in a Hot Cell.



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Ground level, some operations on divertor cassette



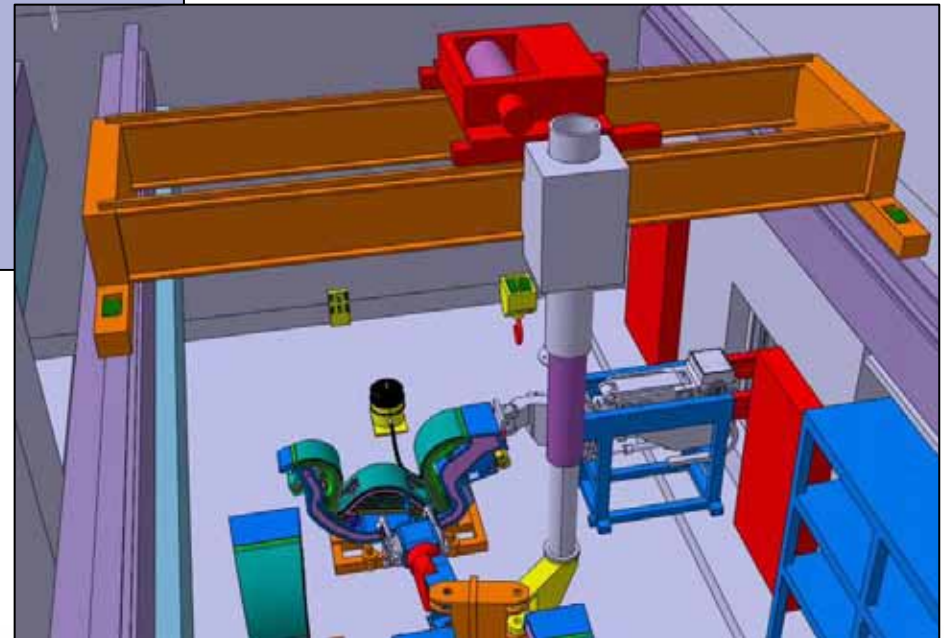
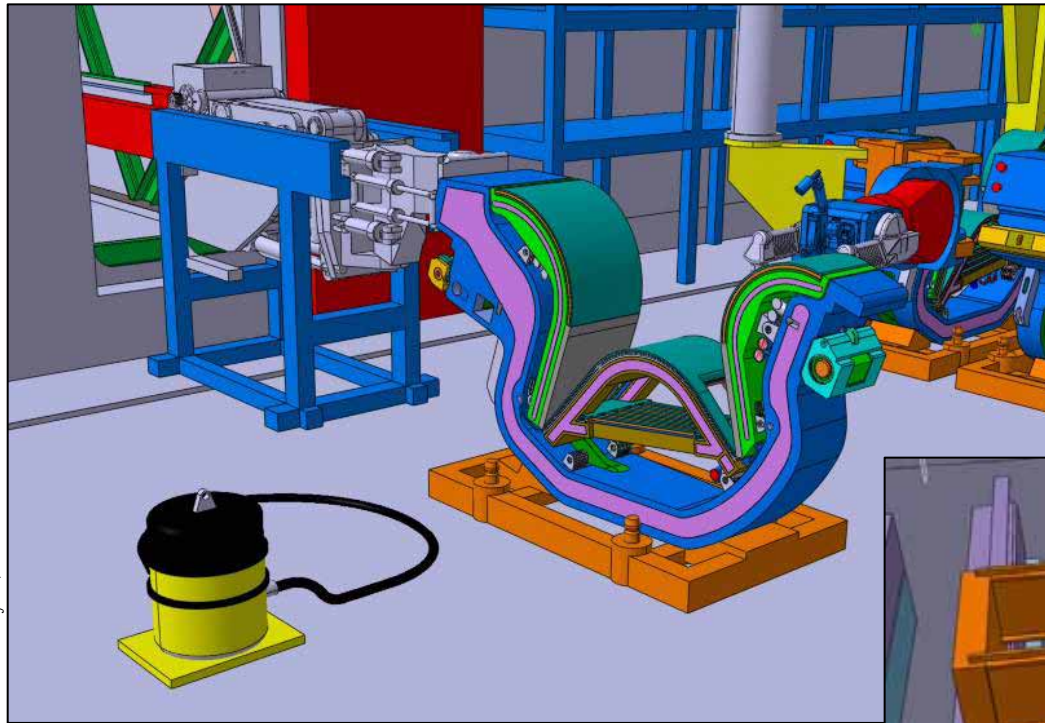
Required Operations in the Hot Cell Facility for Divertor Cassette 1/2

1. Cleaning and dust removal from 54 cassette assemblies
2. Baking for T recovery of 54 cassette assemblies
3. Dismounting of the diagnostics installed onto the PFCs and related cabling
4. Cutting of $(4+2+4) \times 54 = 540$ PFC/CB connecting pipes and 540 caps in CBs
5. Removal of $(12+6) \times 54 = 972$ pin attachments of PFCs
6. Removal of $(20+12+12) \times 54 = 2376$ link attachments of PFCs
7. Insertion of $(2+2) \times 54 = 216$ connecting bars of the VTs
8. Fixation of $(2+2) \times 54 = 216$ nuts onto the connecting bars
9. Removal of $3 \times 54 = 162$ PFCs
10. Visual examination of 54 CBs including the inner and outer locking system to the vacuum vessel
11. Cleaning, inspection, removal/replacement of damage diagnostics installed onto the CBs
12. Machining of the 540 CB pipe ends to be rewelded
13. 3D Geometrical survey using a Computer Aided Theodolite (CAT) - or equivalent equipments - of the CB, its 540 pipes and its 972 PFC attachment holes (accuracy better than ± 0.1 mm)
14. Custom machining of 972 PFC attachment holes from above survey to bring them in tolerance
15. Cutting to length of 540 PFC pipes from above survey to bring them in tolerance with the CB pipes
16. Mounting of $3 \times 54 = 162$ new PFCs into the multilink attachments
17. Insertions of 972 pins and 2376 link attachments of PFCs
18. Swaging of 972 pins
19. Welding of $(4+4+2) \times 2 \times 54 = 540$ PFC/CB connecting pipes and 540 caps in CBs
20. Visual examination of $(4+4+2) \times 2 \times 54 = 1080$ weldings
21. Ultrasonic examination of $(4+4+2) \times 2 \times 54 = 1080$ weldings

Required Operations in the Hot Cell Facility for Divertor Cassette 2/2

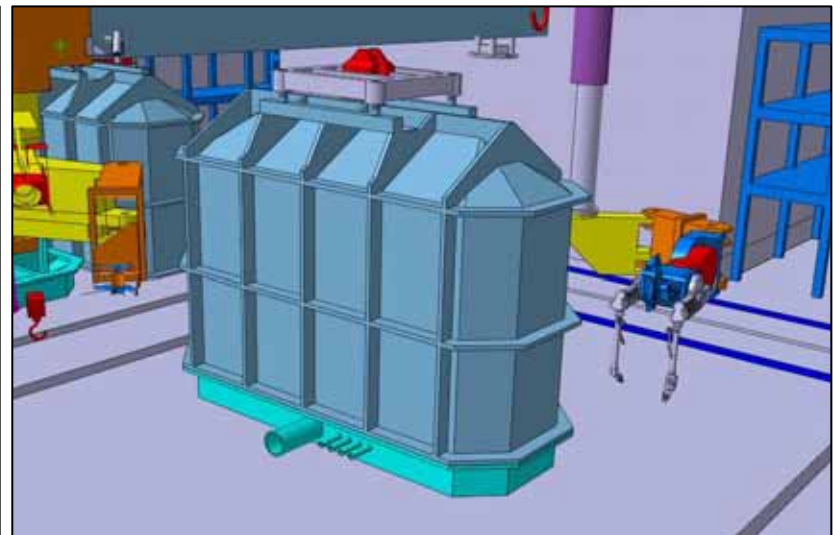
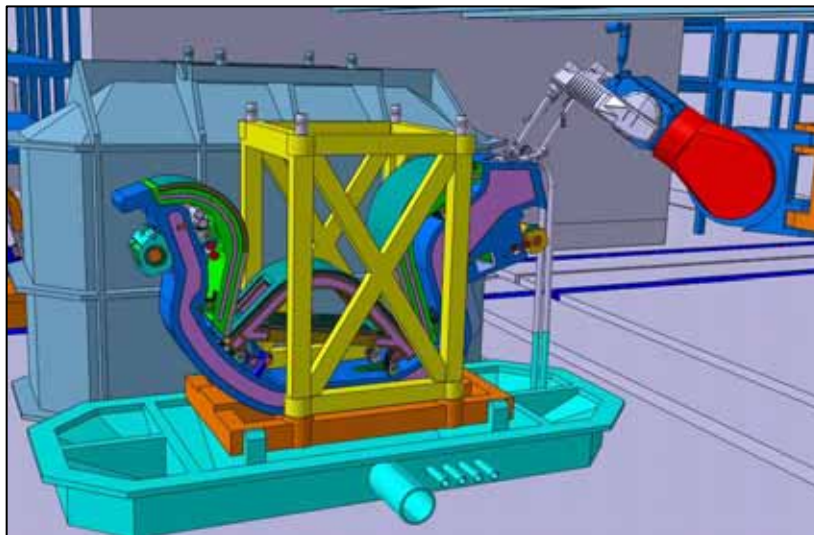
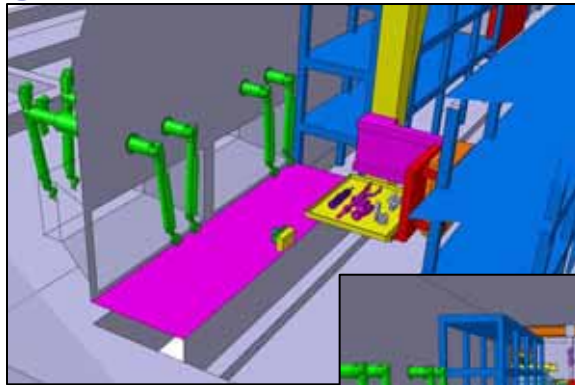
22. Cold He leak test of 54 cassette assemblies; leak rate acceptance level $< 1 \times 10^{-10} \text{ Pa m}^3 \text{ s}^{-1}$
23. Hydraulic pressure tests at 7.6 MPa, 20 °C of 54 cassette assemblies using demineralised water
24. Hot He leak test of 54 cassette assemblies; leak rate acceptance level $< 1 \times 10^{-10} \text{ Pa m}^3 \text{ s}^{-1}$ (hot He leak test at 240 °C is included in the present PP17 but the testing protocol needs to be reassessed)
25. 3D Geometrical survey using CAT of 54 cassette assemblies during pressurization and depressurization of the assemblies
26. Hydraulic flow test (flow rate 18 kg/s per assembly at 100 °C) of 54 cassette assemblies using demineralised water; pressure drops and vibrations shall be monitored
27. Draining (using gravity and forced gas flow of N_2 at 1 MPa, TBC) and drying (using forced gas flow of N_2 at 0.1 MPa, TBC) of 54 cassette assemblies
28. Repeat He leak test of $(4+4+2) \times 2 \times 54 = 1080$ weldings
29. Mounting of new diagnostics installed onto the PFCs and related cabling
30. Alignment and geometrical calibration of the optical diagnostic systems (note: this requires that the CB is brought to the same distortion and temperature level of its operating conditions)
31. Functional tests of the diagnostics
32. Removal of $(2+2) \times 54 = 216$ nuts onto the connecting bars
33. Removal of $(2+2) \times 54 = 216$ connecting bars for the VTs
34. 3D Geometrical survey using CAT of the outer surfaces of the 54 cassette assemblies with particular attention to the plasma interfacing surfaces; all dimensions shall be recorded, and confirmed to be within the specified acceptance criteria
35. Final visual examination of 54 cassette assemblies
36. Cassette assembly is ready

Ground level, main refurbishment area – cleaning work station after entry



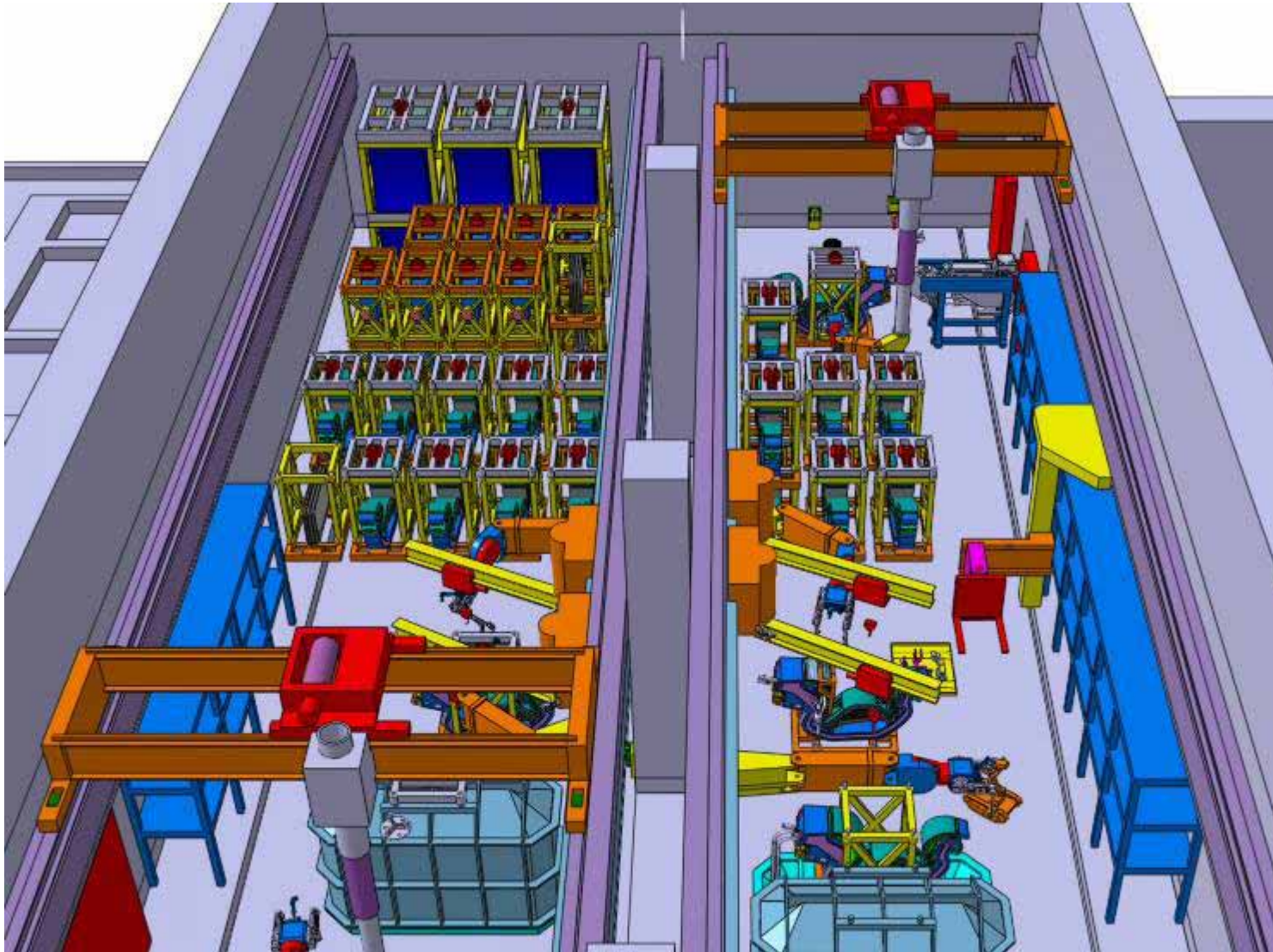
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Divertor cassette refurbishment & testing - ground level



[A. Tesini, "ITER & RH", 1st PREFIT workshop, Culham (UK) 5-6 June 2007]

Ground level, refurbishments & storage areas



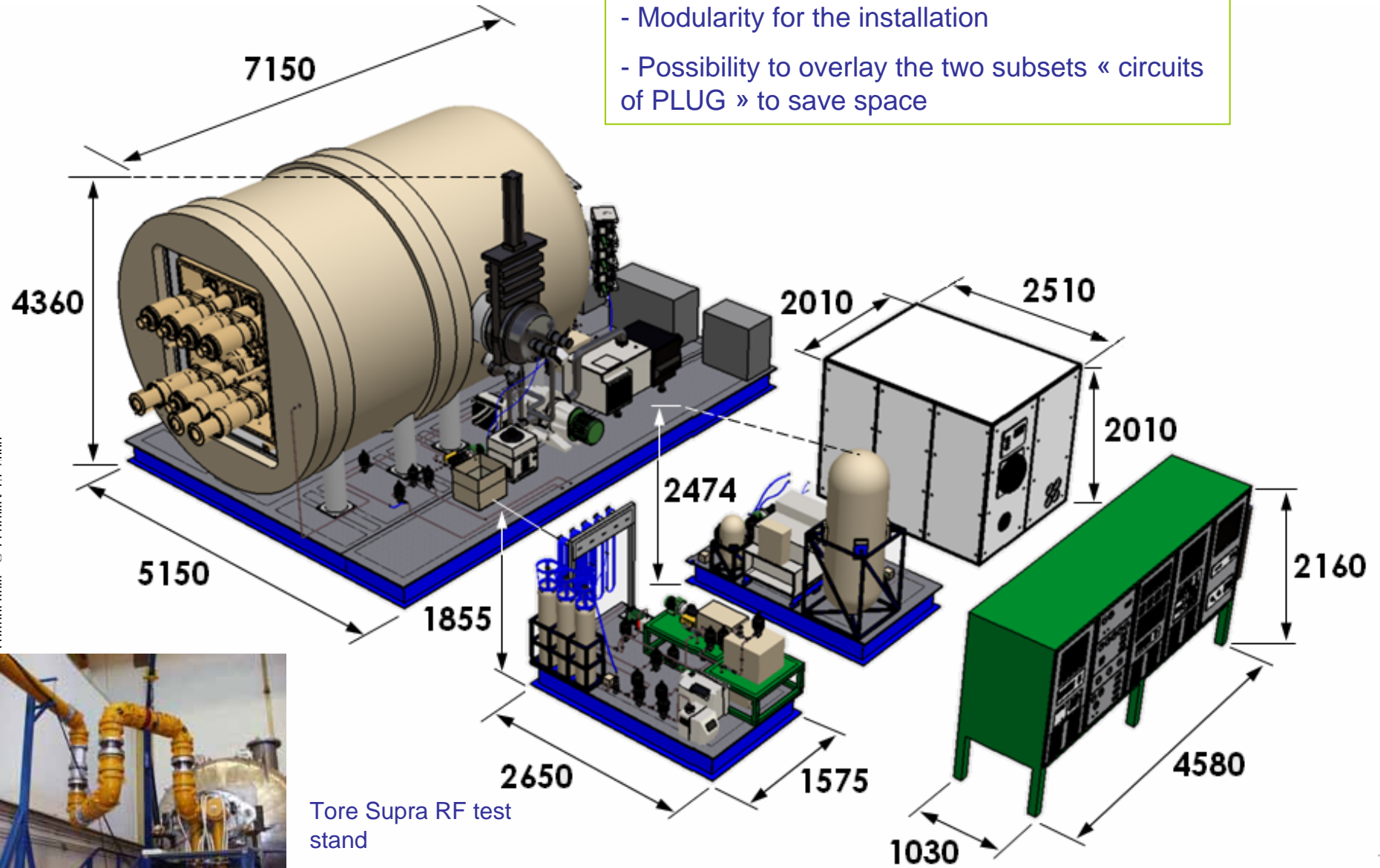
From A. Tesini, 2007.

Test facilities

- For vacuum integrity after repair or refurbishment, severe testing of components will precede re-installation in the vacuum vessel, such as:
- Thermal cycles under vacuum
- Helium leak check
- Functional tests (shutters, mirrors, RF conditioning, etc.)
- This will require dedicated test stand in the red zone. Concept indicates 11m wide x 8m long x 5.5m high, weight 25 tons.
- Detailed design of such a device in a nuclear red zone with likely ESPN regulation to be met and radiofrequency systems, still remains a challenge.

Conceptual design for a test facility

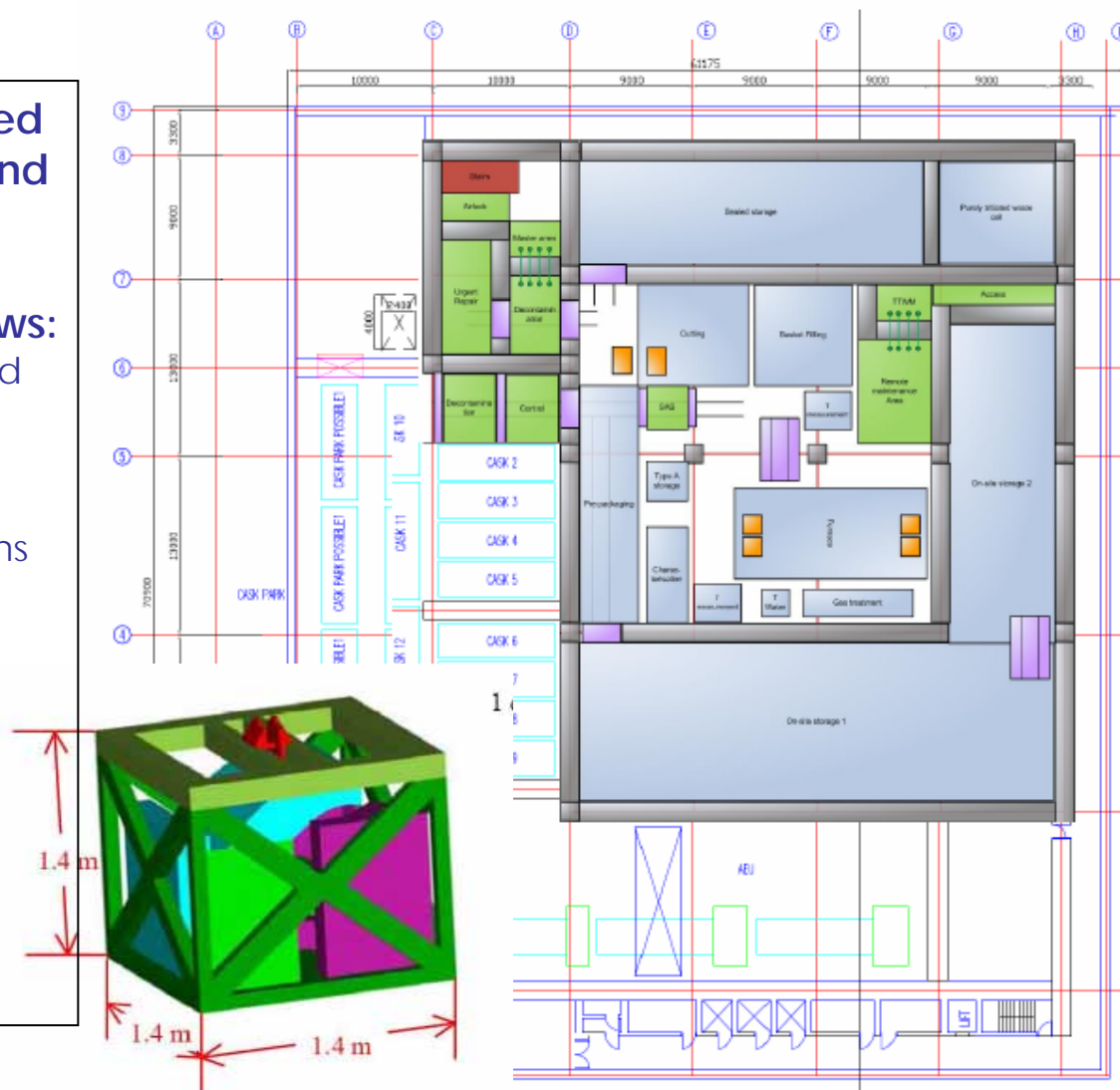
- Modularity for the installation
- Possibility to overlay the two subsets « circuits of PLUG » to save space



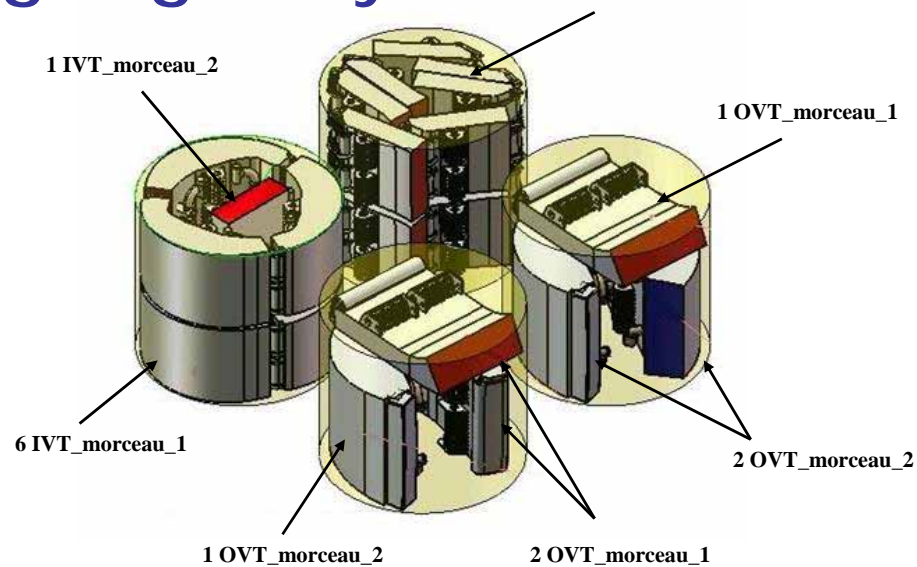
Some elements about waste for information – ongoing study

Basement level is devoted to type B waste, casks and TBM related equipment. For waste, main workstations are as follows:

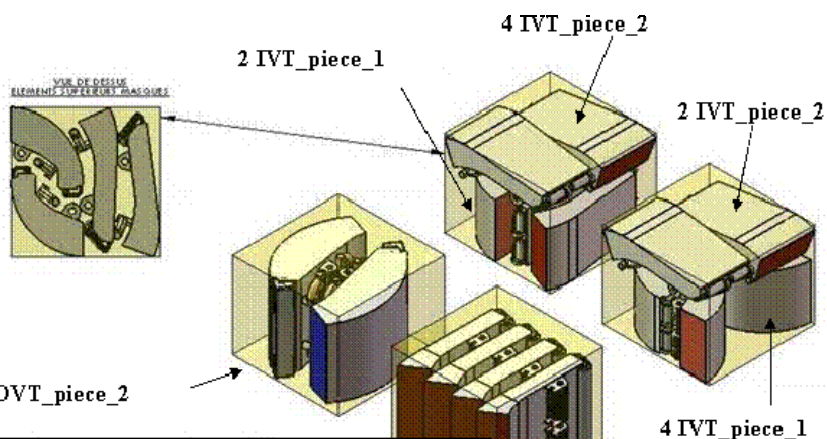
- Receive waste from ground level.
- Buffer storage.
- Cutting station.
- Measurements work stations
- Tritium Oven for tritium recovery.
- Put in container/pre-package for storage.
- Welding work stations.
- Decontamination/rescue workstation.
- Storage of type B waste.
- Final package
- Control, export.



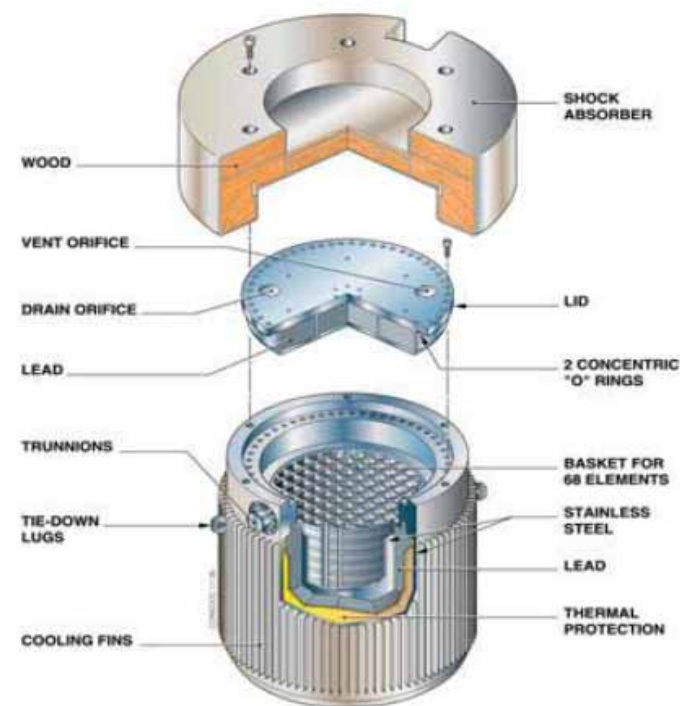
— Some elements about waste for information - ongoing study —



Example of waste packaged in 1.2 m³ boxes.



Example of waste packaged in 1.3 m³ boxes.



TN-MTR™ shipping cask for ITER waste?

Tritium confinement -1/4

Detritiation System, designed to:

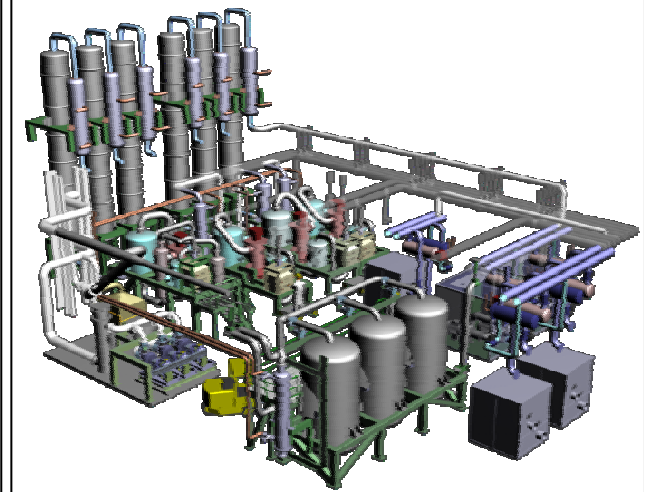
- Provide depression in Red and Amber zones. Air in-leakage rate 20 vol.%/day, current assumption for total volume of red and amber zone about 30000m³.
- Provide air flow from room of lower contamination level to room of higher contamination level.
- Detritiate gases prior to their discharge to the environment (one unique ITER stack).
- Take over from HVAC for providing depression in Green zone in event of air borne contamination

Tritium confinement - 2/4

Concept as follows:

- Two mirror parts installed in different fire sectors and connected to different trains of power supply. Each part includes molecular sieves modules and wet scrubber columns:
 - Molecular sieve modules collect tritium released from in-vessel components inside red zone, and re-circulate air atmosphere inside red zone (and amber zone, if required). Capacity about 1600 m³/h.
 - Wet scrubber column modules provide depression and detritiation of gases prior to their release into the environment. Capacity about 1400 m³/h.

Conceptual design



Modules and systems will be located 1st, 2nd and 3rd floors.

Tritium confinement -3/4

In order to improve this air in-leakage rate, and also to reduce the amount of dismantling waste, liners will probably be implemented in the red /amber zones of the Hot Cell Facility.

Best practice worldwide for hot cells is to use stainless steel liners.

Due to the large surfaces of ITER hot cell facility red/amber zones and the cost of stainless steel, a challenging study is ongoing to find the best solution. First results confirm that technical implementation such as anchorage and support of heavy loads are possible.

~8000 m² !

Tritium confinement concept - 4/4

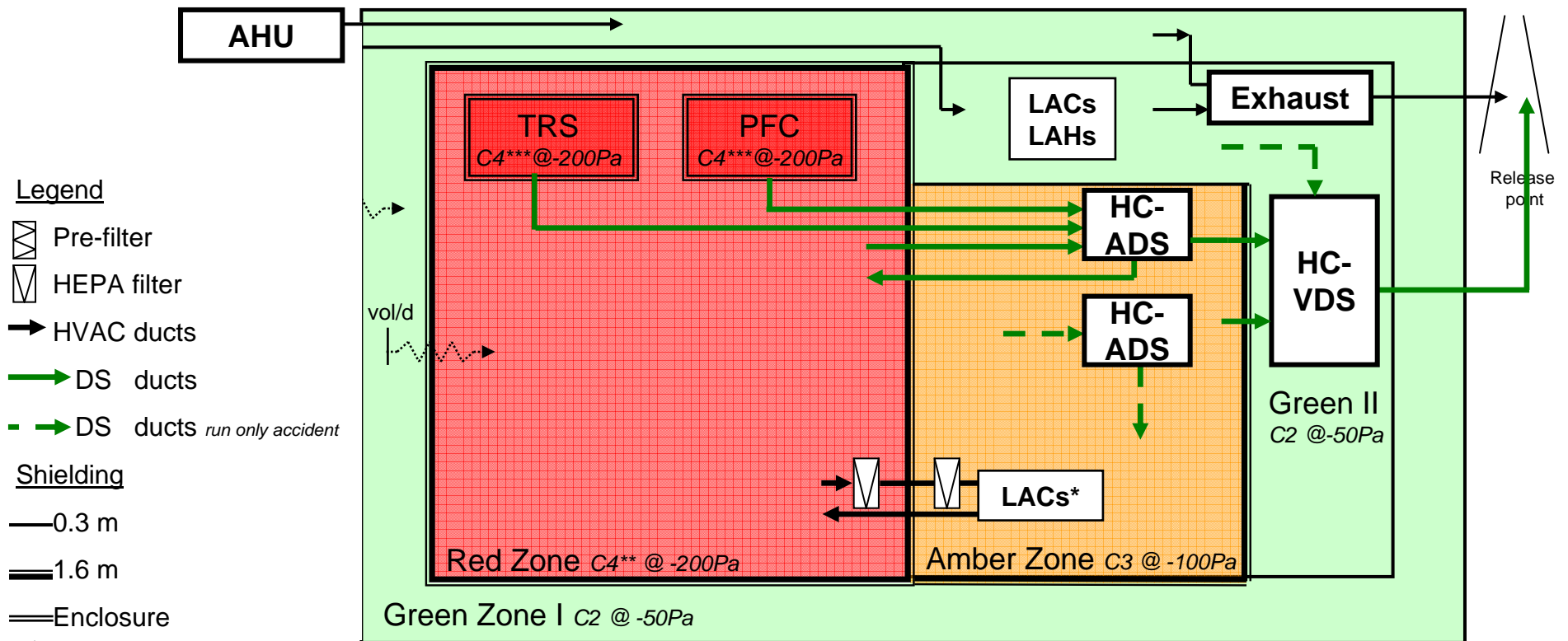


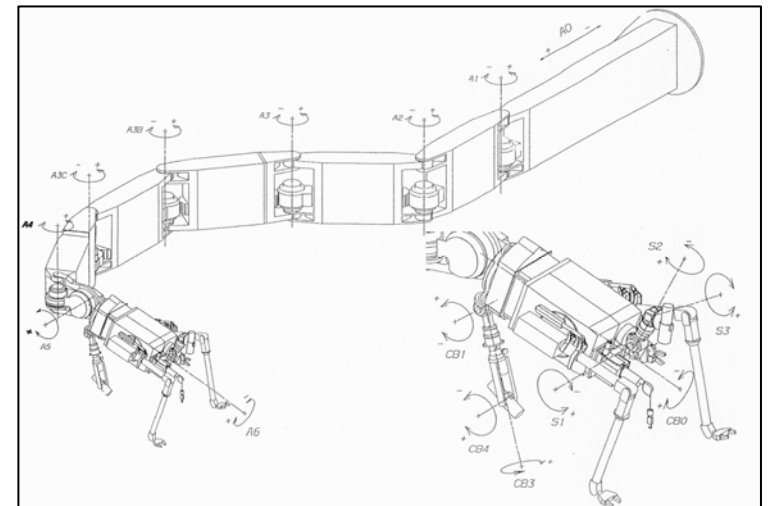
Figure reflecting System location and main proposal

LACs* and HC-ADS located in Amber zone (Exhaust flow from red zone)

HC-ADS : One module (or one blower) dedicated for Red zone. No AD function for Green zone

About remote handling issues – JET feedback

- JET is the only operating platform within fusion where Remote Handling techniques have been developed to a stage that allows in-vessel maintenance work to be carried out fully remotely.
- JET's in-house team developed the methodology and a rational approach that allowed them to succeed in this task
- Example: articulated boom
 - Introduced by one equatorial port
 - Power arm for positioning heavy loads
 - 500 kg max. payload
 - 12,3m long, can reach half of the Tokamak
 - 18 Degrees Of Freedom, 6 main articulations



About remote handling - duties

- The ITER Maintenance System is an essential tool **for the construction, operation and dismantling** of the ITER facility;
- All Remote Handling operations must be thoroughly prepared so that the in-vessel components flow smoothly between the vessel and the Hot Cell;
- The Remote Handling equipment must be highly reliable for a long period of time (radiation hardness, etc.);
- The Remote Handling System for in-vessel and Hot Cell operations must be fully proven before operations.

- The nominal maintenance of a fusion reactor is not only related simply to component replacement
- Supplementary tasks have become part of the nominal maintenance scheme and have often required the development of specific RH equipment:
 - Inspection for leaks, cleaning,
 - erosion measurement, as built metrology,
 - electrical connector replacement and checking,
 - sampling detritiation,
 - checking and re-tightening bolts,

Support for RH operations: RH equipment operating inside an area needs a huge amount of external backup :

- cubicles
- wiring
- storage areas
- maintenance and decommissioning areas
- ...

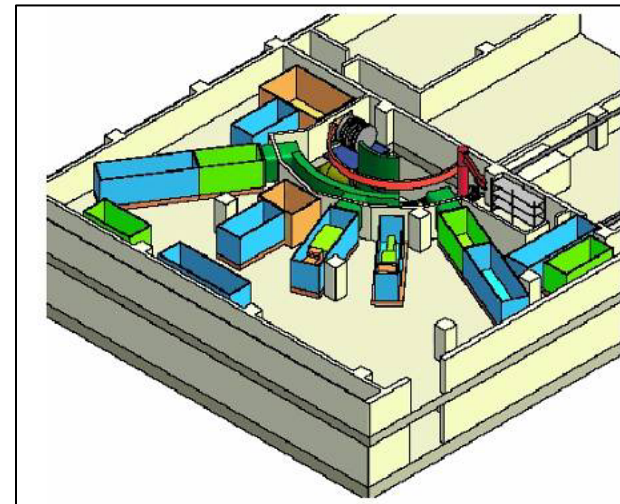
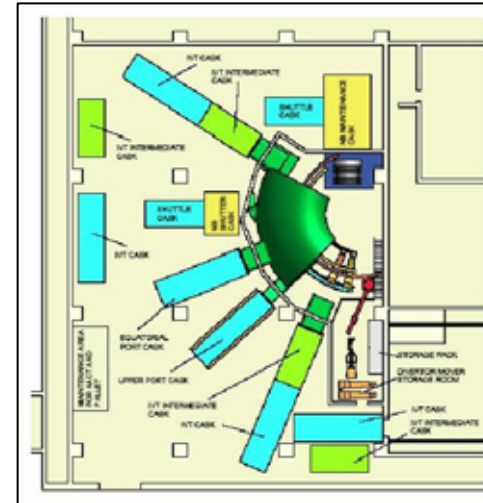
This takes up a large amount of space outside the working zone.

Remote handling classification

<i>RH Class</i>		<i>Components</i>
1	Components that require scheduled remote maintenance or replacement.	Divertor cassettes (54) Test blanket modules (3 plugs, 6 modules) NB filament/caesium oven Equatorial RH port limiter plug (2) Equatorial RH port diagnostics plug (4)
2	Components that do not require scheduled maintenance but are likely to require unscheduled or very infrequent remote maintenance.	Blanket modules (3- 6 modules) Cryopump valve ECH/ICH system plugs antennae (3 equator, 4 upper plugs) Diagnostic plugs (4 equator, 12 upper plugs) NB ion source caesium grid cleaning
3	Components not expected to require remote maintenance during the life time of ITER. The projected maintenance time in case of failure may be long.	Vacuum vessel cryopump (body), cryostat cryopump, port bellows, diagnostics, NB rear liner, thermal shields, magnet termination and module bypass joints, CS, TFC and PFC, vacuum vessel sector and other in cryostat components
4	Components that do not require remote maintenance or repair	Non-essential to ITER operation, with negligible risk of failure

Remote handling test facility – 3rd and 4th floors

- Final tuning of RH procedures in training facilities is essential to succeed during real operations
- JET's experience showed that considerable time could have been saved if personnel had been trained previously to perform in-vessel work
- The way followed by JET is to use a full size mock-up of the in-vessel environment.
- **A similar approach is foreseen for ITER through the construction of an on-site "RH Test stand".**



Summary

- **ITER Hot Cell Facility (HCF) (building 21) is designed to support the Tokamak during the assembly, commissioning, operation, de-activation and dismantling phases.**
- During past years, several designs were proposed for the ITER Hot Cell Facility.
- The 2008 design, based on the 2005 one, sets one's heart meeting all functional, technical and safety requirements. The 2008 design is currently being developed.
- **Interfaces with systems such as remote handling, port plugs testing, detritiation, radwaste and with the concrete structure** are being considered and analysed. Handling & transfers systems are also one important part of the current design activity. This second part of 2008 year is devoted to answer these challenging issues.
- Respectful of **safety project requirements and availability of the ITER machine**, optimization of design/layout is also a important criteria to be considered (thickness of walls, cranes, etc.).
- **Space allocations, services & utilities** of these systems are main input data in order to provide the layout for the comprehensive description of this facility.
- This will lead to deliver the materials required for the **future procurement arrangement of the ITER Hot Cell Facility**, and enable cost estimation being performed end of year 2008.

Thank you for your attention!

... what about joining the international panel of hot cells experts, for assessing the Hot Cell Facility operability? ...

... What is ITER? Let's see <http://www.iter.org/> !

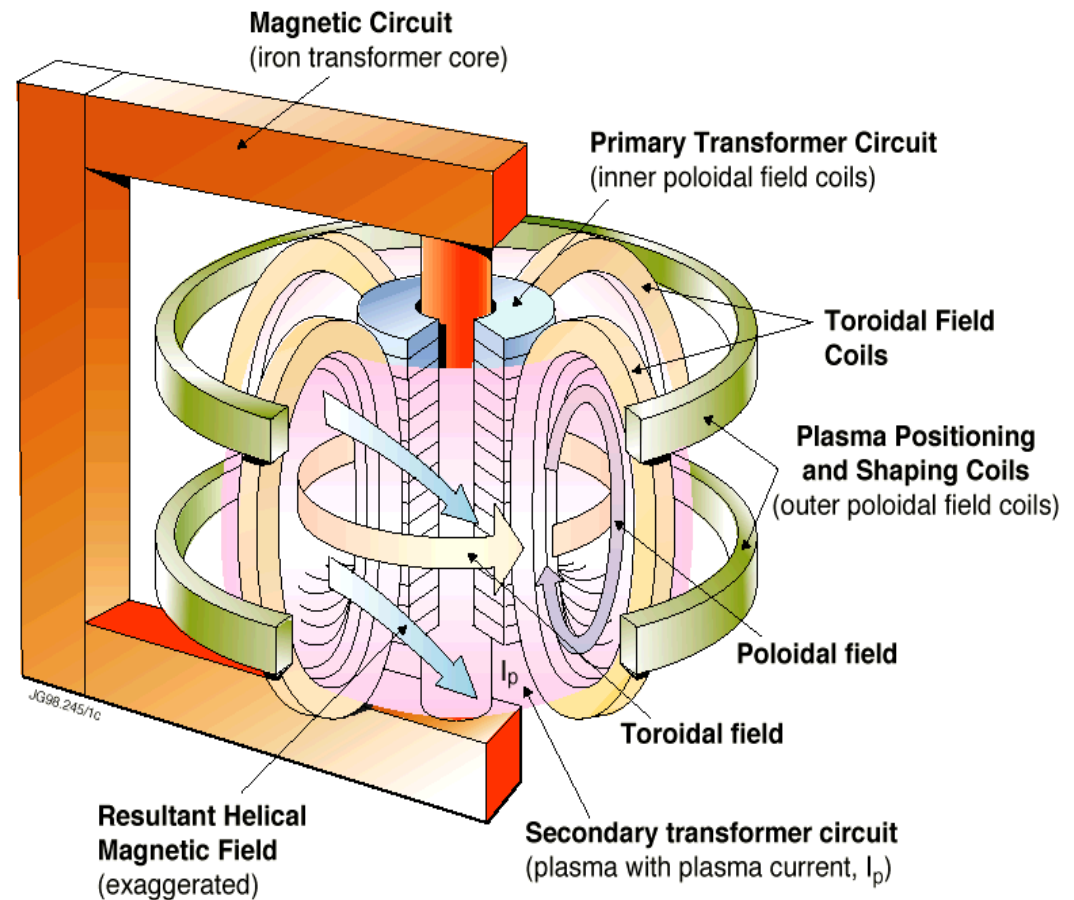
Back-up slides

The Tokamak

The major toroidal magnetic confinement configuration

The Tokamak:

- operationally, is essentially an **electrical transformer**
- **toroidal** magnetic field is produced by external magnetic field coils
- plasma current produces **poloidal** magnetic field
- result is a set of nested **helical surfaces**
⇒ **plasma confinement**

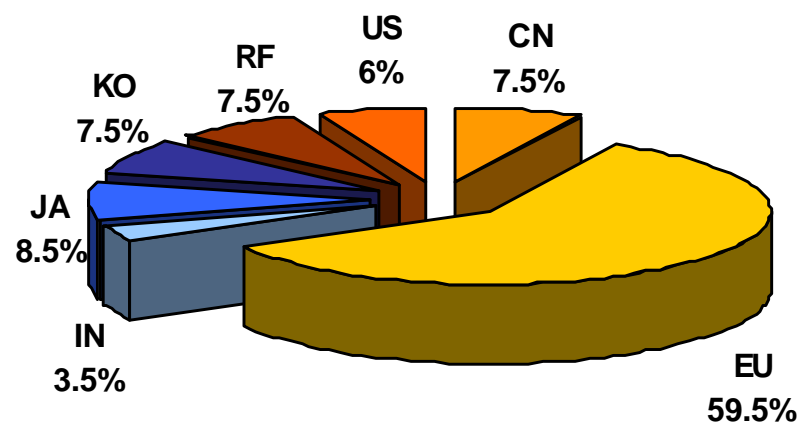


ITER Professional Staff by Members Status: 31 August 2008

Professional staff
by Members as
of 31 August
2008:

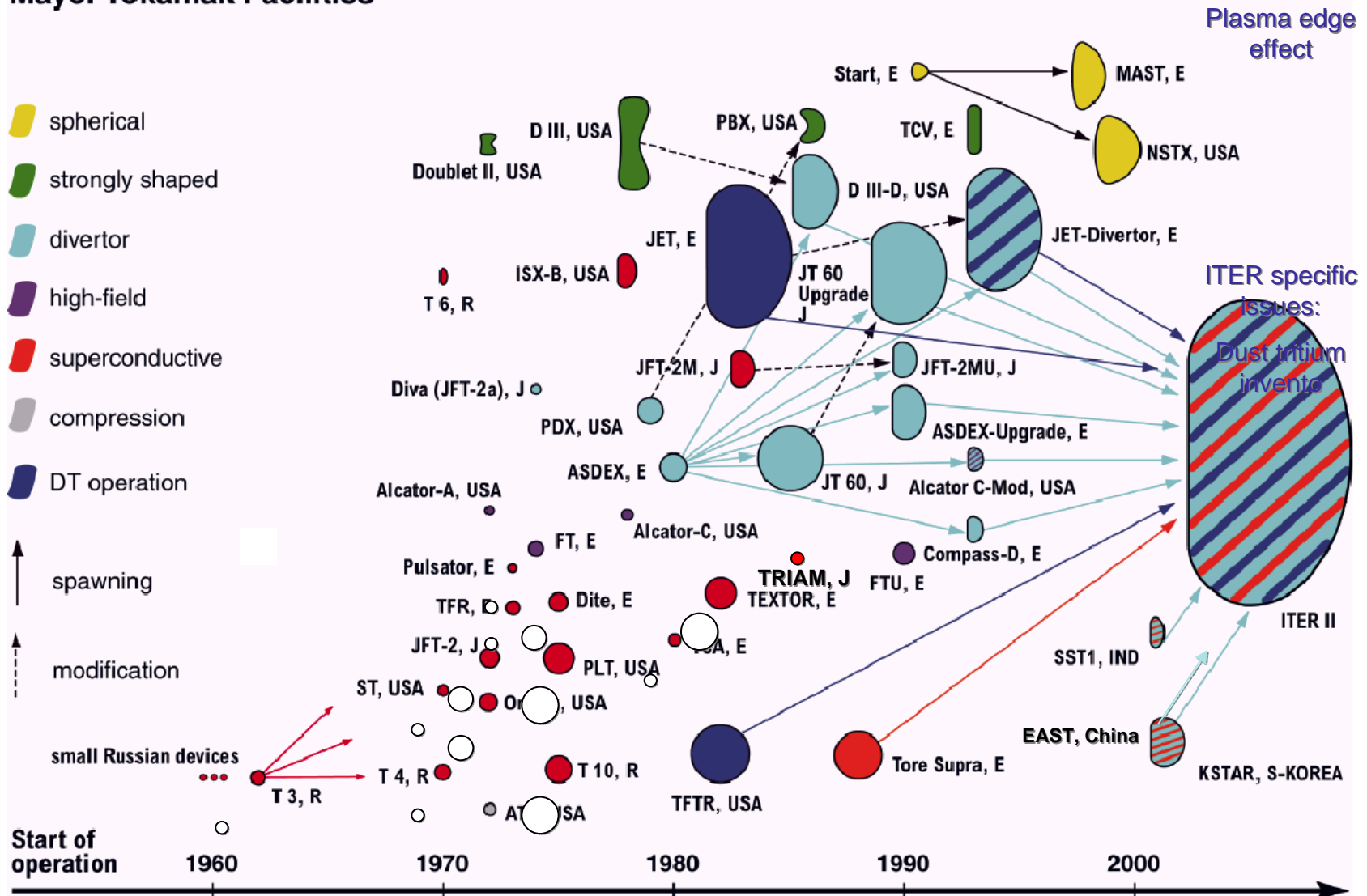
Total = 285

Total of 22 nationalities

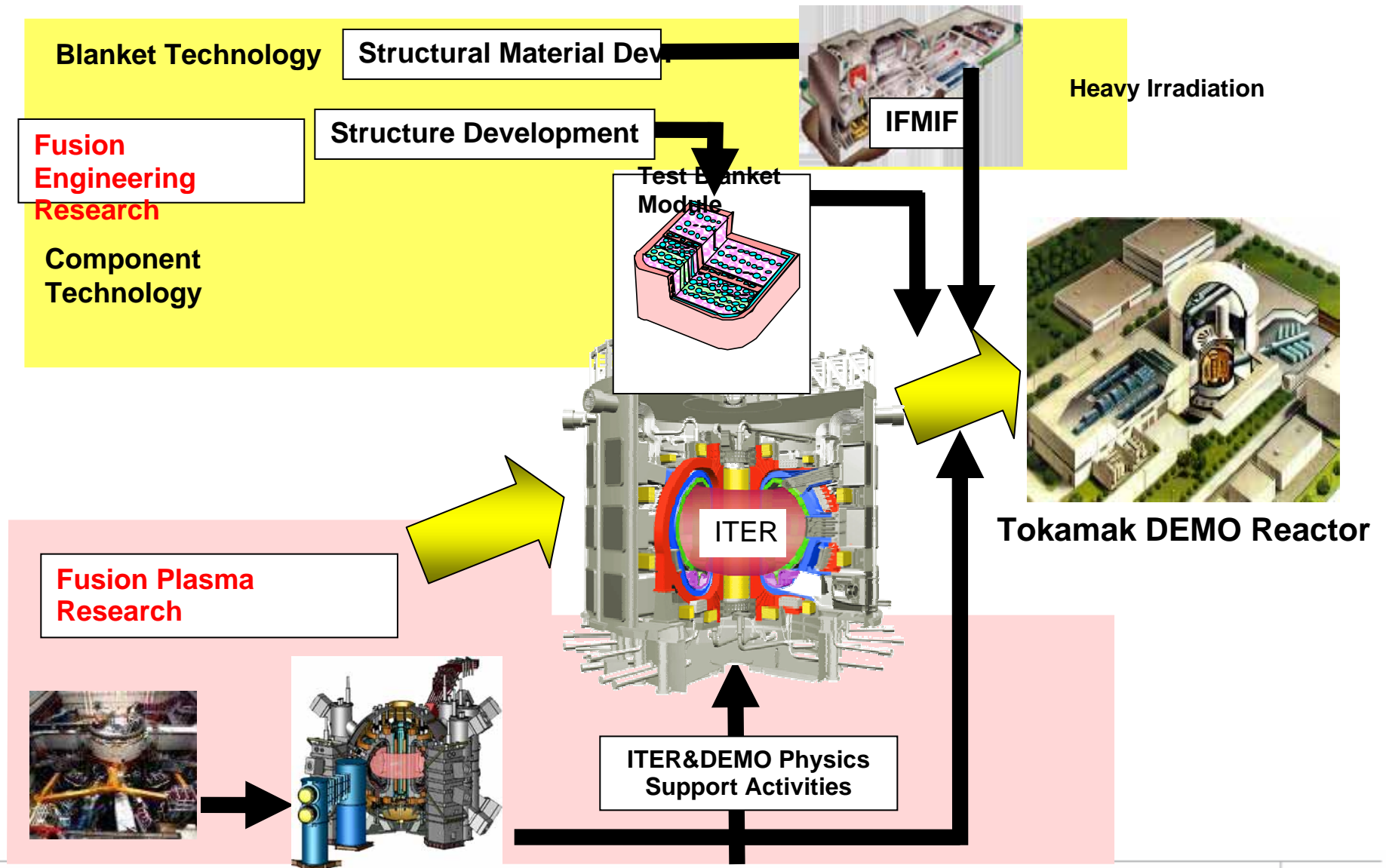


ITER, one of a kind, but not the first fusion facility

Mayor Tokamak Facilities



Road Map to Fusion: The DEMO Reactor



Tritium confinement concept - 5/5



HEPA filter, shielded



HEPA filter



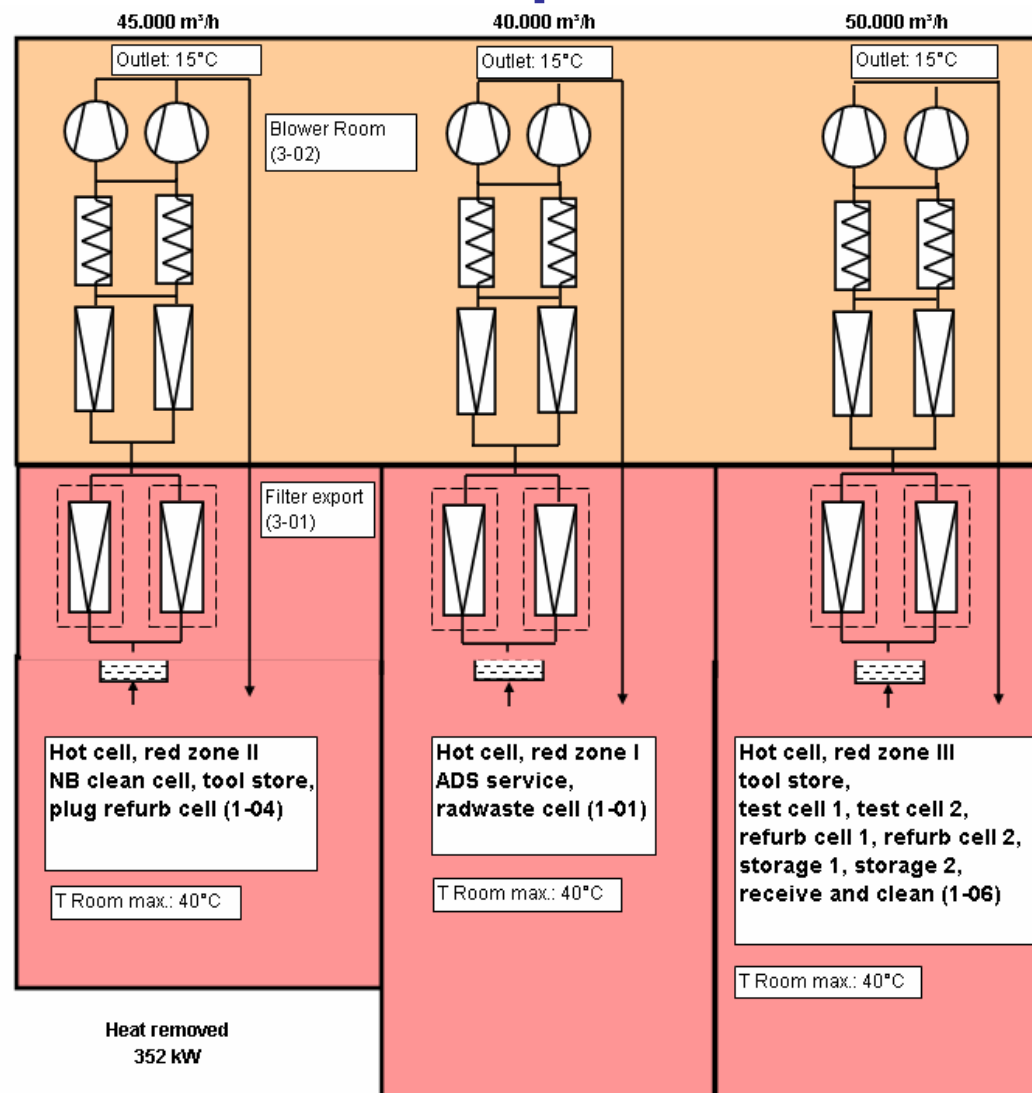
chilled water air cooler



spark arrester



blower



Sum Heat removed: 1,06 MW
Chilled water requ.: 42 kg/s

Heat removed
313 kW

Heat removed
391 kW

-
- 2007 International Summer School on Fusion Technologies, J-P. MARTINS et al., Topic 10 – Remote Handling, Maintenance Schemes, September 2007