The Remote Handling Systems for ITER

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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

**Refurbishment or disposal as radwaste**
Where Remote Handling in ITER?

Refurbishment or disposal as radwaste

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

JET
- Torus diameter = 6m
- Plasma volume = 80 m³
- Fusion Power ~16 MWth

ITER
- Torus diameter = 12m
- Plasma volume = 800 m³
- Fusion Power ~500 MWth
ITER RH vs JET RH

ITER RH overcomes JET RH by orders of magnitude

- **number** of RH components/ devices/ interfaces ($\sim 10^2$)
- **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.

$10^n \times$
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

- Multi-Purpose Deployer
- In-vessel Viewing System
- Transfer Cask System
- Divertor Cassette

Blanket modules

Hot Cell Building
ITER Remote Handling Systems

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Blanket RH System | Purpose

- **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

**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 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.

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

Rail supported through 3 VV ports.
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

Rail

Blanket (4 ton)

Manipulator

Key

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

JAPT
Tokai
Japan
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

- Cable handling Equipment

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

- DF Sensors in Manipulator

- 1.7 m Blanket (4 ton)

- Rail and Cross-section of Cable
ITER Remote Handling Systems

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Divertor RH System

- 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/m²

- Divertor cassettes are refurbished or disposed as radwaste at the HCB

Maintenance frequency

Exchange of the whole divertor 3 times during the 20 years of ITER operation
Divertor RH System

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

Divertor cassette
Divertor RH System | Components

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)
50 TCS journeys to extract 18 divertor cassettes and to take them to the HCB
Divertor RH System

Extraction of standard cassette
Divertor Test Platform 2 (DTP2)

CMM | Divertor Cassette Installation
ITER Remote Handling Systems

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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

Six installation ports: #03, 05, 09, 11, 15, 17.

6 probes whose directions are quasi-radial, converging in couples (this offset is in order to reduce the toroidal distance given the non-uniform spacing of the IVVS ports).
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 Vacuum conditions
- High temperature ≤ 240º
- Gamma Radiation dose rate up to 5KGY/hour
- Total radiation dose up to 10MGY
- Total neutron fluence up to $5 \times 10^{13}$ n/cm$^2$
- Magnetic field up to 8 Tesla
In-Vessel Viewing System | Results

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

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

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

Resolution map obtained on divertor ITER geometry

ENA, Italy
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Multi-Purpose Deployer (MPD) | Purpose

- 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

- 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
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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** without hands-on assistance
Transfer Cask System (TCS) | components

- **Cask Envelope**
- **Pallet**
- **ATS=Air Transfer System**

**Cask envelope**
- Different TCS configurations
- 8.5m (length) x 2.62m (width) x 3.62m (height)
- Wall cooling system
- Double seal door
- Floor

**In-cask equipment**
- Upper plug
- Eq plug
- Divertor

**Drive/steering wheels**
- Air casters
- Swivel wheels
Transfer Cask System (TCS) | Trajectories

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

Criteria:
- Maximum distance from obstacles
- Smoothness
- Safety distance to closest obstacles = 30cm

Trajectories may have maneuvers whenever necessary.
TB Divertor Level from lift to VV port # 7
Transfer Cask System (TCS) | trajectories

TB Divertor Level from lift to VV port # 7

Distance to obstacles (cm)

Velocity (cm/s)
Transfer Cask System (TCS) | VR model

3D Virtual Reality model, with HMI functionalities
- TCS operating mode
- Virtual cameras (in TCS and environment)
Transfer Cask System (TCS) | VR model

3D Virtual Reality model, with HMI functionalities
- TCS operating mode
- Virtual cameras (in TCS and environment)
• 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
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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
Main functions to be performed 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

Divertor Cassette Refurbishment
Cassette Reception

Plugs Refurbishment
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.
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THANK YOU FOR YOUR ATTENTION