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Overview of the ITER remote maintenance design and of the development activities in Europe

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ABSTRACT

For a first-of-a-kind nuclear fusion reactor like ITER, remote maintainability of neutron-activated and contaminated components is one of the key aspects of plant design and operations, hence a fundamental ingredient of its success, as well as of the demonstration of long-term viability of fusion as an energy source. The whole ITER Remote Maintenance System (IRMS) is of unprecedented complexity and includes specifically developed technologies. Its procurement and start of operation will represent a major innovation to maintenance in hostile environments.

Europe is a key contributor, with three remote handling (RH) systems, a.k.a. packages, plus a robotic inspection and metrology tool, currently under design. This paper gives an update on the status of design and procurement activities related to the IRMS. It will first introduce some key aspects of the reactor remote maintainability, and then give an overview of the present configuration of the global system. After this, the scope, status and challenges of the European (EU) packages will be illustrated in more detail, together with some key technological developments.

Finally, the way all these efforts are coordinated will be presented together with the overall implementation scenario and milestones, and the way they fit with ITER construction and operation.

1. Introduction

ITER is first-of-a-kind nuclear fusion reactor in many aspects, including those related to its maintenance [1].

The fact that, soon after the start of the D-T phase, the reactor will become inaccessible to direct human intervention for decades, combined with the complexity of accurate handling of multi-tons components in hostile, space-constrained environment with severe direct viewing limitations, implies that remote handling in ITER is novel, when compared to both present fusion devices and nuclear fission plants. The complicated topology of ITER and of reactor and hot cell buildings is another element to add to the big picture.

As a consequence, special effort has been devoted, and is still on going, to ensure remote handling compatibility of the many components subject to maintenance (blanket, divertor etc.) and of the ITER plant layout (in the tokamak and hot cell areas). At the same time, in parallel with the design of the RHRH systems, some specific technological developments are under way to make sure that the remote maintenance tasks during the ITER nuclear phase will be safe and reliable.

ITER RH will therefore represent a major innovation that will generate significant advances in the fusion community and in the industry. All this experience will be beneficial for DEMO (the first nuclear fusion device meant to produce electricity) and RH industry in general.

In this paper an update is given on ITER RH design, and on procurement and technological development activities in Europe [2]. It is also shown how the EU delivery and installation schedule fits within the overall ITER schedule.

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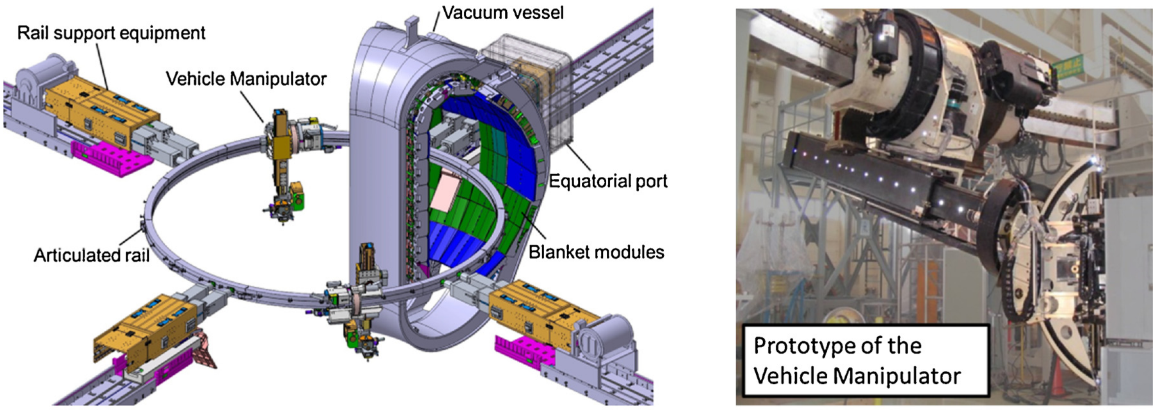


a. b.

Fig. 1. a) BRHS overview. b) BRHS prototype tests.

2. The ITER remote maintenance system

In ITER, the blanket and divertor systems intercept ~98% of the neutrons produced during plasma pulses. Mainly due to the activation of stainless steel, the level of gamma radioactivity inside the vacuum vessel (VV), after a series of long, high power D-T operations, will be in the order of 100 Gy/h at the start of a shut-down, i.e. 10^6 seconds after the last plasma pulse (unpublished report "Vessel LTM Radiation Map" by H. Labidi, Doc ITER U8VUEB, 21.06.2017). Considering Co-60 as the main contributor to residual radioactivity in the longer term, in order to go down by a factor 2^{20} ($\sim 10^6$) – hence below 100 μGy/h, where direct human intervention starts to be foreseeable – 20 Co-60 half-lives, i.e. ~105 years, are needed. In other words, once it goes nuclear, the ITER tokamak will become a remote world to its operators for a century.

During shutdown, other peripheral areas of the reactor, like port cells and galleries, will also be inaccessible once bio-shield and port plugs are removed and transportation of activated-contaminated components takes place. This shows how important both remote handling compatibility of the ITER components, and the effectiveness, reliability (including recoverability from failure) and safety of the RH devices are to the future success of the ITER project.

Actually, the number of coils; the in-vessel component segmentation; the size, location and features of heating and diagnostics plugs and of the Neutral Beam injectors; the tokamak building internal layout; the hot cell (HC) design: all these are the result of a compromise between operational and maintenance needs.

In the following sections some of these aspects will be further illustrated. In broad terms, ITER RH can be divided in two main categories, i.e. in-vessel and ex-vessel maintenance, the last one referring to all those components that are at the tokamak "borders" – various kind of "plugs" in the VV ports, plus the Neutral Beam Injectors – or to the operations occurring in the hot cell, typically replacement/repair of components (or parts of). In vessel RH on blanket and divertor has to face a higher level of radioactivity, and in general lower accessibility and visibility. It also requires a significant deployment of equipment from the entry ports. Overall, it is more challenging. For this reason, and also because the core tokamak systems have been defined first in the ITER project, in-vessel maintenance has historically received earlier attention and is presently more developed. Nonetheless, design solutions and technologies from in-vessel maintenance can be made common to all RH systems irrespective of where they operate and this is clearly advantageous in terms of procurement and operation costs.

In the next sections the RH systems will be illustrated. They are treated separately as they have different functionalities, but in ITER they will act as a whole, coordinated, Remote Maintenance System.

2.1. Blanket remote handling system (BRHS)

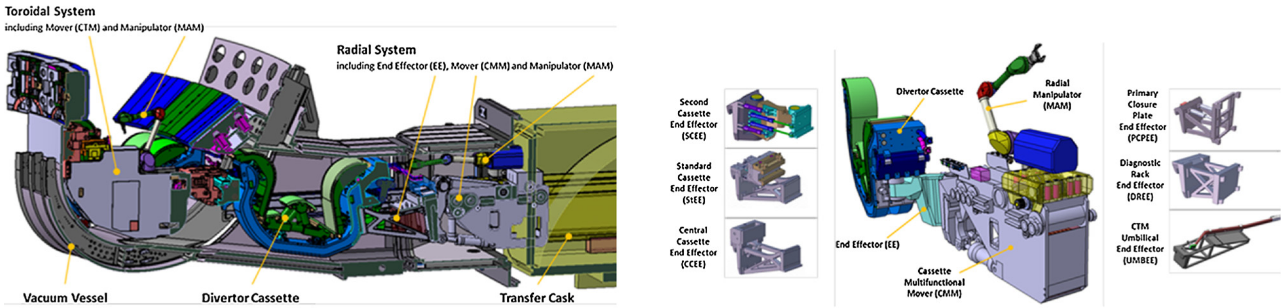
The ITER blanket [3] is segmented in 440 modules (BMs, each poloidal row being made of up to 18 modules), whose approximate max dimensions and weight in meters and tons are 1.4 × 1 × 0.45 and 4.5, respectively. Each BM is made of a First Wall Panel (FW) detachable from a bulky shield block module (SB).

Such modularity has been decided, given the experimental nature of ITER, to maximize the flexibility of maintenance, allowing for replacement of individual FW panels and, where needed, of their underlying SB (but there are a few locations where a SB is trapped by the surrounding modules). An alternative segmentation has been chosen in DEMO [4,5], where bulky "banana" blankets (5 per VV sector, each obtained by "merging" all the inboard modules and all the outboard ones belonging to the same poloidal row, respectively) are adopted in the design. This second scheme is challenging because it requires handling of much more massive elements, whose integral neutron activation scales up accordingly, and therefore is more complicated also for ex-vessel transportation and radioactivity (with heavier impact on building layout, radioprotection and rad-waste management). On the other hand, the price to pay for ITER finer modularity resides in the fact that the BRHS has to be deployed in the center of the vacuum vessel, which is mechanically much more complicated than lifting from the top a blanket segment like in DEMO, and also in the fact that the RH equipment has to operate exactly where there is the highest level of gamma radioactivity (up to ~500 Gy/h). This implies more challenging requirements on radiation hardness of sensitive components like motors, sensors, cables. In addition, accessibility of the cooling pipes is also more problematic, as well as re-weldability of irradiated pipes.

The BRHS consists in a cask-based, self-deployable monorail system that carries a bulky gripper able to reach, unlock and take away the FW/SB. Complementary tasks are performed by manipulators and tooling assisting the main transporter. Two casks (one short, one long) are docked in series to the allocated equatorial ports, previously emptied of the plug installed there. Actually the blanket maintenance involves a complex series of preparatory works in the port cell (partly performed with hands-on assistance, depending on accessibility and radiation levels) before the BRHS deployment into the vessel can start. The BMs are taken away by the outer cask to the HC. See Fig. 1 below.

Blanket geometry and weight, required accuracy, hostile environment, pipe welding, cutting and inspection, BRHS recovery after failure are among the key technical challenges, together with the integration of this RH device with the hosting casks system (Section 2.3) and the overall logistics.

The BRHS can be deployed in 3 toroidal configurations, i.e. 100° with two access ports, 180° with three access ports, and 360° with four access ports for complete blanket change over (it could last up to two



a. b.

Fig. 2. a) DRHS overview. b) DRHS: details of the radial system.

years), during which human access to the tokamak building equatorial level is partially or totally precluded.

The ITER Japanese Domestic Agency is in charge of the BRHS procurement until installation and site acceptance. The hand-over to ITER Organisation (IO CT) will occur well in advance to the BRHS first operation during the blanket assembly phase (planned in 2027–2028). Presently the design for the system is on-going and the monorail system including the main transporter is almost finalized [6], supported by structural and Reliability Availability Maintainability Inspectability (RAMI) analyses [7,8], as well as by R&D activities including irradiation tests [9].

2.2. Divertor remote handling system (DRHS)

The divertor is broken down in 54 cassettes, to be accessed from 3 lower ports at 120° toroidal angle each other (Fig. 2a). Diagnostics racks in the access ducts are removed first.

Therefore, the cassettes can only be removed serially, starting with the ones located at the access ports [10]. Like for the blanket, the basic handling tasks are cooling pipe cutting, cassette unlocking and cantilever transportation (as there is no space beneath the cassette for inserting a carriage). The technical challenges in this respect are therefore similar to the BRHS ones. A complete cassette change-over is scheduled during ITER lifetime (RH class 1), and has to be performed within 6 months, with each one of the 3 ports utilized in series. During this time the divertor level of the tokamak building will remain partly inaccessible to personnel.

The DRHS is composed of two basic devices: the Cassette Multifunctional Mover (CMM) able to travel radially and remove the 1st cassette and the 2 cassettes left and right to the 1st one, and to transport the Cassette Toroidal Mover (CTM). This one in turn enters the vessel and removes toroidally all the other cassettes (7 on the left and 8 on the right of the entry port) and hands them over to the CMM. This one, finally, travels back to the cask docked to the VV port to return to the Hot Cell with the removed cassette on board.

Each mover is equipped with a suite of rad-hard force feedback manipulator, tooling, cameras and sensors. To ensure a long lifetime of these components compared to the number of hours spent in vessel during a shutdown, the components must be 1-MGy-rated. The DRHS is complemented by pipe isolators in the port cell that enable opening the cooling lines and inserting an in bore alignment and/or inspection tool to support pipe cutting and welding (after the challenging task of pipe joining).

It is worth to notice that, being the DEMO divertor concept similar to the ITER one, their DRHS are similar too (but due to harsher radiation conditions, only CMM is foreseen which operates from all the divertor ports).

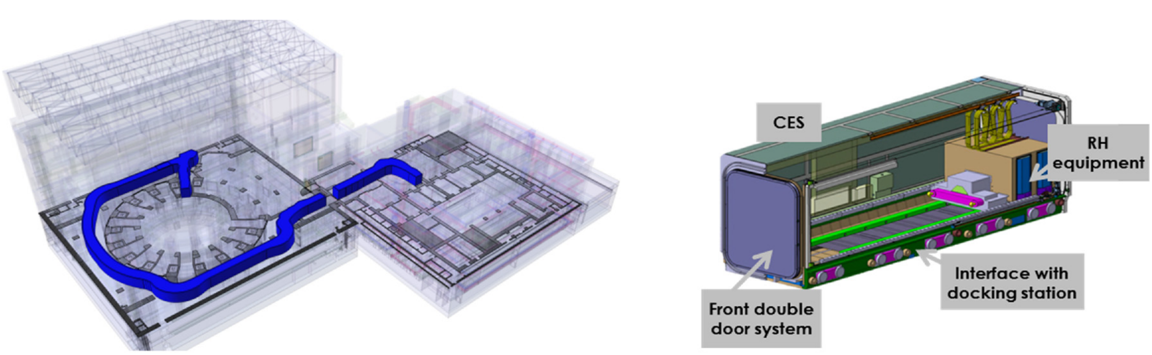
Fig. 2 includes snapshots giving some of the DRHS details.

2.3. Cask and plug remote handling system (CPRHS)

The CPRHS consists in a fleet of 15 casks, of different typologies and sizes, able to travel across the tokamak and hot cell buildings and dock to VV ports and hot cell docking station to deliver RH equipment (like BRHS and DRHS) and components (blanket, divertor, plugs etc.), [11]. The layout of these two buildings indeed has been defined also in order to be compatible with the swept volumes of the casks, indicative dimensions in m 8.5 × 2.6 × 3.5 (Fig. 3a).

These casks are therefore at the heart of ITER RH, ensuring access to the vessel, deployment of the other RH systems, and nuclear confinement during transportation. To stay within the 100-ton ITER cargo lift capacity during the transportation of a ~50 tons heating or diagnostic equatorial plug, these units are unshielded to limit the weight and have to travel without any operator around (hence are RH devices). Indeed access to the tokamak building is prohibited when this happens (during the night shift) and port cell and cargo lift doors are also opened/closed remotely.

Nuclear confinement, autonomous power, wireless navigation,



a. b.

Fig. 3. a) Example of cask trajectory between tokamak building and HC. b) Equatorial cask details.

accurate docking, system logistics are among the specific challenges of the CPRHS. In terms of radiation hardness, being ex-vessel and dealing with transportation of individual components or small groups of them (e.g. the blanket modules mentioned before), the requirements are less stringent compared to DRHS.

It is worth to mention that in DEMO, with its bulky, ~80 ton banana blankets, the casks are much bigger and have a much deeper impact on the plant layout. Fig. 3 illustrates some features of CPRHS.

2.4. In vessel viewing system (IVVS)

An inspection inside the ITER vessel in between nuclear pulses (e.g. overnight), to verify that the status of the damaged surfaces facing the plasma and the level of their erosion is still acceptable for safe operations, is far from being trivial, considering the environmental conditions: VV chamber totally dark, level of gamma radioactivity > 1 kGy/h, multi-Tesla magnetic field, Ultra High Vacuum, temperature close to 100 °C.

The 6 identical IVVS plugs do exactly this [12]. Parked in the VV in a relatively protected port extension during plasma pulses, they enter into the main chamber by means of their RH deployment systems. Each IVVS probe, at the tip of the device, scans 1/6 of the surfaces of the in-vessel components: by means of a front end rotating prism, a ~1 mm^2, amplitude modulated, near infrared laser ray of 10 mW illuminates the surface and the back scattered light is compared with the incident light. This way, a grey scale snapshot can be reconstructed after the individual "pixels" are combined together, and a 3-D profile of the surfaces is also obtained by such cloud of points (which are the prism-target measured distance). As the inspected surface area is ~1000 m^2, it results that the global illuminating power of the six IVVS probes together is close to 10 MW.

By treating properly the cloud of points, hence the reconstructed surfaces, the changes due to erosion/deposition of Be (from blanket FW) and W (Divertor) can be estimated, provided the original surfaces can be superimposed to the modified ones. From there, combined with other local measurements by other diagnostics, the amount of dust present in the vacuum vessel can be inferred. It is important to detect with sufficient accuracy how such amount stays below the established limit of 10^3 Kg, set to avoid excessive overpressure in case of explosive interaction between dust and hot water in accidental conditions. For this, it has been estimated that the IVVS measured distance accuracy must be at the level of ~0.1 mm.

In addition to remote operation, specific challenges of the IVVS design include the required accuracy, and compatibility with vacuum, magnetic field, temperature (including baking at ~120°) neutrons and gammas [13,14]. Fig. 4 provides an overview of the system as it stands today.

2.5. Neutral beam remote handling system (NBRHS)

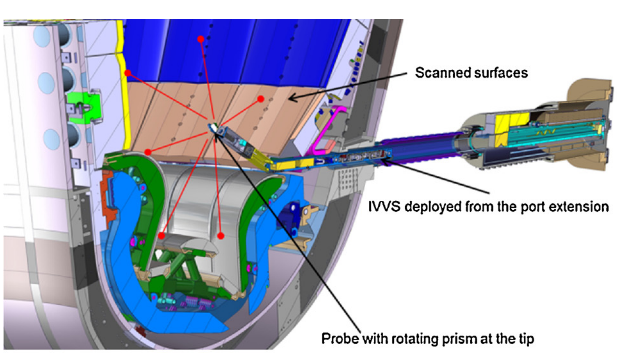
The NB cell is a complex, confined environment at equatorial level, extending to the upper floor, where 3 massive heating and 1 "smaller" diagnostic NB injectors are located. In the same cell, there are other systems and components located like 4 upper port plugs (in a mezzanine area) and the vacuum vessel suppression system (VVPSS) line. The VVPSS intervenes in case of overpressure into the vacuum vessel originated by accidental injection of cooling water: the line is therefore opened and the water vapor (and suspended radioactive dust) is channeled by the pipes to suppression tanks in the floor below the NB cell.

The HNB components are those expected requiring likely maintenance as they have to handle significant amount of "wasted" power (~33 MW per injector, whit ~16 more actually delivered to the plasma) during the plasma pulses; whereas the Cesium oven, needed for negative deuterium ion production, and located in the NB source, requires regular replacement. On the other hand, the upper port plugs are classified as not requiring maintenance during ITER lifetime but this cannot be totally excluded. The rear of the NB cell, with all injectors closed, is accessible to personnel for short intervention, while it is not once the NB injector maintenance starts (> 100 μSv/h).

The injector maintenance concept is based on individual replacement of components thanks to vertical access from a top lid (beam line components) or rear door (beam source-accelerator) [15]. This ensures maintenance flexibility as only the failed/damaged items have to be removed once access to them has been granted. After removal, these components are delivered to a platform near the NB cell exit. From there, they are transferred to a cask docked just outside, in a hot cell corridor, from where they are moved to the HC in order to be disposed and replaced. Overall, the NB cell can be conceived like a sort of hot cell where crane, manipulators, and tooling are required for a variety of complex tasks. The nature of such tasks is not dissimilar to those mentioned for BRHS and DRHS, as it still consists in opening doors, disconnecting pipelines and electrical cables, unlocking and lifting massive components with millimetric accuracy. The milder radioactive environment (~1 Gy/h) implies a longer lifetime for the NBRHS radiation-sensitive components.

The main RH device is represented by the 40-ton monorail crane, able to move around the various components following a complex pattern that includes switching points from where different rail branches can be accessed. The crane is complemented by manipulator arms (that can be located on different transport devices), a variety of tooling, lifting frames, special handling tool for the ion source-accelerator, etc.

The opening of the HNB rectangular top lid (~3 × 9m^2) and handling of the related metallic O-ring, the cutting/welding of ~200 mm diameter cooling pipes, the access to a constrained and congested space, the ~20-ton ion source-accelerator, are all very complex RH operations to be considered among the others needed in



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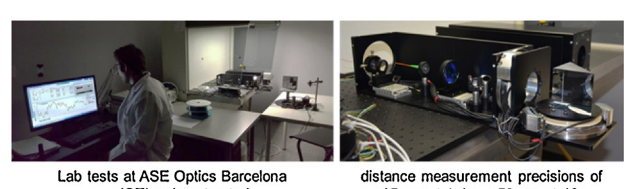


b.

Fig. 4. a) IVVS overview. b) IVVS optical design.

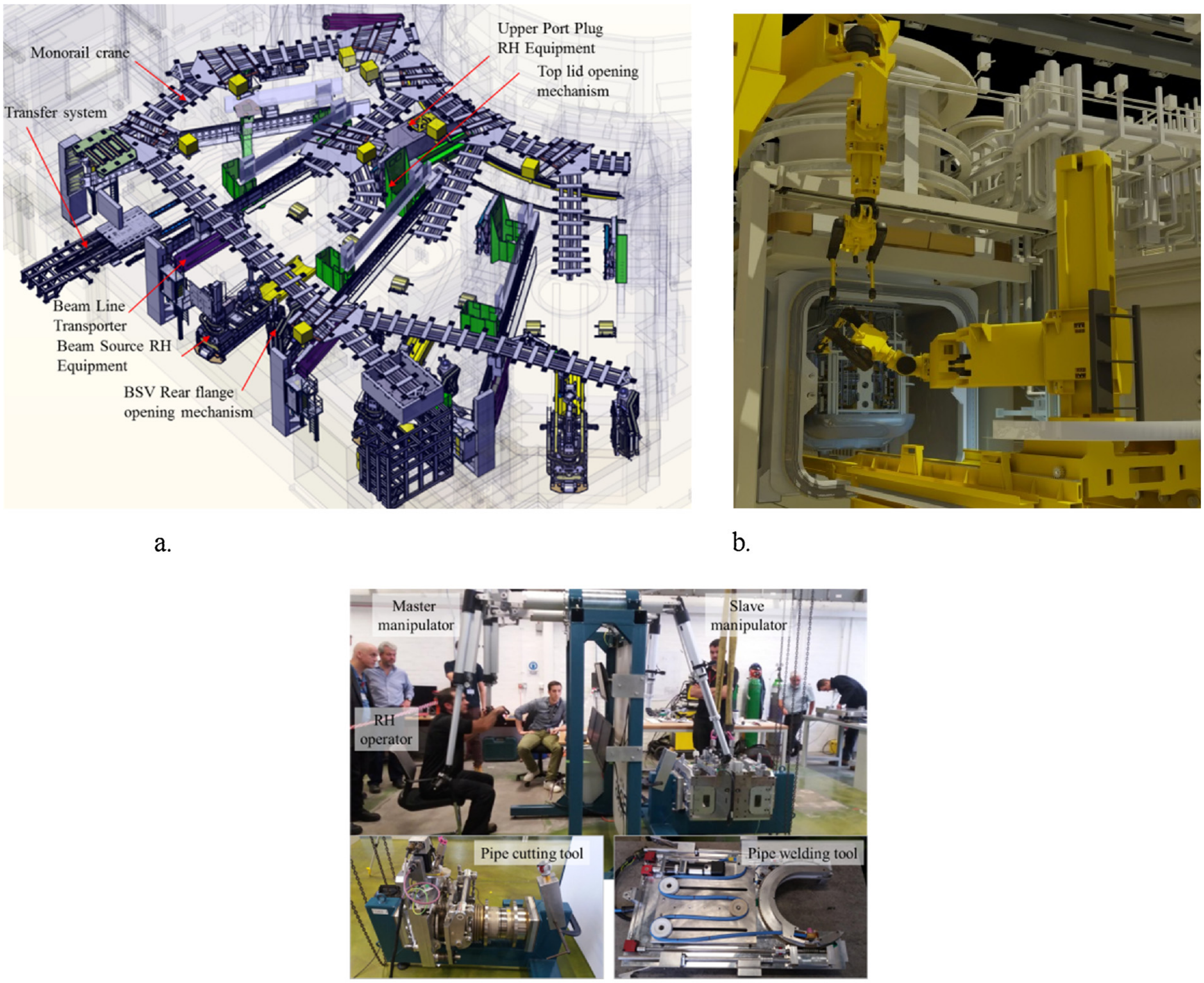


Fig. 5. a) NBRHS overview (injectors not shown). b) Example of NBRHS operations on beam source. c) NBRHS tests.

the NB cell (Fig. 5). The intricate layout of the NB cell also implies a complex maintenance logistics.

Recently, the VVPSS layout has been modified and the components that require inspection and maintenance (bleed valves and rupture discs) are located inside the cell, between the HNB injectors (Fig. 6).

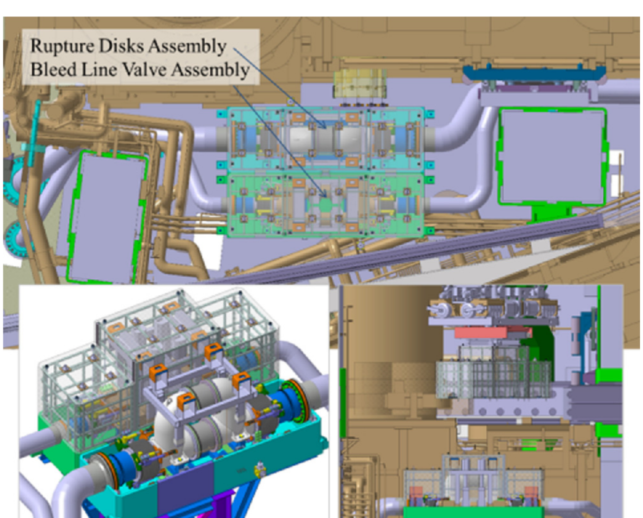


Fig. 6. VVPSS lines in the NB cell.

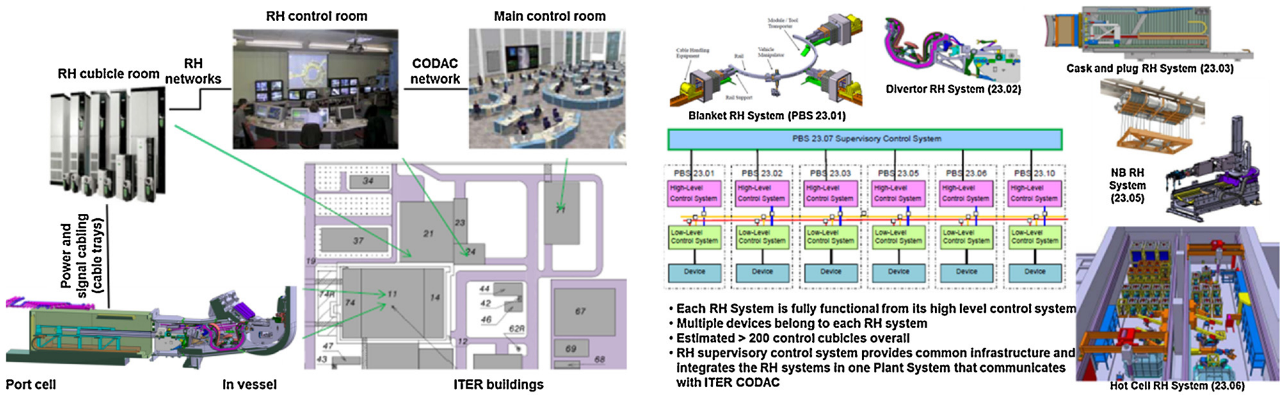
Therefore, a new branch of the crane rail has been added, and a series of new VVPSS-specific RH tooling has been added.

2.6. Hot cell equipment (HCRHS)

The ITER Hot Cell is a large, multi-store building connected via a cargo lift to the adjacent tokamak building. The same lift also allows transfer of components between the various HC levels. The casks described in Section 2.3 ensure confined transfer of components from/to the HC areas, some of them totally inaccessible to human intervention (red zones) given the level of radioactivity and contamination (including Be dust chemical toxicity). In a reinforced concrete structure a complicated internal lay-out ensures the following operations [16]:

- Delivery of components from the VV (blanket, divertor, plugs etc.) and possible refurbishment or
- Preparation of items (e.g. size reduction) for disposal as rad-waste (waste management)
- Inspection and cleaning/decontamination
- Test of repaired components (e.g. port plug test facility)
- Maintenance/repair and test of the other RH equipment (see previous sections)
- Parking/storage of casks and in-cask equipment

The Hot Cell is always in operation during ITER life, both in shutdown time – when a peak of activities involves the various RH devices



a. b.

Fig. 7. a) IRMS in the ITER plant. b) RHCS architecture.

operating from the HC docking stations in order to deliver old components from the tokamak and take back new ones for installation – and during plasma pulses, when a series of maintenance and repair works, including periodic tests on the various RH equipment, are performed. To fulfil these functions, the HC is populated by a variety of RH cranes and other lifting devices (e.g. Fig. 7b bottom right), manipulators, tooling not dissimilar in nature by those mentioned in the previous sections.

Because it involves a reduced number of components to be handled at a given time, compared to the in-vessel maintenance the level of radioactivity is one order of magnitude lower, hence the lifetime of the RH equipment is proportionally longer. The main challenges relate to the complexity and variety of tasks to be performed, among which the need to clean the RH devices, before they can be accessed by personnel for inspection, pre-emptive maintenance or repair.

The HC building is presently being defined at concept level together with its permanently resident RH devices. The latter, which are under procurement responsibility of IO CT, will benefit from design and technological advances coming from the other, more advanced RH packages described in the previous sections.

2.7. RH control system (RHCS)

From the previous sections it is evident that the IRMS is a diffused system in the ITER plant, that is always deployed in the HC during ITER plasma operation, and also inside tokamak building and VV during shutdown.

Actually, the RH devices are operated as an overall coordinated entity from a specific control room located in the HC complex. A system of cabling, cabinets and Wi-Fi connections where needed (e.g. during cask travelling) is embedded in the ITER plant. The RH control room will be at the heart of reactor operations when in shutdown, with the main control room for plasma operation ensuring the needed plant nuclear safety supervision. During the plasma pulses, the RHCS will still control the IRMS operated or parked in the hot cell building. The communication-coordination layer between RHCS and the rest of the ITER plant is ensured by the supervisory system. This system is fundamental in a variety of situations, e.g. cask and cargo lift coordination; cask docking to the VV; DRHS deployment inside the HC cleaning area; etc. IO CT is in charge of the supervisory system procurement; a tender process for its design and manufacture is in progress.

The main components of the RHCS are, from the operator point of view, the human machine interface, the viewing system, and the virtual reality system that complement and enhances the other two systems. It must be stressed that, being the VV totally inaccessible during maintenance, the effectiveness, reliability and safety of the RHCS is as important as those of the field equipment. Fig. 7 shows some features of the RHCS.

3. European design and development activities

Europe is in charge of procuring in kind a significant number of RH systems – namely DRHS, CPRHS, NBRHS, plus IVVS, and their control systems – on which it had already contributed at the stage of conceptual design and initial R&D. Each RH system is composed of a certain number of units and per-se already represents a complex, multi-technological challenge. After allocation to F4E of the various packages via Procurement Arrangements, the real industrial phase has now started.

Following market survey and supplier selection, a long term framework contract (up to 7-year duration) has been placed on each package with a different European Industry. These contracts cover the design and the manufacturing phase (or part of). In this way, the procurement is implemented in stages (named task orders) during which a certain scope of activity is decided and implemented. Gradually, this will culminate in the delivery to ITER of the various RH systems.

The advantages of this approach are:

– Same supplier is enabled to work on a given procurement from design to final acceptance
– Adaptable implementation path; durations adjustable to the overall ITER schedule (see Sect. 4)
– Cross cutting technologies can be shared; synergies across the packages are favored.

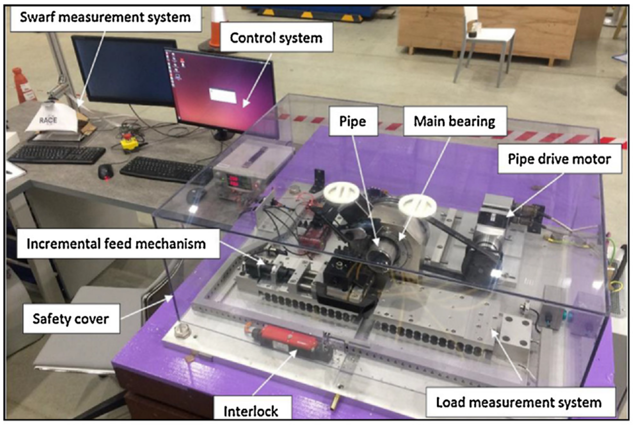
A further element to consider is that these are multiple framework contracts in cascade: it means that in case of problems in implementing a certain scope of activity with one supplier, there is the possibility to go to the next in cascade (Fig. 8, in grey fonts). This increases resilience to the F4E procurement strategy.

The four packages are presently all in the preliminary design phase, more (DRHS, NBRHS) or less advanced (IVVS, CPRHS) depending on

Involved industries and laboratories :

- *DRHS (OMF 340 lot 1):* ***AUK (started 04/2014)***, Astrium-Areva, AMEC
- *NBRHS (OMF 340 lot 3):* ***AMEC Foster Wheeler (03/2015)***, AUK, Nuvia-Cegelec
- *IVVS (OMF 383):* ***CNIM/Bertin (11/2015)***, Tecnatom
- *CPRHS (OMF 577):* ***AGILE (06/2016)***, CNIM
- *Engineering support contract (OMF 633):* ***OTL (12/2015)***, Assystem France, James Fisher Nuclear
- *Active grant beneficiaries and (sub)contractors:* VTT, TUT, Hytar, Tamlink, RACE, ASE, SCK-CEN, KU Leuven, Magics, ISAE-SUPAERO, Laboratoire Hubert Curien, Jean Monnet University, CEA-DAM, GTD, AMADA, ENEA, KIT

Fig. 8. European suppliers for RH.



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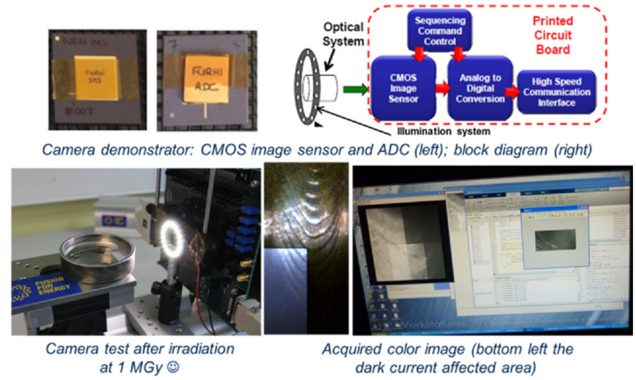

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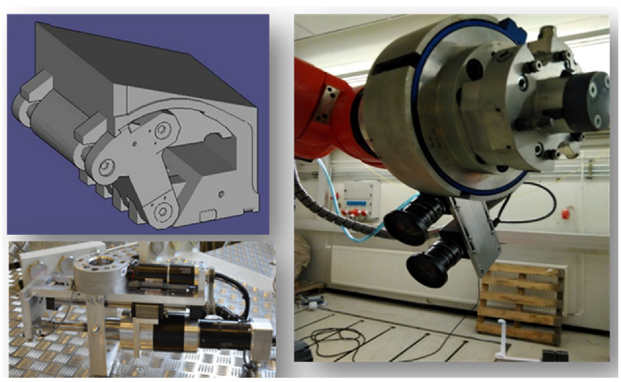

c.

Fig. 9. a) DRHS pipe cutting tests. b) Development of rad-hard digital cameras. c) Computer assisted teleoperation tests.

the start date of the procurement. The pattern of implementation common to them all starts with analyzing and refining requirements, interfaces, conceptual design, main technological issues, and then moves on with the preliminary design, substantiated by all needed analyses and support R&D. This will be followed by final design and prototyping, before manufacture. Such staged approach also reflects a certain order of priority of the many different RH devices to be delivered to ITER (see also Section 4). In addition, engineering support is provided to F4E by other industries, to perform complementary design or additional R&D or to follow up the main suppliers. Fig. 8 shows the present suppliers for the EU procurements. Such wide involvement at EU level is positive for establishing in the long run a platform of industrial capability for ITER Remote Maintenance and beyond.

R&D recent or on going actions include (Fig. 9):

- Tooling for pipe remote weld/cut/inspection [17]
- Rad-hard electronics for signal conditioning and multiplexing (on board of RH devices to decrease number of cables/size of umbilical harness)
- Mini rad-hard digital camera to fit into constrained environment like around divertor
- Water-hydraulic digital valves for DRHS to replace less robust servo-valves
- RHCS: development of standardised generic RH control software named Genrobot, remote diagnostics and computer assisted tele-operation.

It is clear that the procurement of these ITER systems implies a major technical and organisational effort. Designing in parallel many different devices (while the interfaces and integration with much of the ITER plant are evolving), and coordinating the development of common technologies, at same time managing complex industrial relationship, is another challenge added to the novelty of the design. Nonetheless, the experience gained and the technology developments underway are going to represent a major step towards the creation of a new industrial culture in nuclear fusion RH.

4. EU procurement schedule

The RH systems are actually needed for the D-T phase of ITER. But the adequacy of the design with respect to nuclear safety must be demonstrated to the regulator well before. Besides, an early utilization of these systems, already during the assembly phases of components, represents a valuable opportunity to verify that the IRMS is able to reliably, effectively, and safely perform its duties. Given the complexity of operating such nuclear-grade devices, extensive training of the operators is required in order to improve their skills and speed of operation, and define in detail the RH sequences. The extent of the usage of RH during assembly, however, cannot compromise the tight schedule and therefore a compromise will need to be found between a fast installation (with simpler tools or with the RH devices operated with hands-on assistance in local configuration, i.e. not from the RHCS) and a time consuming, fully remote handling demonstration.

As explained in Sections 2.6 and 2.7, the final location of the IRMS is in the hot cell building. Because this will be available only around 2028 (TBC), while delivery, installation and operation of some of the RH systems are needed well before, there is a need to establish a RH integration and testing facility elsewhere on the ITER site, for which options are already under evaluation. The only RH components that are going to be installed since the beginning in the tokamak building are trapped parts like cabling, together with the monorail crane that is a massive system which will go straight into the NB cell.

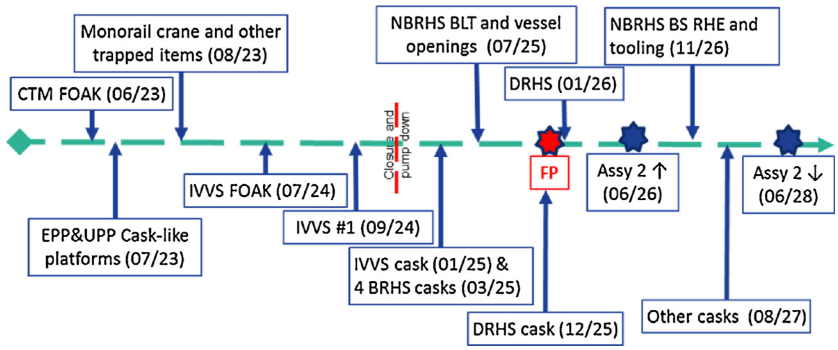

Fig. 10. EU overall delivery scenario (timeline not in scale).

It is planned that the RH test facility will become operational from 2022 to 2023 and will be intensively used by IO—CT RH team to test devices and train operators until migration towards the hot cell takes place (via the assembly hall and the tokamak building). Even after the initial integration and test phase, the facility shall remain on line for the development of new systems and tooling and for the continuous development of new RH processes and procedures. See deliver schedule below (Fig. 10).

5. Summary

The sections before have illustrated the complexity of the whole ITER RH, and the approach to procurement by Europe to its part. In addition to the technical novelty and challenges, there are organisational, commercial and schedule aspects that require attention and coordination.

The nuclear-grade IRMS – that by definition is variable and reconfigurable and as such must be conceived – will eventually act as a full integrated system deeply embedded in, and interconnected with, the rest of the ITER plant. To reach this final status will take not less than 5 years starting from the first deliveries, and will therefore follow a long, multi-step trajectory.

The initial configuration of ITER RH in the RH test bed will be progressively enriched and modified and a major change will occur for the transfer of the devices into the hot cell and connection to the final RH control room. Meanwhile, there will be also the need to operate the devices for training and assembly purposes. The current design and R&D are being therefore defined having in mind not only the final status of IRMS, but also all the intermediate stages and the transitions in between.

Overall, it can be said that ITER RH is a fantastic challenge not only from the technical standpoint, but also because of its extremely complex implementation scenario. There will be a lot to learn from this experience for the next fusion reactors and beyond.

Disclaimer

The views and opinions expressed herein do not necessarily reflect those of the ITER Organization or F4E.

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