

Plasma Diagnostics for RTO/RC – ITER

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1. Introduction

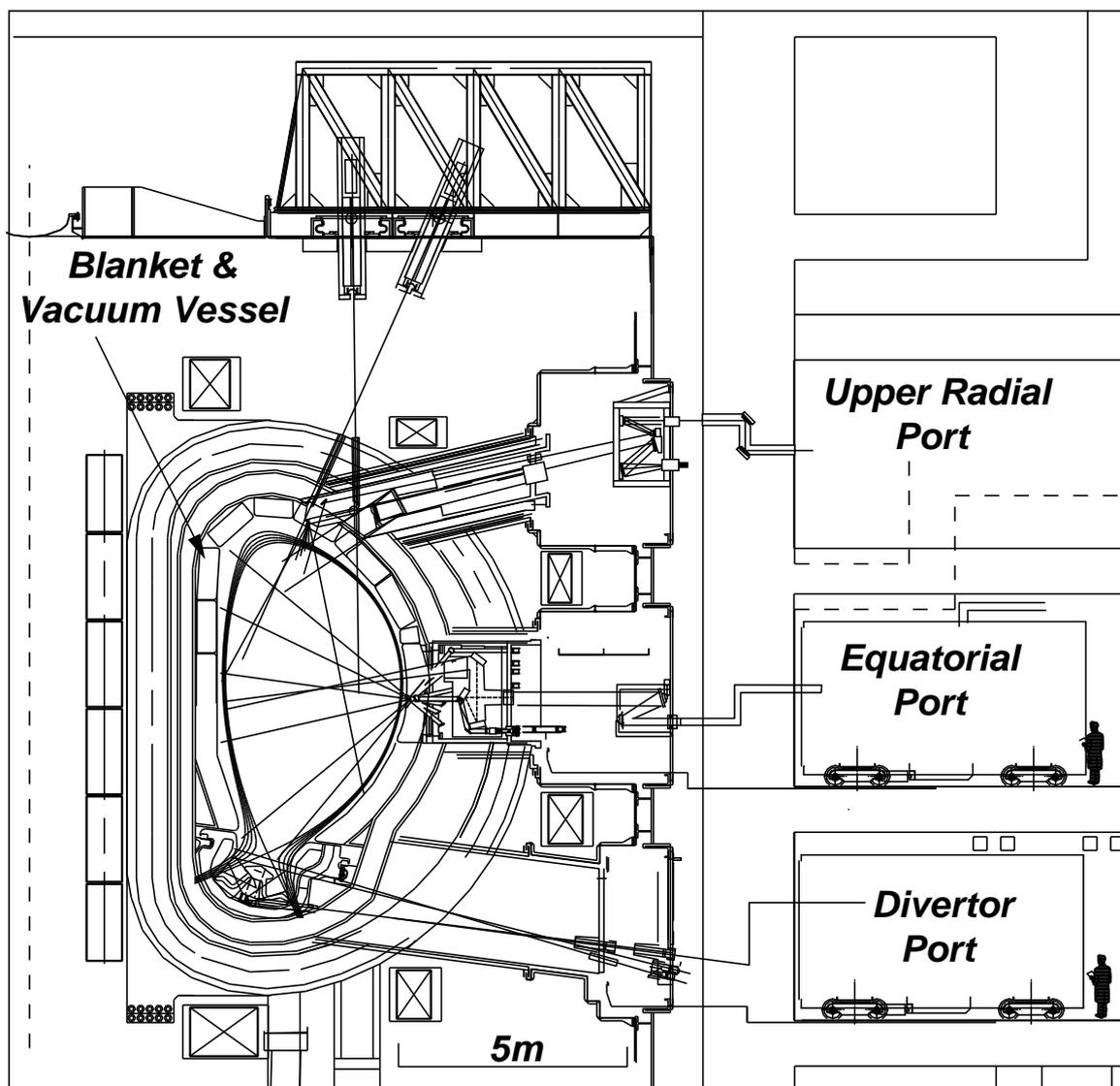
The type and number of individual measuring systems required for the Reduced Technical Objective/Reduced Cost International Thermonuclear Experimental Reactor (RTO/RC – ITER) will be similar to those developed for the Final Design Report (FDR) version of the machine [1]. The performance of the individual systems, however, and the details of the implementation and integration of the systems into the vacuum vessel and ports, will be different, due to changes in the measurement requirements, and the revised design of key machine components and layout.

The principal drivers for change in the measurement requirements are: (i) the change in the plasma size and shape and (ii) the change in experimental program priorities. Both (i) and (ii) affect the detailed measurement specifications; (ii) in addition affects the timing of implementation of the measurements. The time scales for plasma formation, build up and shut down, and for the basic plasma phenomena on Reactor RTO/RC – ITER are similar to those for FDR – ITER, and so no change in the time resolution of the measurements is required. The experimental program of the RTO/RC – ITER is expected to place an enhanced emphasis on high performance modes of operation which require active profile control, such as reverse shear operation. Measurements of key profiles such as q , pressure, and rotation, will therefore be required earlier in the experimental program and at a high level of reliability, and this has been taken into account in assigning measurement priorities. Similarly, the proposed extension to the hydrogen phase of operation to include a significant physics program drives a requirement for more detailed measurements early in the operational program. On the other hand, measurements of fusion products (neutrons, gammas) now come later in the programme with the start of the D-trace T operation.

Key component changes in RTO/RC – ITER include the significant reduction of size, the possible absence of a back-plate, the configuration of the ports (whose size also decreases, but not to the same extent as the machine size), and the building layout. Figure 1 shows one of the possible cross-sections. Changes in diagnostic performance, key outstanding issues, and implementation are discussed first, followed by the integration of the systems into the machine.

2. Changes in Diagnostic Performance and Implementation, and Key Issues

As for the FDR **magnetics**, there will be a set of pick-up coils, saddle loops and voltage loops mounted in behind the blanket modules and coupling to the plasma through gaps between the modules. In addition, there will be a set of coils mounted in the divertor diagnostic cassettes, four continuous poloidal (Rogowski) loops mounted on the outside of the vacuum vessel, four poloidal diamagnetic loops mounted inside the vessel, and Rogowski coils mounted around the earth straps of the blanket modules for measuring the 'halo' currents. The measurement capability will be the same as that developed for the FDR – ITER. The key issue for the design of the magnetic diagnostics remains the need for the pick-up coils and loops to have good electromagnetic coupling to the plasma simultaneously with a long lifetime and low noise performance in the high radiation fields that will be present in ITER. Radiation induced EMF



(discussed in [1]) has since emerged as a potential threat to long-pulse (>1000 s) operation, and is being studied in a dedicated R&D programme.

The RTO/RC – ITER will require the same set of **neutron diagnostics** as the FDR – ITER. The configuration at the top of the machine with no dedicated vertical port requires a modified concept for the vertical neutron camera. The number of sightlines of the camera may be reduced due to interference with the coil support structure, and a few sightlines would be distributed over several sectors. The microfission chambers will be installed on the plasma side of the vacuum vessel if the back plate is absent. Their optimum distribution will be re-examined when the blanket structure is determined since this affects their efficiency. The number and location of the ex-vessel neutron flux monitors are essentially unchanged. The key issue for the design of the neutron diagnostics remains the need to provide accurate and reliable calibration method over a wide dynamic range of seven orders of magnitude, starting from the lower end of a relatively weak calibration source. For one of the products of interest, alpha particles, measurement techniques are still in their infancy and so the basis for designing measurement systems for ITER is very limited.

The number and type of **optical / IR** systems for the RTO/RC – ITER will be the same as for the FDR. The concepts and designs developed for the implementation at the mid-plane and divertor levels will also be the same. The new large radial upper ports make it possible to adopt an approach which is similar to that developed for the equatorial ports: labyrinths in shielding blocks provide the optical access at the same time as providing the necessary shielding. It should now be possible to find an implementation for the edge

Thomson scattering system which meets the measurement requirements for edge temperature measurements for a wider variety of plasmas, and for the full edge region ($r/a > 0.9$). For all these systems, a key issue is the first mirror, which is unavoidably exposed to the plasma and so subject to a high level of radiation, nuclear heating and particle bombardment. This problem is particularly severe in the divertor. Further, the optical systems are distributed with the active components (sources, detectors etc.) located outside the biological shield and so alignment of multiple, distributed, components must be maintained even when the supporting structures are moving. Two systems, the toroidal interferometer/polarimeter system and the poloidal polarimetric system, require retroreflectors embedded in, or mounted behind, the blanket. These are as vulnerable as the other mirrors, and harder to maintain.

The **bolometric** system will have the same number of detectors and lines of sight as for the FDR – ITER. The detectors will be mounted in port plugs and in the divertor, and in the gaps between blanket modules. The key step in applying bolometry to ITER is the development of a bolometer head that will have good S/N and long lifetime in the hostile ITER environment. A dedicated R&D program is planned to address this issue.

The RTO/RC – ITER will require the same array of passive and active **spectroscopic diagnostics** as for the FDR – ITER, but in some cases the implementation of the diagnostics will be simpler and the performance of the systems will be improved. The simplifications arise mainly for the systems working in the visible and infrared regions installed in the upper radial ports (see above). At this location, the impurity monitoring systems operating in the VUV will view the edge plasma without the background of the hot core and this will lead to an improvement in the signal/noise ratio. However, in the absence of vertical ports for diagnostics, VUV views of the inner core (high field side) will not be possible and so information on the spatial location of impurities will be reduced. For MSE measurements, there will be no significant change in the performance of the diagnostic. The performance of the passive NPA system will be improved, mainly due to the reduced plasma size. Active spectroscopy (CXRS) with the **diagnostic neutral beam (DNB)** will have an improved performance for similar reasons. The power, modulation and pulse length requirements for the DNB will be the same as FDR – ITER. The optimum beam energy needs to be re-evaluated, and may now be slightly less than 100 keV/amu. At the divertor level, the spatial resolution in the measurements will be reduced because the cassettes are smaller and fewer sight-lines can be accommodated. Apart from the first mirror problem discussed above, an additional issue is the need for a vacuum extension outside the bioshield for the VUV/X-ray systems.

The biggest hardware changes for **microwave systems** are expected in the reflectometer for plasma position, which needs to be fed through the upper radial ports, and has a design sensitive to the details of the vacuum vessel and plasma-facing component designs. The performance of most of these diagnostics will be unchanged. However, because of the changes in the machine geometry and operating conditions, second harmonic access for the ECE system improves. For divertor reflectometry, the smaller size of the divertor cassettes will reduce the number of channels that can be installed and will lead to a reduction in the extracted spatial information. The key issues for microwave systems are in the area of calibration for the ECE, and transmission through non-optimised waveguides for the reflectometers.

The number and type of **plasma-facing and operational diagnostics** required for the RTO/RC – ITER are very similar to those required for the FDR – ITER: Viewing systems will be used to survey the first wall and divertor plates during a pulse, and the temperature of the divertor plates will be measured by infrared thermography. Additional operational systems include monitors for runaway electrons, Langmuir probes, pressure gauges and gas analyzers. The problems of implementation on ITER vary with each diagnostic.

3. Diagnostic Integration and Maintenance

As for the FDR – ITER, the integration of the different diagnostic systems including the design of the port plugs and in-vessel machine components is an important part of the design process. In this activity proper account must be taken of the nuclear shielding requirements, tritium containment and vacuum requirements, as well as maintainability with remote handling equipment. In general the change from the FDR geometry affects diagnostic installation in all locations, but the most substantial change occur at the upper port level, due to the large radial

ports. This change has mostly beneficial consequences, detailed below. At the mid-plane and divertor levels the changes are less substantial and the concepts and most of the designs for diagnostic installation developed for the FDR – ITER are directly applicable:

Vacuum vessel: Diagnostic components (for example magnetic pick-up coils and bolometers) are now installed on the plasma side of the vacuum vessel (rather than the plasma or vacuum vessel side of the backplate). The proposed installation of pre-assembled double sectors of vacuum vessel allows most diagnostic equipment to be installed prior to the vacuum vessel assembly. The wiring paths to equipment on the vessel are simplified with respect to FDR ITER.

Upper horizontal port: This port takes over the functions of the FDR design vertical port. In this design, more sophisticated shielding structures can be incorporated in the diagnostic block, and there is, in principle, more straight forward access for maintenance of in-vessel components (with the exception of the ports residing over the neutral beam cell). These two factors should allow designs with better access to the plasma (apertures of up to ~ 150 x 600 mm are potentially feasible). For several optical systems, it is now possible to view the edge with sufficient signal path, yet with no background from the core. Finally, this port admits the use of a one-piece front end diagnostic block, in contrast to the three-piece FDR design, allowing easier alignment of systems with separate transmit / receive lines.

Equatorial port: In the Port Plug, standard remote handling components (connectors, RH welded pipes, etc.) and diagnostic components (e.g. windows, mirrors etc.) will remain at approximately the same size as for the FDR – ITER, and effective neutron shielding labyrinths will be maintained. These features may consume a larger fractional volume of the plug and consequently it may not be possible to install as many diagnostics per port. A provisional arrangement for the distribution of diagnostics has been made, producing approximately the same measurement capability as for the FDR – ITER. All the measurements required for machine protection and plasma control are accommodated.

Divertor port: Four full access diagnostic ports are planned at the divertor level, although the final number depends on the remote handling access port configuration. Because of the smaller cassette and port, the access details for the diagnostics at this level will have to be redefined. Congestion at this level is eased somewhat by the displacement of the magnetics and bolometry wiring access routes to the upper horizontal port level.

4. Performance Assessment and Planned Future Work

Relative to the FDR – ITER, the diagnostic system is expected to have approximately the same measurement capability. In some areas the measurement capability should be improved, for example the measurements of the edge temperature and density by Thomson scattering and the measurements of light ion impurities by active CXRS with the DNB, while in others it will be reduced, for example, the spatial resolution in the measurement of impurities in the divertor region will be less. An important measurement is that of the current profile which now has higher priority. Both of the methods being pursued, multiple chord polarimetry and MSE, have implementation difficulties under ITER conditions and require dedicated design work. Additional topics, such as the survivability of key in-vessel diagnostic components, for example, first mirrors and bolometers, and RIEMF, remain important and will be covered in the supporting R&D programme.

Acknowledgement

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References

- [1] Technical Basis for The ITER Final Design Report, Cost Review and Safety Analysis (FDR), ITER EDA Documentation Series No. 16, IAEA, Vienna (1998)
- [2] ITER Physics Basis: Chapter 7: Measurement of Plasma Parameters, Nuclear Fusion (to be published)