# Interface Definition and Integration in the Equatorial Port 01 of the ITER In-Port Radial Neutron Camera

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The ITER Radial Neutron Camera is a diagnostic whose objective is measuring neutron emissivity and fusion power density through an array of detectors placed in collimating structures. The RNC is composed of two subsystems (In-Port RNC and Ex-Port RNC), located in the Equatorial Port 01 of the ITER tokamak. Although the measurements from the RNC are required for ITER D-T phase, its In-Port components must be ready for Assembly phase 2. Consequently, the two subsystems will be delivered at different times.

At the current status of the design the In-Port RNC interfaces must be defined, if not fully specified, in order to allow for the subsystem integration in the Port Plug. A thorough assessment of the interfaces of the subsystem with all the diagnostics, plants and services in the port has been made, taking into account the concurrent development of the Equatorial Port 01 and the progress in the design of some of the subsystem components that may affect the identification of interfacing Plant Systems.

This paper deals with the process that led to definition of the internal and external interfaces of the In-Port RNC, highlighting the main issues and the solutions adopted to perform integration within the Equatorial Port Plug 01.

Keywords: ITER diagnostics, Interfaces, Integration, Radial Neutron Camera

## 1 Introduction

Neutron emissivity detection in ITER [1] is fundamental to optimize plasma performance and control plasma burn. A key neutron diagnostic – the Radial Neutron Camera (RNC) – is being designed to measure the line integrated neutron flux across the poloidal section of ITER, in order to obtain, through a spatial inversion procedure, the neutron emissivity and the fusion power density during Deuterium-Tritium operations [2]. These measurements must be delivered to ITER Plasma Control System.

The RNC is composed of two subsystems: the In-Port RNC and Ex-Port RNC, both hosted in ITER Equatorial Port 01 (EQ01). Even if the measurements from RNC are required for ITER D-T phase, its In-Port components must be delivered for the Assembly Phase 2, due to take place in 2027 [3,4]. Hence, the two subsystems will undergo separate design reviews.

The In-Port RNC has successfully completed the Preliminary Design Review (PDR) process. In this phase, the interfaces with other systems have been completely defined to achieve integration in the EQ01. This paper describes the In-Port RNC interfaces and the process that determined their definition and integration in EQ01.

The paper is organized as follows: Section 2 provides a quick overview of the RNC subsystems; the themes of integration strategies and interface definition are presented in Section 3. Section 4 describes In-Port RNC internal and external interfaces, and the conclusions are reported in Section 5.

## 2 RNC overview

The RNC, sketched in Figure 1, is composed of two fan-shaped subsystems hosting an array of neutron flux detectors with a total of 22 collimated conical Lines Of Sight (LOS):

- In-port RNC is made of six LOS located in the Port Plug, viewing the plasma edge (r/a>0.67), and featuring a $^{238}U$ fission chamber (FC) and a single crystal diamond (sCD) matrix detector in each LOS.

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*The following acronyms are used throughout the paper: **RNC** (Radial Neutron Camera); **EQ01** (ITER Equatorial Port 01); **PDR** (Preliminary Design Review); **LOS** (Lines of Sight); **HRNS** (High Resolution Neutron Spectrometer); **RGRS** (Radial Gamma Rays Spectrometer); **FC** (Fission Chamber); **sCD** (single Crystal Diamond); **DSM** (Diagnostic Shielding Module); **H-LVPS** (High-Low Voltage Power Supply); **EUDA** (European Union Domestic Agency); **IO** (ITER Organization); **EU** (Embarked Unit); **DFW** (Diagnostic First Wall); **FEM** (Finite Element Model); **PBS** (Plant Breakdown Structure); **PCSS** (Port Cell Support Structure); **RH** (Remote Handling); **PPTF** (Port Plug Test Facility); **SVS** (Service Vacuum System); **REMS** (Radiological and Environmental Monitoring System); **RW** (Radiological Waste); **CD** (Contaminated Water Drainage); **DS** (Detritiation System).*

- Ex-Port RNC is made of sixteen LOS located in the Interspace, viewing the plasma core (r/a<0.54), and featuring a sCD matrix detector, a plastic and a He4 scintillator in each LOS.

Thermocouples for detectors' temperature measurements are also provided in all LOS. The remaining four LOS in the Ex-Port right hand side plane are reserved to two interfacing diagnostics: one LOS is for the High Resolution Neutron Spectrometer (HRNS) exclusive use, while three LOS are owned by the Radial Gamma Ray Spectrometer (RGRS). A LOS in the Ex-Port RNC left hand side plane is shared between RNC and RGRS.

The RNC system components are distributed in three zones (Port Cell, Port Interspace and Port Plug) within Equatorial Port 01.

Both In-Port and Ex-Port RNC subsystems feature a cooling system to maintain the temperature of the detectors – with the exception of the fission chambers - below the damage threshold in all operational phases: the temperature of commercially available sCD detectors must be kept below 150 °C (during baking Port Plug temperature reaches 240 °C); and the Ex-Port scintillators temperature must be kept below 30 °C both during baking and during plasma operations, since Interspace temperature may range between 50 and 120 °C [5].

The In-Port RNC components in the scope of the current PDR (Figure 3) are the following:

1. the Ex-Port RNC optical paths in the Port Plug Diagnostic Shielding Module 2 (DSM2) [1]
2. the In-Port RNC optical paths in DSM3
3. the cassette assembly, containing the detector modules, in DSM3
4. the collimators, in DSM3
5. the shielded cabinet hosting In-Port RNC detectors preamplifiers, on the Port Cell Support Structure.

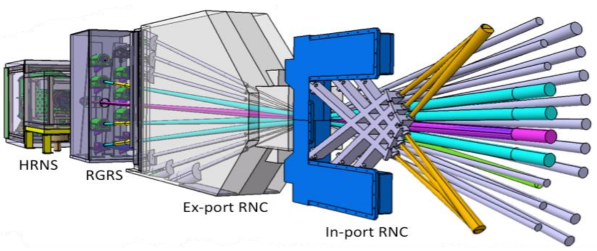


Fig. 1 – RNC layout, showing RGRS (light blue) and HRNS (magenta) dedicated LOS.

The RNC Power Supply System (H-LVPS), powering the In-Port RNC detectors and located in the room 11- L1-02E in the tokamak building (Figure 4, top right) is also included in the scope. The sCD detectors cooling system is out of the scope of this PDR, and will undergo separate design reviews. Figure 4 gives a compact view of the internal and external interfaces of the In-Port RNC components mentioned above.

## 3 In-Port RNC integration and interface definition

The EQ01 and the diagnostics hosted therein, namely the RNC, Neutron Flux Monitor, Motional Stark Effect, Divertor Impurity Monitor, Bolometers, Radial Gamma Ray Spectrometer and High Resolution Neutron Spectrometer, are being designed concurrently and are at different stages of development; hence, to achieve integration, a strategy for the definition of all interfaces had been followed, based on system engineering best practices [7].

The primary source of information for the definition of interfaces between different ITER systems consists of a set of documents, the Interface Sheets (IS), detailing the boundary of responsibility between each interfacing system; the interface is completely defined when the IS has reached the maturity level required for the design phase of the diagnostic.

The process leading to the definition of the In-Port RNC interfaces required close interactions among multiple parties: the European Union Domestic Agency (EUDA) Port Integrator, in charge of designing Port Plug, and integrating all equipment hosted by the Interspace and Port Cell Supporting Structures; ITER Organization (IO) Port Integrator in charge of the design of the Port Plug Closure Plate, integration of all equipment outside supporting structures, the integration of the supporting structures with the port and the balance of services among the diagnostics; and the interfacing PBS responsible officers. The process started at the earliest stages of the project, at the RNC requirements definition, the production of operating scenarios and the design of the RNC baseline [9]. The functional and physical interfaces thus identified were assessed through iterative interface verification meetings with the interfacing systems Responsible Officers and IO Port Integrator.

The definition of the interfaces between In-Port RNC and the Equatorial Port 01 was performed with a process aimed at managing the complexities of integration, summarized as follows:

- In-Port RNC components have been assigned to dedicated volumes, named *Embarked Units* (EU), in the EQ01. Each EU identifies sets of components that may be treated as a single unit for what concerns integration. The design teams and CAD officers developed their own components within those volumes;
- Any changes impacting those volumes have been agreed among the parties;
- Interface data were agreed for each EU, for example total mass, size and position of interface surfaces (typically mechanical attachments or areas for the ingress of cables or services).

The outcome of this process is a set of data including, beyond the interface data listed above, details on the gravity, seismic, nuclear and electromagnetic loads

[1] The DSM is a standard component of Equatorial Port Plugs, described in [6]

applied to the attachment surfaces. This is the primary input to RNC-EQ01 Interface Sheet [8].

The approaches described above had both proven to be effective in identifying and defining In-Port RNC interfaces to the level of maturity required for the PDR.

Beside concurrent development, another issue impacting interface definition is the progress of research, development and prototyping of custom components. In the case of the In-Port RNC, thermal tests will be conducted on custom sCD matrix detectors prototypes to assess their resistance to baking temperatures. The results of these tests will determine, upon failure, a revision of the design of the system: the consolidation of the In-Port cooling system design and the addition of new interfaces with plant systems or services.

## 4 In-Port RNC interfaces

Interfaces are logically divided into two groups: *internal interfaces*, when the two interfacing systems share the same Level 1 Plant Breakdown Structure (PBS) code; and *external interfaces*. ITER systems are identified by their PBS code. The RNC PBS code is 55.B1, where "55" is the Level 1 code corresponding to the Diagnostics group to which RNC belongs.

### 4.1 Internal interfaces

In-Port RNC internal interfaces are listed in Table I. All the interfaces mentioned in this section are described in the corresponding interface sheets.

*55.Q1* - The interfaces with 55.Q1 subsystems are mainly mechanical and have been defined through the process described in Section 3, and detailed in the Interface Sheet [6]. A view of the interfacing components is in the left hand side of Figure 4. Structural analysis has been performed to verify that the gravity, seismic and electromagnetic loads on all mechanical interfaces are below the damage limits.

In some specific instances (In-Port collimators and preamplifiers shielded cabinet), the analysis led to modifications of the number or size of the attachment points. In the following, the case of the preamplifiers' shielded cabinet will be detailed as an example. The shielded cabinet is a specially designed multilayered box (composition: Boron carbide, Cadmium, Tungsten carbide and Iron, size: 90x60x2500 mm, mass: 6155 kg), with an inner 31x31x1915 mm cavity and four legs, each with eight M16 bolts to connect to PCSS attachment surfaces (Fig. 2). For the preamplifiers shielded cabinet a Finite Element Model (FEM) was developed to calculate the natural frequencies of the system and verify the attachment points against seismic loads (SL-1 seismic level) according to RCC-MR [10]. Starting from the first definition of the interface shared with the EUDA PI, the bolted connections for the preamplifiers shielded cabinet have been verified according to RCC-MR RB 3280. The result of the analysis was that the number of bolts was insufficient for the cabinet to withstand seismic loads; hence, a new bolted connection was proposed: the best configuration compatible with geometrical constraints and verifying the rules for mechanical loads was identified in the use of twelve M16 screws per attachment surface.

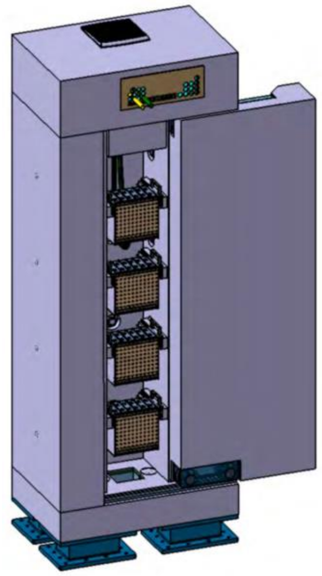

Fig. 2 – CAD model of preamplifiers' shielded cabinet. The sliding door is opened to show the crates containing preamplifiers.

The calculations have been performed by:

- Calculating the loads on the bolting elements according to RCC-MR A6.4400;
- Assuming no preload on the bolts in order to evaluate the minimum pretension needed to avoid the detachment of the connected parts and the shear stresses on the bolts;
- Selecting Grade 660 Stainless steel for the bolted connection.

According to RCC-MR A6.6222, the bolts' preload is calculated to ensure that the shear loads are taken up by adhesion, resulting in a preload value of 24 kN. Such value has been assumed to calculate the axial load on the bolting elements according to A6.4410.

The new bolted connection has been then verified, considering the rules for the preloaded bolt assemblies not maintaining leak tightness. In this case, the mean stress intensity in the screw core due only to maximum mechanical loads applied shall be no greater than the allowable stress intensity ($S_{mB}$) defined for SS 660 bolts.

In such configuration, the mean stress intensity $\sigma_m$ due only to the mechanical loads applied, resulted as in (1)

$$\sigma_m = \frac{4N}{\pi d_n^2} = \frac{4 \cdot 26400}{\pi \cdot 13{,}55^2} = 183MPa < S_{mB}\ (200\ at\ 20°C) \quad (1)$$

where N is the axial load on the bolting element calculated according to A6.4410 and $d_n$ is the diameter of the bolt core.

The maximum stress limit, according to RB3284.1113 has been also verified:

$$\sigma_m + \sigma_b = \frac{4N}{\pi d_n^2} + \frac{32M}{\pi d_n^3} = 204MPa < 1{,}33x[0{,}9R_{p0,2}^t]\ (718\ at\ 20°C) \quad (2)$$

where $\sigma_b$ is the total bending stress, $R^t_{p0.2}$ is the 0.2% yield strength and M is the bending moment. As shown in

(1) and (2), the new configuration is well within the limits for the selected bolted connection. The analysis was performed using Ansys Workbench Mechanical 2019R1.

Table I – List of In-Port RNC Internal Interfaces

| ***PBS*** | ***Description*** |
|---|---|
| **55.Q1** | Equatorial Port 01 |
| **55.NE** | Electrical Services |
| **55.B7** | Radial Gamma Ray Spectrometer |
| **55.BB** | High Resolution Neutron Spectrometer |

*55.NE* - The interface with Electrical Services consists of connections to electrical power sub-distribution boards, powering the RNC equipment in the Port Cell shielded cabinet; the junction boxes in the Interspace support structure and Port Cell Support; special requirements regarding cables connectors.

*55.B7* – The interface with the RGRS includes the special design for the three dedicated LOS whose diameters had to be enlarged to grant the required brightness to RGRS detectors, as well as the corresponding cut-outs on the Diagnostic First Wall (100 mm diameter at DFW, while RNC LOS are 60 mm), and a shared LOS (Figure 1). A further interface consists of a space reservation in one of the RNC preamplifiers shielded cabinet internal chassis, to host the RGRS detectors front-end electronics.

*55.BB* – The interface with the HRNS consists of one dedicated LOS (Figure 1), whose size and DFW cut-outs (100 mm diameter) have been specially designed to meet HRNS needs.

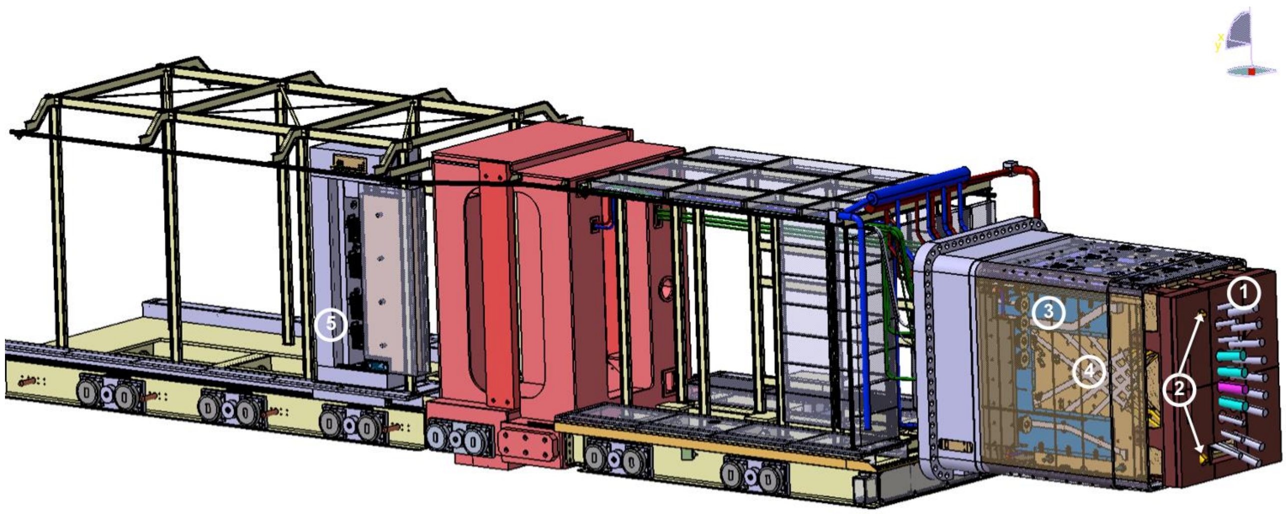

Fig. 3 – In-port RNC components positioned in EQ01.

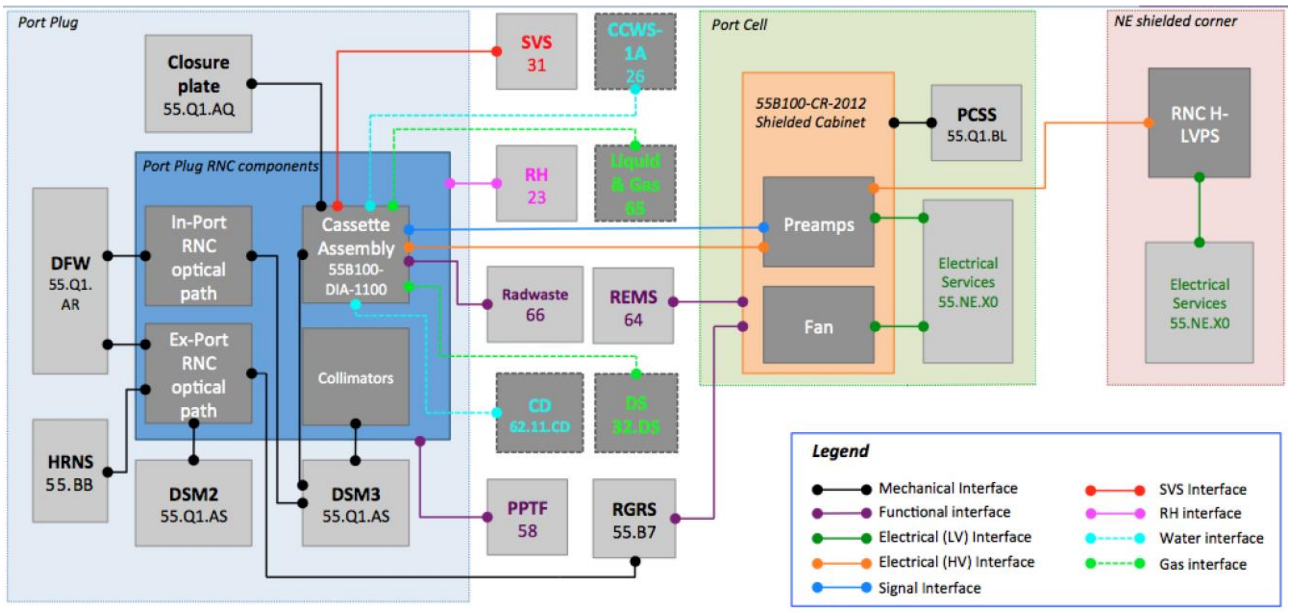


Fig. 4 – Block diagram of the In-port RNC interfaces. The acronym and the PBS code (where existing) of the interfacing components are shown. The dashed boxes and connectors are related to the interfaces of the cooling system, which is not in the scope of the PDR. All acronyms are reported in the first page of this paper.

### 4.2 External Interfaces

The In-Port RNC external interfaces are listed in Table II. All the interfaces described below are detailed in the corresponding interface sheets.

Table II – List of In-Port RNC External Interfaces

| *PBS* | *Description* |
|---|---|
| **23 - RH** | Remote Handling |
| **31 - SVS** | Service Vacuum System |
| **58 - PPTF** | Port Plug Test Facility |
| **64 - REMS** | Radiological and Environmental Monitoring System |
| **66 - RW** | Radwaste |

*PBS 23 – RH*. In-Port RNC maintenance scenarios foresee the replacement of the cassette assembly and the collimators. These operations must be performed by RH tools when the Equatorial Port Plug is disassembled in the Hot Cell Complex.

*PBS 31 - SVS*. The six $^{238}$U fission chamber detectors in the In-Port RNC constitute pressurized (Argon 4 bar) in-vessel volumes that must be monitored and evacuated in case of leakage. Consequently the RNC cassette structure and associated feedthroughs - acting as a single enclosure – must be pumped and monitored by SVS. He backfilling for leakage testing is also required.

The range of required pressure values is 100 Pa in normal operation to 100 kPa during backfilling. The physical interface consists of a DN 15 stainless steel pipe (ID=10mm, OD=12mm). The total volume to be monitored is ~100 litres.

*PBS 58 – PPTF*. Tests dedicated to In-Port RNC Port Plug components are foreseen in the PPTF. The leak tightness of the cassette structure will be tested during environmental PPTF tests [9]. Functionality tests on the FC and sCD detectors, to check the compliance with reference Pulse Height Spectra, and on thermocouples, are also planned.

*PBS 64 – REMS*. The interface between RNC and REMS is a functional interface. Input data for the definition of the interface are the maintenance scenarios (working place, number of operators, type of maintenance, tools) and the associated risks for the personnel involved.

In this case, the maintenance activities will be performed in the Port Cell and consists of the replacement of preamplifiers in the shielded cabinet.

*PBS 66 – RW*. The cassette assembly and collimators, when disassembled, will be stored in the Radwaste. In order to define this interface, a complete activation analysis for all the subcomponents of the In-Port RNC has been performed, using the FISPACT-II inventory code [10] within the SA2 irradiation scenario [11]. The total activity, surface effective dose rate, dose rate at 1 m distance, Tritium content and Tritium activity have been calculated for each subcomponent, after 12 days from the shutdown. The results of the analysis are shown in Table III for the peak contributors to the total activity.

Table III – Input data for the definition of 66-55.B1 Interface

| | ***Cassette*** | ***Collimators*** |
|---|---|---|
| **Total activity [Bq]** | 6.10E10 | 1.58E11 |
| **Dose rate at surface [Sv/h]** | 3.11E-1 | 3.74E-1 |
| **Dose rate at 1 m [Sv/h]** | 3.07E-3 | 8.69E-3 |
| **$^{3}$H content [g]** | 1.96E-5 | 4.51E-8 |
| **$^{3}$H activity [Bq]** | 6.78E9 | 1.46E7 |

If the outcome of the thermal tests on sCD detector prototype will lead to the necessity of including In-Port RNC detectors cooling system in the design, there are further interfaces to consider:

- **PBS 26.CC.1A** *Component Cooling Water System (CCWS-1A)* to run the cooling loop
- **PBS 65.00.CA** *Compressed air system* to drive the cooling loop pneumatic valves
- **PBS 65.00.NG** *Nitrogen Gas Distribution* to drain and dry the cooling loop
- **PBS 65.00.HE** *Helium Gas Distribution* to backfill the loop with He to prepare for NOC
- **PBS 62.11.CD** *Tokamak Complex Contaminated Water Drainage* to dispose of the liquid effluents
- **PBS 32.DT** *Tokamak Complex Detritiation System* to dispose of the gaseous effluents.

Most of the data characterizing these interfaces are already available.

## 5 Conclusions

This paper dealt with the definition of In-Port RNC internal and external interfaces. The state of the art of the interfaces has been described as presented at the PDR: all interfaces have been assessed, even if minor adjustments could be needed in preparation for the subsystem Final Design Review. Further modifications will be performed if the thermal tests on diamond detectors will confirm that the In-Port RNC cooling system must be included in the design.


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