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Technical Specifications (In-Cash Procurement)

Summary of Technical Specification for In-Vessel Diagnostic Installation

The purpose of this document is to provide a high-level definition of the scope of work and the required competences for the In-vessel Diagnostic Installation Contract.
The document summarises the scope of the Contract, designated as In-vessel Diagnostic Installation (IDI), details the essential expertise, experience and skills required for performing the work, and provides a brief description of the various systems and works organisation.

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1 Purpose

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2 Abbreviations

The following table lists and defines the abbreviations used in this document.

Abbreviation	**Definition**
ANB	Agreed Notified Body
ASN	Autorité de Sûreté Nucléaire
CPD	Construction Process Description
CMA	Construction Management Agent
CMM	Configuration Management Model
C&S	Codes and Standards
CWP	Construction Work Package
DES	Diagnostic Electrical Services
ECH	Electron Cyclotron Heating
EDH	Electrical Design Handbook
EFT	Electrical Feedthrough
ELM	Edge Localized Mode
ESP	Equipements Sous Pression (“Pressure Equipment”)
ESPN	Equipements Sous Pression Nucléaires (“Nuclear Pressure Equipment”)
FPPC	First Plasma Protection Components
GIS	Gas Injection System
HFS	High field side
INB	Installations Nucléaires de Base (“Basic Nuclear Installation”)
IO	ITER Organisation
ISI	In-Service Inspection
IVN	In-vessel Nacelle
IVS	In-vessel Staging

IVTC	In-vessel tower crane
IWP	Installation Work Package
MFC	Micro-fission chamber
MIC (or MI cable)	Mineral Insulated cable
NA	Not Applicable
NAS	Neutron Activation system
NBI	Neutrol Beam Injection
PED	Pressure Equipment Directive
PIA	Protection Important Activity
PIC	Protection Important Component
PIS	Pellet Injection System
SAT	Site Acceptante Test
SIC	Safety Important Component
SVS	Service Vacuum System
TCPH	Torus Cryopump Housing
TIEMF	Thermally induced electromotive force
TPTS	Through-port transfer system
UHV	Ultra High Vacuum
V0	In-Vessel
VS	Vertical Stability
VV	Vacuum Vessel
VVOI	Vacuum Vessel Operational Instrumentation
WP	Work Package
X0	Ex-Vessel

Table 1: Abbreviations and Acronyms

For a complete list of ITER abbreviations see: ITER_D_2MU6W5 - ITER Abbreviations.

3 Technical Description

3.1 The ITER Project

For a complete description of the ITER Project, covering both organizational and technical aspects of the Project, visit www.iter.org.

3.2 Contracting plan

The In-vessel installation activities for Assembly Phase 1 are split into three different packages.

Lot 1 (BESP) - Welded attachments to the vacuum vessel, comprising of welded bosses and Blanket Earth Straps Pedestal.

Lot 2 (IDI) - Installation including primarily Diagnostics, such as: looms, flux loops, magnetic sensors, connectors, feedthroughs, waveguides, micro-fission chambers, neutron activation system, as well as vacuum vessel and internal components operational instrumentation, pellet and gas injection systems and In-service inspection.

Lot 3 (FMI) – Mechanical Installations including VS coil handling, in-vessel coil feedthroughs & feeders (captive), First Plasma Protection Components (FPPC), 3 port plugs (2 diagnostic and 1 EC heating) and related structures and shielding, Installation of 35 VV port closure plates, including feedthroughs, removal of tools, final inspection.

Important note: This contract will focus on main in-vessel Diagnostics installation activities for First Plasma, falling under IDI, Lot 2, as described above. Lots 1 and 3 are outside the scope of this procurement.

3.3 The ITER Facility

The ITER Facility is currently under construction in Cadarache, Southern France.

Central to the facility is the Tokamak Complex, a nuclear rated structure in reinforced concrete that comprises three integrated buildings, Figure 2. The Complex has a footprint of 118 x 81 m, extends vertically from -15 m to +40 m relative to ground level, and contains the plant systems that service (power, heat, cool, condition, fuel, monitor and control) the Tokamak.

To support the assembly of the Tokamak machine there is a steel-framed Assembly Building and Cleaning Facility, arranged to form a continuous working space.

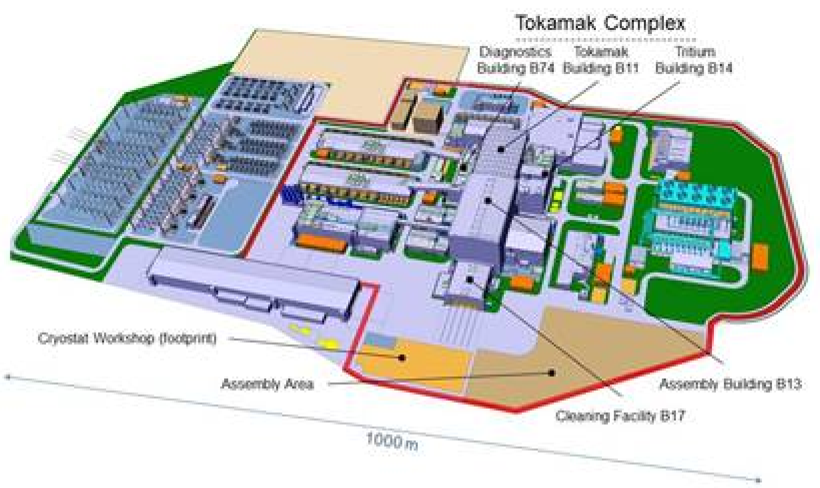

Figure 2: Layout of the ITER Site

4 Assembly Process

The overall assembly process is illustrated at the highest level in Figure 3, with assembly Phase 1 sub-divided into six groups of assembly activities (sequences).

The Tokamak is assembled from nine sectors, each encompassing a toroidal angle of 40°, and comprising a 40° VV sector, two TF Coils, a 40° VV Thermal Shield sector, and the associated interconnections and supports. The components are delivered to the site individually, and sub-assembled into sectors using purpose-built jigs and fixtures in the Assembly Building *(Assembly Sequence A2)*.

Prior to the sector installation in the Tokamak pit, the gravity supports, lower cryostat sections, and the components which cannot be installed following final assembly of the sectors, principally the lower poloidal field coils, lower correction coils, the lower and side correction coil feeders, and the lower pre-compression rings, are installed or temporarily stored within the cryostat base *(Assembly Sequence A1)*. In parallel, components of the feeders for the superconducting magnets are installed in the lower level gallery of the Tokamak Building.

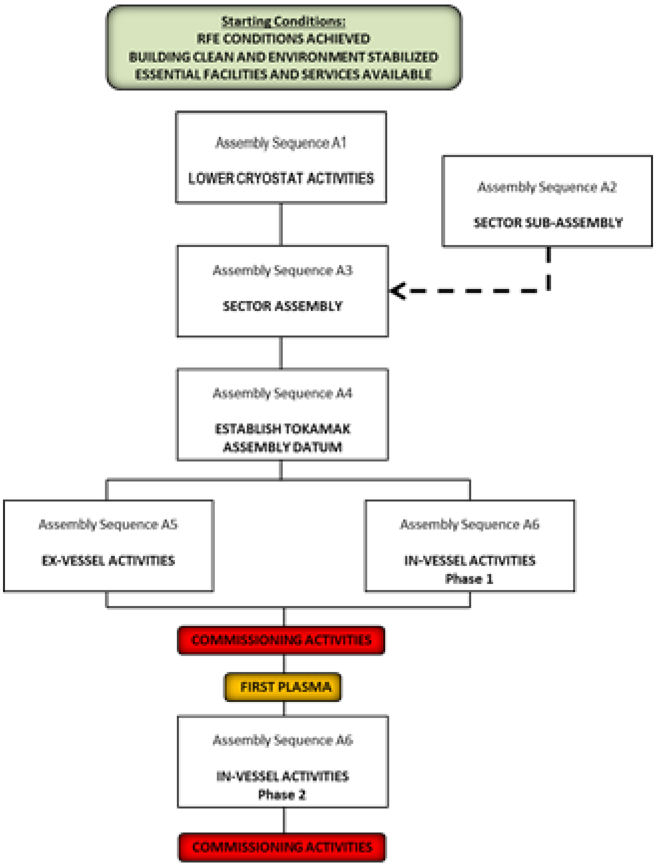

Figure 3: Tokamak Assembly Process

The sectors are then transferred to the pit sequentially where, following alignment, the TFC's are attached to their permanent supports and connected sequentially, the VVTS sectors are also connected sequentially, whereas the VV sectors are joined (welded) according to a plan which aims to minimise deformations, and the associated technical risk. Following installation of the final sector the VV is closed toroidally with the simultaneous welding of the last 2 sectors field joints (*corresponding to the end of Assembly Sequence A3)*

The permanent VV Gravity Supports are positioned, and attached to the VV and Cryostat. The TFC pre-compression rings are then installed in their final position, and the preload applied to each of the coils. A detailed dimensional survey at this stage provides the geometrical estimate of the magnetic datum for the as-built TF magnet, and this is used as reference for all subsequent alignment operations. The major Sector Assembly Tools are disengaged, and removed from the pit to allow the subsequent assembly sequences to proceed *(corresponding to the end of Assembly Sequence A4).*

The completion of the installation of the ex-vessel components proceeds with completion of the Cryostat in parallel (*Assembly Sequence A5).*

Internal VV access is via selected horizontal ports at the lower (divertor) and equatorial levels. Clean conditions are established inside the vessel, and the installation of the Phase 1 in-vessel systems is performed *(Assembly Sequence A6)* in parallel with A3/A4 and A5 sequences. **This current contract is part of A6 Assembly process.**

5 Scope of the ITER In-Vessel Diagnostic Installation Work for First Plasma (IDI)

5.1 ITER Diagnostics

The Diagnostics System provides accurate measurements of plasma behaviour and performance, including those needed for machine protection and basic machine control; those required for advanced plasma control; and those required for evaluation and physics studies. Implicitly this includes also first wall measurement functions. This instrumentation has significant differences to conventional plant instrumentation, and so requires specialised skills for installation.

ITER requires approximately 70 diagnostic systems that utilise a variety of techniques to measure diverse physical phenomena such as magnetic, optical, microwave, x-ray, gamma rays, and neutron. A key requirement is that the diagnostics have to view or be in close proximity to the plasma – implying special requirements in the construction, materials, and assembly techniques, for example, radiation tolerance, thermal conductance, ultra-high vacuum compatibility, resistance to large electro-magnetic forces. Some systems are inaccessible after construction and these have very high reliability requirements.

The systems are situated in 3 main areas:

- In-Vessel – mainly magnetic diagnostics, but also several thousand other discrete sensors, together with the cabling system to transmit the signals. In total > 60 km of mineral insulated cabling, ~200 000 stud welded cable clips, and ~15 000 welded attachments to the VV are included. There are also some passive components attached to the blanket modules and first wall panels – **part of this contract.**
- Outer VV surface – mainly magnetic diagnostics, and cabling.
- Port systems – consist of a port plug that faces the plasma, and equipment racks in the port cell that intercept and process the signal. The port plug (up to 45 t, 2 m x 2 m x 4 m) provides access to the plasma, but it also has a function for shielding, and cooling, and unusually for such a large structure, alignment is critical. The primary tasks for installation are the handling of the components, alignment of the support rails, customisation and bolting/welding of the vacuum seal, and interconnection of system modules.

5.1.1 Diagnostic Electrical Services

The majority of the in-vessel installation work within this contract is related to the installation of the Diagnostics electrical services and Magnetic diagnostics.

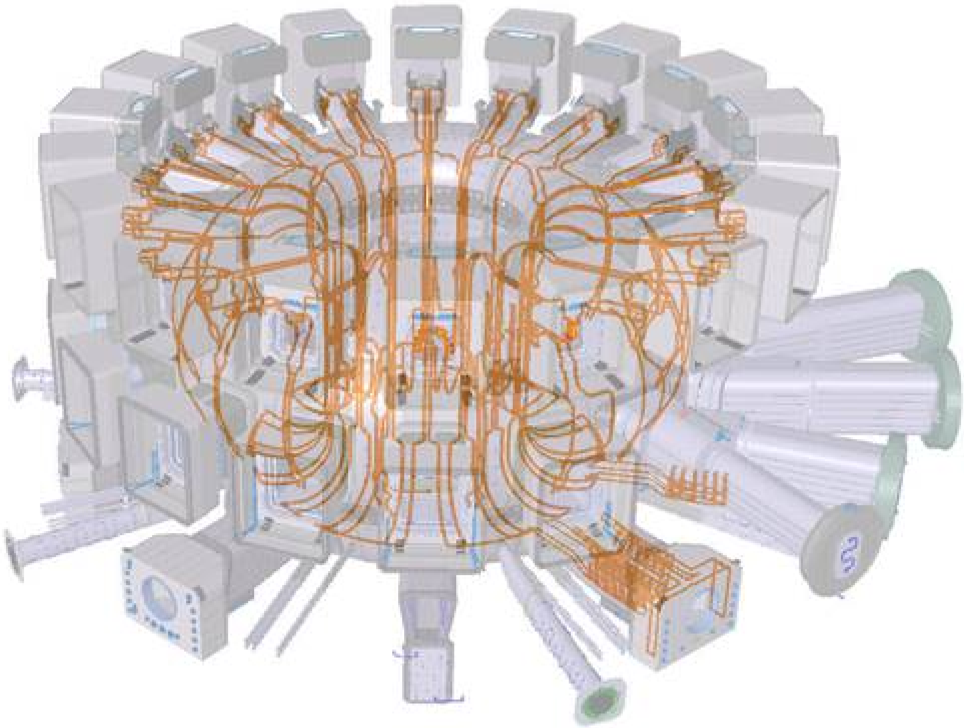

Figure 4: Loom system (103 looms) inside the VV

The layout of the Diagnostic electrical services is presented on Figure 4. The looms are responsible for carrying the signals of many diagnostics. A typical signal path is shown in Figure 5 and Figure 6. An MI cable is connected to the sensor (in some cases there is a separate sensor connector or junction box), then the cable tail (cable attached with clips) is routed to the cable to the looms. In the looms other cables are also collected and taken into the port marshalling area, to the in-port connector. From the in-port connector another cable takes the signals to the feedthroughs and the exterior of the VV.

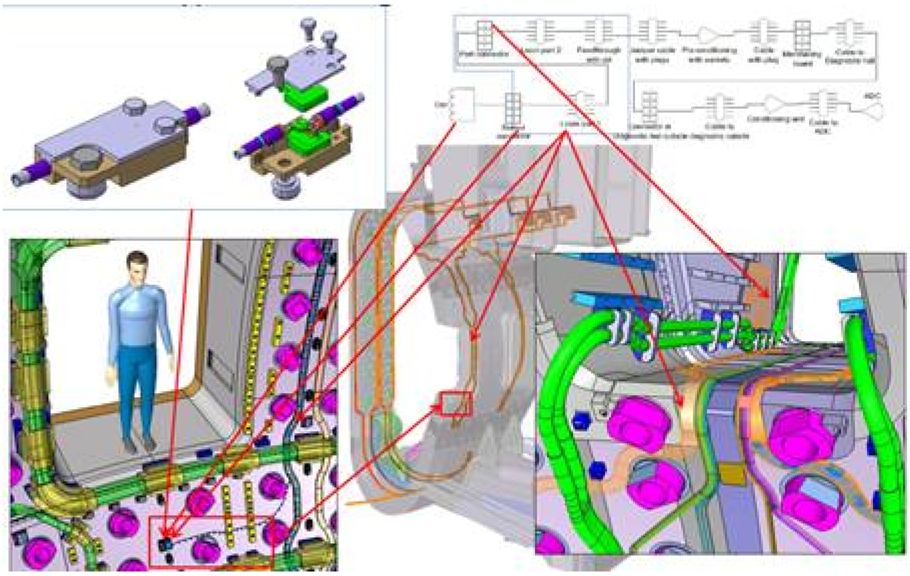

Figure 5: Typical signal path of a sensor in the main VV chamber

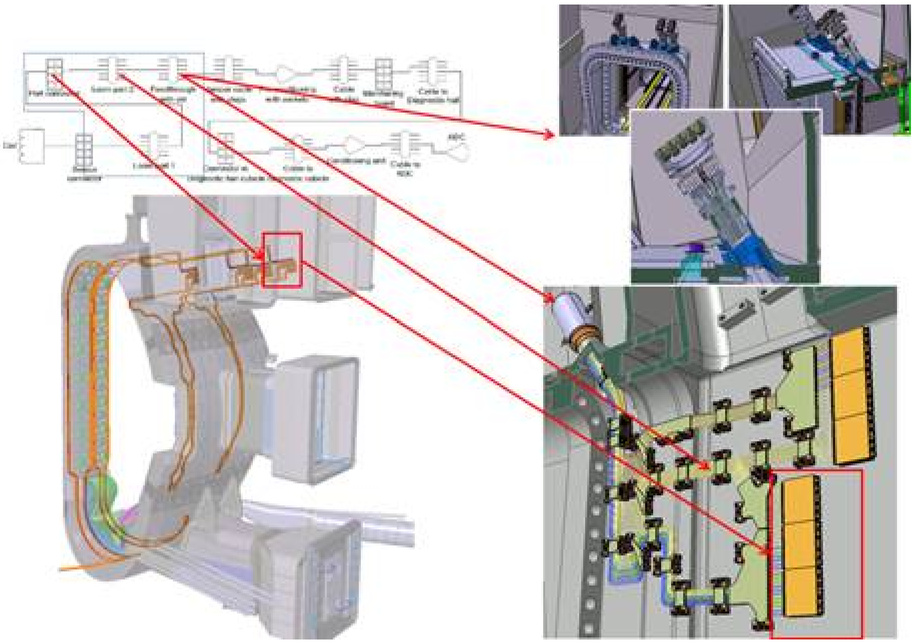

Figure 6: Typical signal path for a sensor inside a port. Marshalling area – bottom right picture.

There are 103 identifiable cable looms, broken down to several similar sub-types with variable numbers of cables (from 1 to 36) as looms are filled up as they approach ports. Cable tails from the loom to the diagnostic transducer usually carry a single cable and have a separately designed attachment clip comparable to that used for fastening flux and saddle loop cables to the vessel surface. Other significant design drivers include:

- Very limited physical space and tight tolerance requirements (+/- 1 mm) for the route including the allocation of tooling space for fixing and maintaining other in-vessel components.
- Difficult combinations of loads to which in-vessel components are subjected. This includes most of the major thermal load types present in the VV: nuclear loads, ECH loads and plasma radiation, and in some cases, where the components are in blanket gaps, they become plasma facing components, with the load not being screened by blankets or divertor cassettes leading to high temperatures and problematic thermal gradients.

- Accuracy requirements on signals flow down from project objectives and impose significant constraints of noise generation (e.g. effect caused by temperature variations along the cable, TIEMF) and screening.
- Low maintenance and access excludes the option of dedicated, active cooling. Instead, the VV (with a relatively constant temperature skin) is used as a heat sink for thermal loads in loom components.
- Welding of the tens of thousands of separate attachment pieces of the Diagnostic electrical services system to the VV, which is a nuclear pressure vessel, is monitored by relevant nuclear authorities (ASN). MI cables act as pipe bundle and if attached strongly at intervals to improve thermal contact, temperature differences between cables and the VV can generate significant thermal stresses in both attachment structures and VV. The large majority of loads are related to thermal cycling, the attachments are subject to very strict design codes aiming to limit fatigue damage to the VV.
- Assembly time constraints and co-activity (constructability).
- Significant constraints come from integration of the system to the ITER environment. For example, the system has to accommodate the uneven VV surface, which comes from sectors welded together (9 sectors joints with splice plates in between) and sector internal welds. It is not possible for looms to avoid crossing weld lines and even partial or full overlap with weld beads. There are geometric interfaces with many of the other systems inside the vacuum vessel such as blankets, which require cut-outs for loom and cable tail tracks, ELM/VS coils and cable crossings with other diagnostic systems such as flux loops and saddle coils. In the upper and lower ports, they are usually port structures, such as rails, water cooling pipes and manifolds and neutron shielding requiring careful interface design.

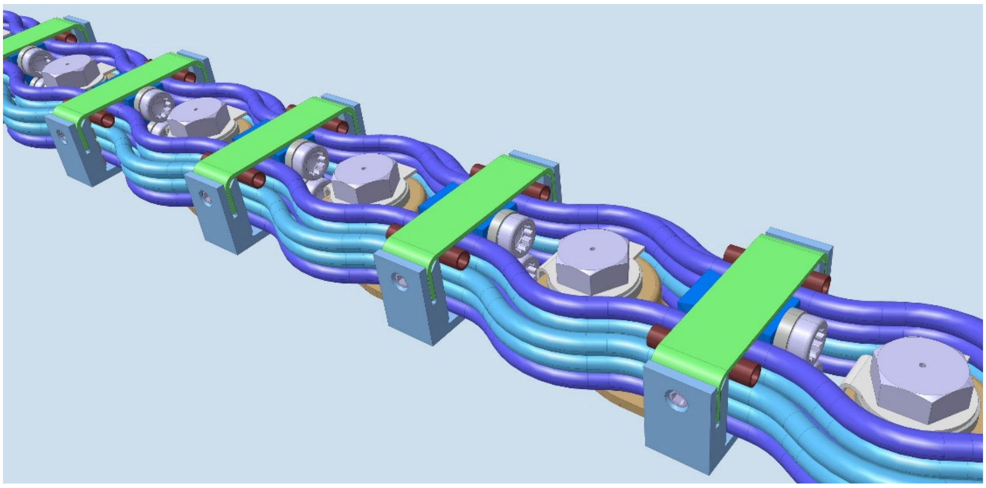

Figure 7: Close up view of a Section of Loom

5.1.2 Magnetic Diagnostics

In-Vessel Magnetic Sensors consist of a myriad of discrete magnetic sensors installed to the inner surface of ITER Vacuum Vessel (VV). These sensors are essential diagnostics for magnetic equilibrium topology and instabilities measurement. In total ~450 sensors of various kinds are densely distributed over the entire vacuum vessel torus, in a pattern that forms several poloidal or toroidal arrays. Most of these sensors assembly comprises of a common mechanical support structure which is to be welded to the fixation bosses and electrically connected with the in-vessel cabling, and a housing with a protective cover that encloses the magnetic sensor.

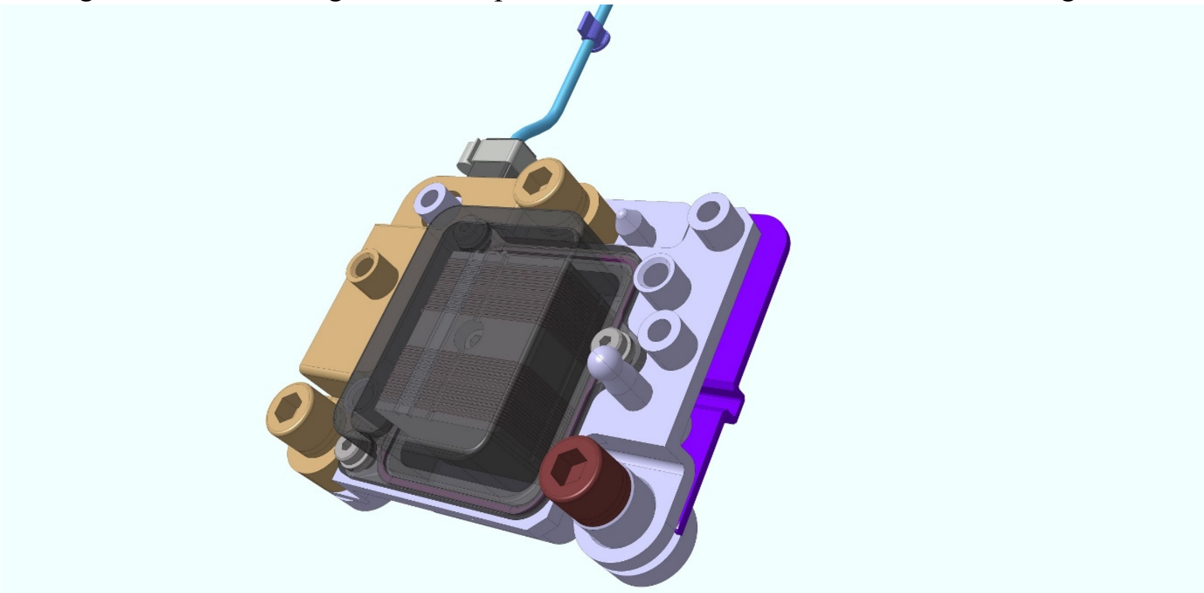

Figure 8: Example of a Poloidal and Toroidal Array Sensor

Magnetic Loops are a group of distributed magnetic diagnostics deployed on the inner surface of ITER VV to measure the linked magnetic flux threading through the respective encircled area, which are essential input for magnetic equilibrium reconstruction. There are in total ~360 diagnostic flux loops of various kinds to be installed to the VV. Each diagnostics loop is formed into the designated (closed) shape from MIC, fixed to the VV by a series of cable clips pre-welded to VV, and electrically wired with the in-vessel cabling inside a junction box placed at the extremities.

5.1.3 Reflectometry

The main plasma High-Field-Side (HFS) reflectometer is a diagnostic system designed for the measurements of plasma electron density profile as well as the properties of the electron density fluctuations. The plasma is probed with microwave radiation of 12 - 90 GHz (X-mode) and 18 - 140 GHz (O-mode) frequency range, which is launched/received by in-vessel antennas located on inboard equatorial plane in slits between Blanket modules.

From the upper port feedthroughs the HFS-R waveguides are routed to microwave electronics located in Diagnostic Building 74 and Assembly Building 13.

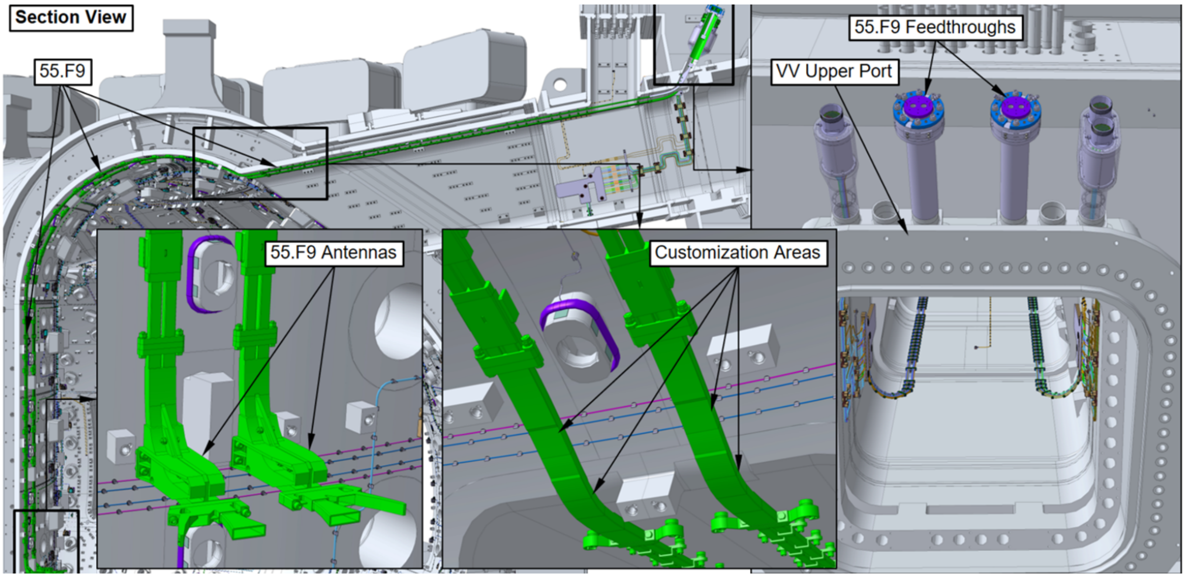

Figure 9: Reflectometry system

5.1.4 Neutron Activation system

Neutron Activation System (NAS) is based on pneumatic post system that transfers foil samples of different materials to a number of dedicated irradiation ends in different positions. Irradiation ends are positioned on the vacuum vessel inner wall surface as well in the upper and equatorial ports.

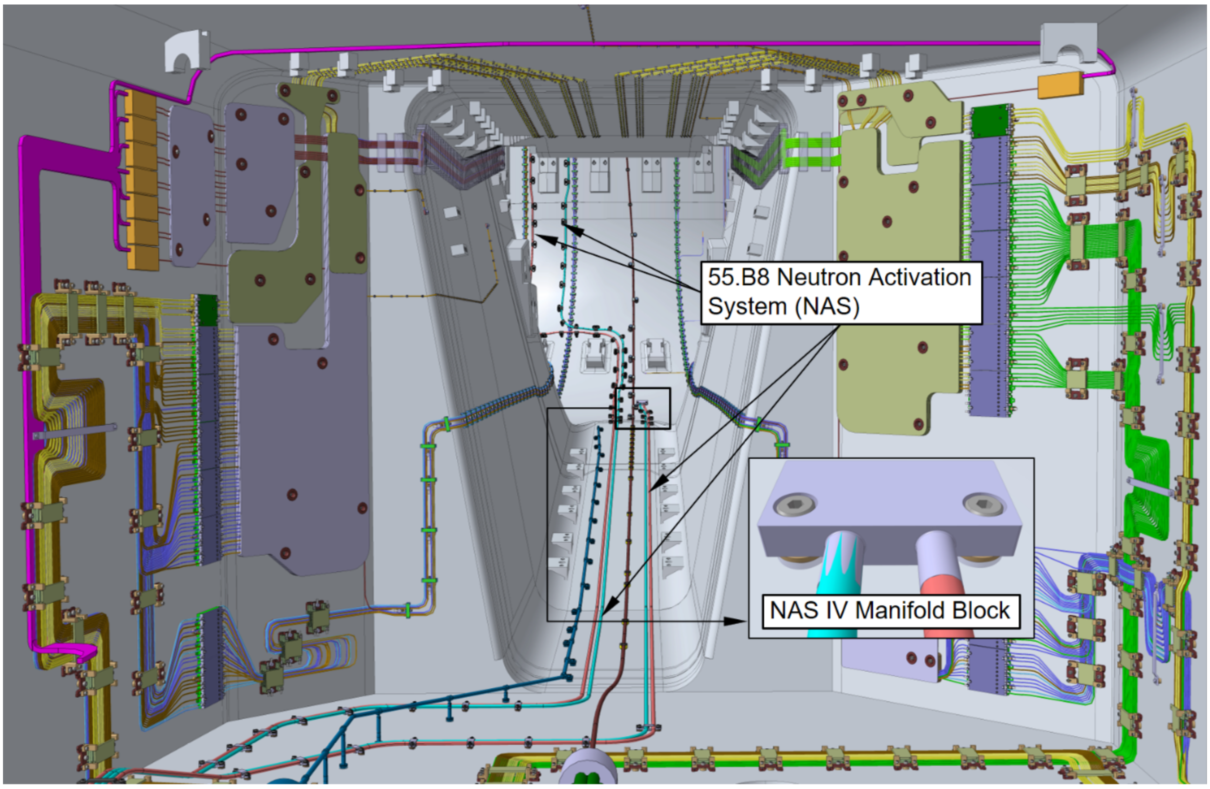

Figure 10: Overview of Neutron Activation System.

5.1.5 Micro-fission chambers

MicroFission Chambers (MFC) are designed to carry on the measurement of total neutron emission during all phase of ITER operation. In order to fulfil the task, fission chambers with different uranium content are employed at multiple locations. They are designed to measure high levels of neutron flux corresponding to high fusion power levels during DT operation phase. MFC will be installed in VV sectors 1, 2, 5 and 6 (near ports 3 and12) outboard, between the blankets modules and the inner shell of the Vacuum Vessel.

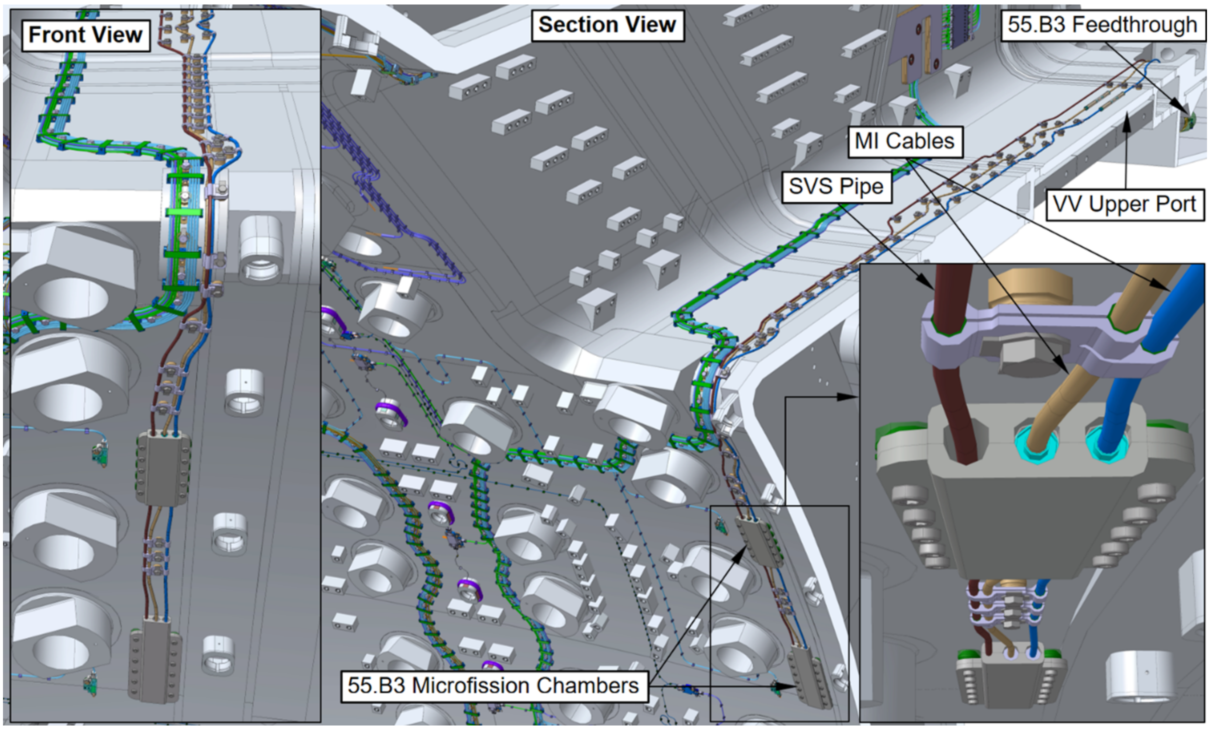

Figure 11: Overview of Micro-fission chamber system.

5.2 ITER Internal Component Operational Instrumentation

ITER internal components such as the Blanket, Divertor and First Plasma Protection Components are located inside the vacuum Vessel (VV). They are equipped with Operational Instrumentation for the measurement of thermal, mechanical and electromagnetic parameters during operation. These measurements are performed by two types of sensors:

- Optical for strain sensors, linear displacement sensors, temperature sensors;
- Electrical for Rogowski coils, magnetic flux loops, thermocouples.

The Optical Fiber Feedthrough (OFF) allows the transmission of measured signals from optical fiber sensors located in the VV to the data acquisition system by routing the optical fibers through the VV barrier.

The optical fibers connected to sensors will be routed from the inside of the VV using Optical Fiber Feedthrough located at the VV port wall and containing multiple optical fibers to transmit the optical signals to the Control Cubicles and data acquisition system.

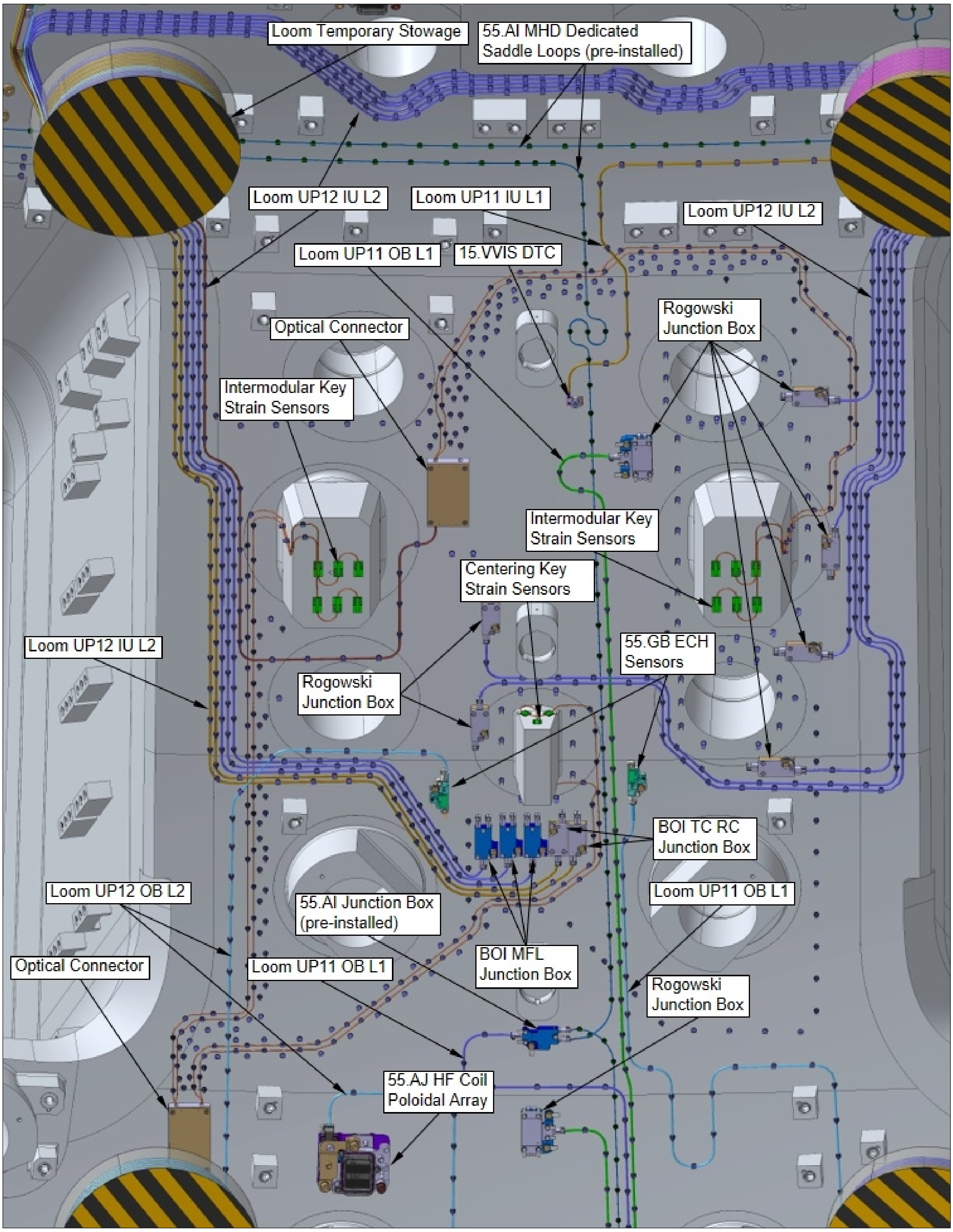

Figure 12: Close up view of the Operational Instrumentation on the VV outer wall

5.3 Fuelling and Wall Conditioning Systems

The fuelling and wall commissioning systems installed within this contract comprise the Gas Introduction System (GIS) and Pellet Injection System (PIS).

The PIS is not required for First Plasma operation, but the pipework and valves routed below the TCPH, are captive components, and must be installed in assembly Phase 1.

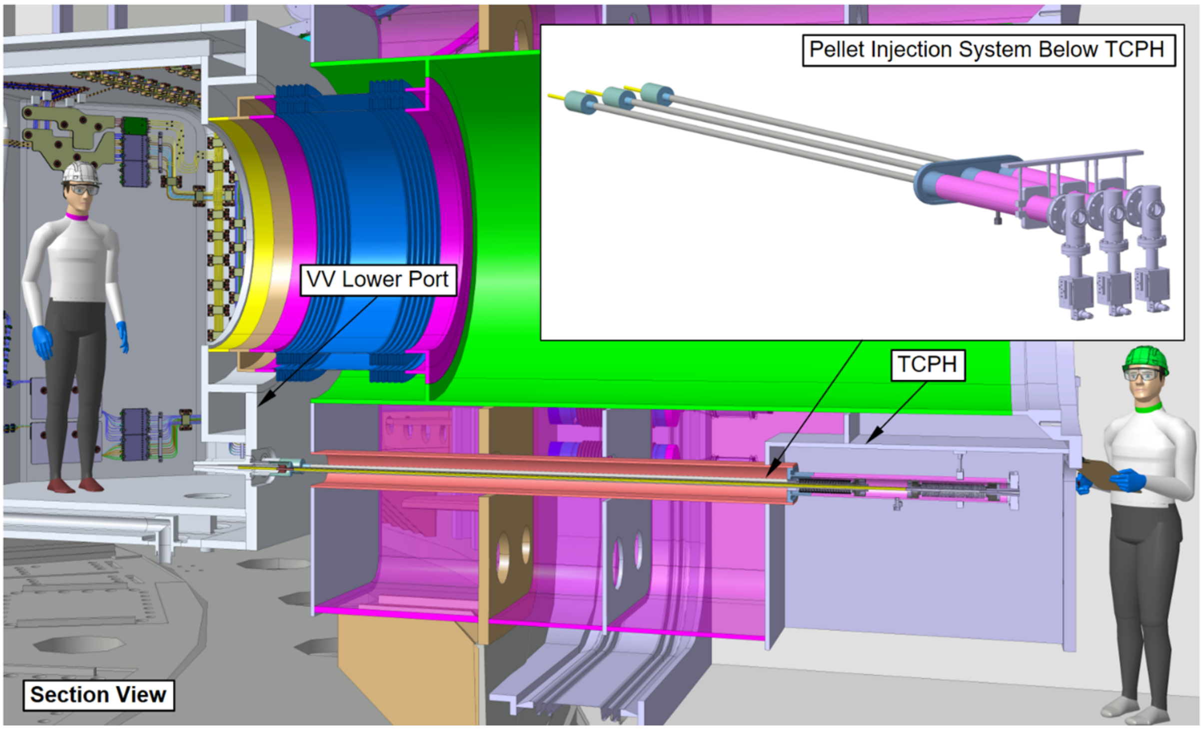

Figure 13: Pellet injection system

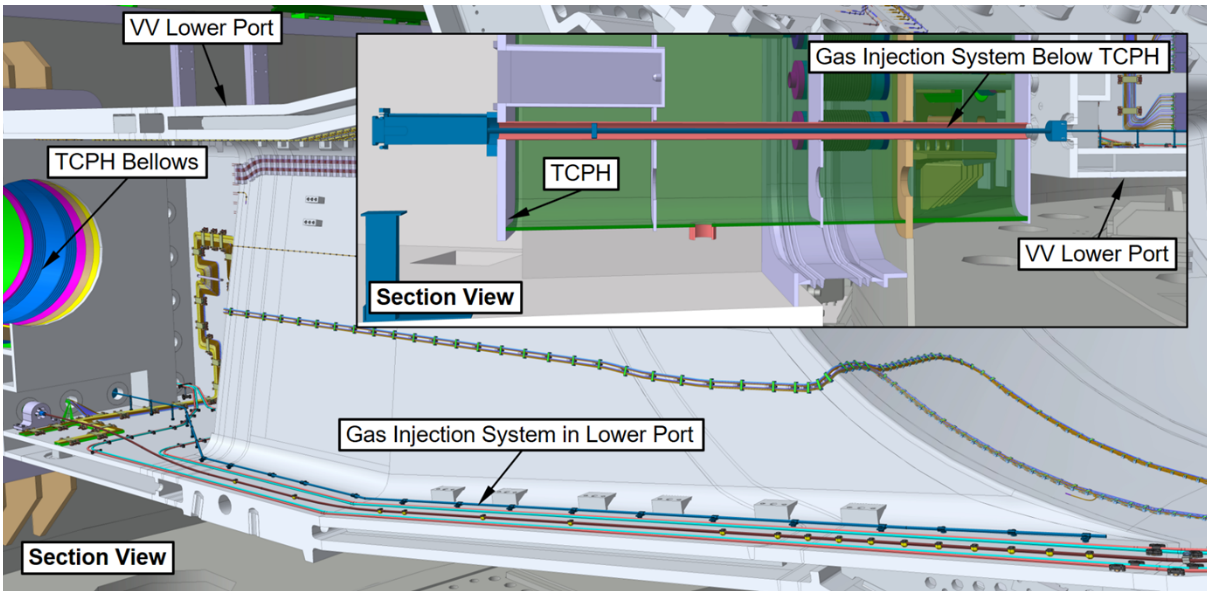

Figure 14: Gas Injection System

5.4 Vacuum Vessel Instrumentation

The Vacuum Vessel Operation Instrumentation (VVOI) is aiming at monitoring the thermal and structural behavior of the Vacuum Vessel, first confinement barrier. This monitoring shall survive the full ITER life time and be able to monitor all event including seismic events.

The thermal monitoring covers both the inner and outer shell of the vacuum vessel, by using thermocouple types N, spread over the surfaces in critical zones.

It also covers all 9 sectors and all levels ports. Most of VVOI in-vessel thermocouples (~360), the ones dedicated to the monitoring of the inner shell, are routed inside the Diagnostic electrical service, section 5.1.1. The 24 remaining thermocouples are installed in irregular equatorial HNB ports.

Thermocouples are made of MI cables (4mm) terminated by a hot junction corresponding to the sensing part. They are all fixed to the surface using M8 studs and attached using copper base supports.

5.5 In-service Inspection

During ITER's life, it is necessary to monitor the wear of the VV inner wall inboard welded joints of centering keys and intermodular keys accessible through lower ports penetrations to guarantee a safe operation of ITER. The in-vessel guide tubes are used as inspection infrastructure for the In-service Inspection (ISI) of the centering keys and inter-modular keys accessible through lower ports penetrations 6, 12 and 18. The main functions of this system are the followings:

- Allow access to the inner wall inboard welded joints for inspection;
- Allow inspection of the desired inspection zone by the ISI equipment;

The entry point of the in-vessel guide tube system is located in front of Lower Ports Extension 6, 12, and 18 through which respective centering keys and inter-modular keys can be accessed for inspection. Another part of the installation will be done under the TCPH, including installation of PIC valves. The PIC valves help to maintain the vacuum and contamination boundaries with respect to the VV.

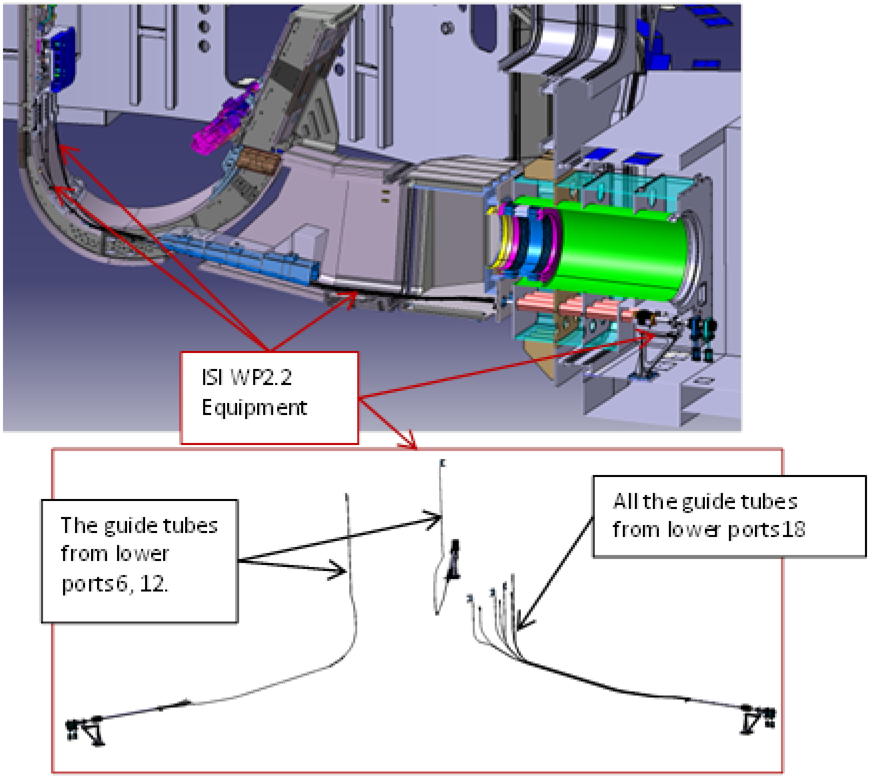

Figure 15: Overview of In-service inspection

6 Contract Description

6.1 Contract Periods and Duration

The A6 Assembly Phase I, (IDI) is estimated to last 40 (forty) months from the Commencement Date, which includes a process qualification phase of 8 months.

The summary schedule is based on activities executed with 2 shifts per day of 7.5 productive hours per shift, 6 days per week. The night shift is considered to be used for hazardous activities like Radiographic Testing (generating exclusion zones).

The main contract execution periods to be considered are the following (tentative scope and duration of each period will be confirmed at Call for Tender):

6.1.1. Preparation Period (16 months)

This period will start right after Contract Signature and Commencement Date and is estimated to last 16 (sixteen) months:

- Contractor will implement its proposed organisation, the project and contract management procedures, mobilise the required resources and facilities (on-site / off-site), develop its execution engineering and installation method statements
- During the same period, the Contractor will develop and implement a comprehensive qualification and mock-up program, which shall address the development, and qualification of main technical special processes required for the installation of the IDI Components. Specific tooling will also be designed and manufactured during this period

- This preparation period is estimated to 16 months with a reasonable overlap with the first in-field activities (next section).

6.1.2. In-Field (Pit) work – In-vessel assembly (12 months)

This period is estimated to last 12 (twelve) months with reasonable overlap with the Preparation Period to ensure that all necessary processes and personnel are qualified to start this first works:

- In-Vessel Assembly will start within the Vacuum Vessel when a minimum of four (4) Vacuum Vessel Sectors are welded together;
- The corresponding Vacuum Vessel inner area is then accessible to the Contractor with a minimized co-activity with VV welding activities which allows for proceeding with the works;
- The IDI installation on the VV sectors will then follow the sequence for sector assembly until closure of the VV torus. This will correspond to a period where the VV is lowered onto its gravity supports, where the handling radial beams can be removed and therefore allowing to proceed with the welding of lower, equatorial and upper ports.

6.1.3. In-Field (Pit) work – In-Port assembly (20 months)

This period is estimated to last 20 (twenty) months with reasonable overlap with the Preparation Period to ensure that all necessary processes and personnel are qualified to start the first works:

- In-Port Assembly works will start after the first Lower Port extensions welding are being completed and will progress in parallel and following the sequence of Port extension welding sequence from Lower Ports to Upper Ports and then Equatorial Ports;
- Multiple teams working in parallel on several ports are considered
- Work is performed in co-activity with the Port extension welding but also with the installation of the In-Vessel Coils Works.

6.1.4. Final documentation (3 months)

This period is estimated to last 3 (three) months after all Field works are completed and will enable Contractor to produce the last Mechanical Completion dossiers including As Built documents and Installation Quality Records.

6.2 Scope of Contract

The scope to be performed under this contract will generally consist of the preparation, qualification, execution, control and documentation of the permanent works, plus any temporary works required to achieve the permanent works, as described in section 5 of this document.
The Contractor shall demonstrate experience and compliance with the highest standards in project and contract management ensuring that the objectives for schedule, cost and quality related to the contract scope execution are met. The Contractor shall comply with all instructions and requirements during the execution of the contract and shall put in place an accurate quality management system.

The site works will be executed under the management of the Construction Management as Agent (CMA), and IO has appointed MOMENTUM SNC as CMA for the Construction Project.

The Scope of Works of this Contract includes:

- Project and Contract Management;
- Development of Installation Work Packages (IWPs) from the documentation provided by IO and the CMA;
- Identification, definition and provision of any required temporary works required to complete the permanent works, such as, lighting, protection, temporary access, safety equipment, standard tooling, etc.;
- Design, procurement and maintenance of purpose-built tooling, including the maintenance of IO supplied tooling;
- Provision of offsite, custom machining facilities; custom machining of IO supplied components;
- Qualification of works and methods as a result of a contractor's IWP development including the necessary mock-ups;
- Provision of all consumables and accessories required to complete the works;
- Execution of the permanent works on site in accordance with the Project schedule;
- Performance, and documentation of all required installation tests and verifications;
- Preparation and issue of detailed as-built drawings, specifying dimensions achieved.

The Contractor's personnel shall have access to the ITER facilities as allowed by the IO.

7 Required Competences

The tokamak fusion reactor system integrates a uniquely extensive variety of high technologies in its design, that include: ultra-high vacuum, superconductivity, cryogenics, advanced cooling technologies for high heat flux components, low-z (beryllium) plasma facing components, high-z (tungsten) plasma facing component, etc.

The competence and experience of the Contractor, and the ability, experience, and training of their engineering and construction team will have a direct influence on quality, re-work, and schedule. The Contractor will be required to demonstrate competence and experience in a number of key areas including the engineering capacity to develop and qualify fit-for-purpose assembly processes.

Core competences are identified in Table 2, below. The remaining competencies may be obtained by sub-contracting subject to the limit which will be specified at the Pre-qualification stage, in which case the Contractor or Consortia will be required to identify staff members for the area of competence sub-contracted to guarantee adequate technical supervision.

Section	Area of Competence	Core Competence
7.1	Assembly Tooling	
7.2	Clean Conditions Working	√
7.3	Mechanical and Electrical Codes and Standards	√
7.4	High Vacuum and UHV	√
7.5	Occupational Safety	√
7.6	Bending, forming and precision Assembly of Mineral insulated cables	√

7.7	Process Development and Qualification	√
7.8	Quality Assurance / Quality Control	√
7.9	Regulated Construction	√
7.10	Welding	√
7.11	Clean Conditions Staging	
7.12	Cleaning	
7.13	Inspection and Non-Destructive Examination	√
7.14	Instrumentation Installation	√
7.15	Metrology	
7.16	Lifting and Handling, up to 1000 kg	√
7.17	Reverse Engineering, Customisation and Precision Machining, Workshop	√
7.18	Tooling Maintenance, Storage and Preservation	√

Table 2. Required Competencies and Experience

7.1 Assembly Tooling

The Contractor shall assemble, commission (facilitating load testing and certification as required), operate and maintain, the tooling supplied by IO. On-site technical support will be provided by IO during assembly and commissioning of these tools, as will documentation (manuals) covering the operation and maintenance of the tools. Some of the special purpose built assembly tools might need to be finalised or fully developed and manufactured by the Contractor.

Experience in the design, manufacture, commissioning, testing, certification, operation and maintenance of precise tools, jigs and fixtures is required.

7.2 Clean Conditions Working

The VV is classified UHV and High Vacuum respectively, as are all of the components and systems contained within each volume. Establishing and maintaining cleanliness and controlling debris and foreign objects is vital for machine performance and reliability. As the Tokamak is not designed to be systematically cleaned at the end of assembly, strict control must be implemented throughout the assembly cycle to ensure contaminants do not accumulate. Experience in clean assembly works, and in the strict control of personnel and equipment is required.

7.3 Codes and Standards

The systems that comprise the Tokamak have significantly varied functions, operating conditions, safety classifications, quality classifications, integrate a wide range of technologies, and the hardware is being sourced among all of the ITER Parties. A number of Codes and Standards apply to the design and fabrication of the Tokamak systems, including RCC-MR and ASME Section III for the Vacuum Vessel.

Accordingly, experience in the practical application of a broad range of codes and standards, to site construction activities, is required.

7.4 High Vacuum and UHV

The achievement of the Ultra-High Vacuum (UHV) environment necessary for Plasma operation inside the VV, and the high vacuum environment that thermally isolates the superconducting magnets and other in-cryostat components operating at cryogenic temperatures inside the cryostat is fundamental to the successful operation of the Tokamak. Experience in the assembly of vacuum systems is an essential requirement. All site assembly works on vacuum components and piping, such as assembly welds, will be subject to vacuum leak test controls by the Contractor implementing the work, and relevant experience is essential.

7.5 Occupational Safety

The working environment of the Tokamak presents numerous occupational safety risks, which include; lifting and handling, confined spaces, suffocating gasses, working at heights, hot work, industrial radiography, pressurised equipment and pressure testing, and co-activity. Maintaining safe working conditions in this environment shall be a key priority for IO and for the Contractor.

The Construction Management-as-Agent (CMA) operates a work permit system, and co-ordinates work between contractors, but the Contractor shall be responsible for performing and documenting risk assessments for each work package, augmented by point-of-work risk assessments.

A clear, uncompromising commitment to safety and excellent track record, demonstrating the practical and consistent application of best-practice principles to ensure a safe working culture is required.

7.6 Precision Assembly of Complex Mechanical Systems

The scope of the Contract is primarily the installation of cabling, sensors, feedthrough, pipes and the tight tolerances and other requirements specified for the major components necessitate high precision work, and rigorous and robust quality control. A broad range of experience and skills is demanded, including; handling, installation and alignment of sensitive and high value components; precise fit-up and electrical connections; piping installations; instrumentation installations, cable bending and forming, testing.

The workforce shall be constituted of qualified and experienced (SQEP) mechanical, electrical and instrumentation craftsmen.

7.7 Process Development and Qualification

Assembly of the first-of-a-kind will require tests and trials to develop and successfully qualify the specific procedures and processes.

Experience in the development and qualification of detailed, novel assembly processes and procedures is required – examples: looms, feedthroughs (section 5.1.1, 5.2)

7.8 Quality Assurance / Quality Control

Quality Organizations consistent with achieving and guaranteeing compliance with the demands that nuclear regulation and regulator surveillance imposes; ISO 9001:2008 accreditation of the Contractors' QA systems is required.

The Contractor is responsible for controlling the quality of their work, and that of their sub-contractors. Certain work must be witnessed by a Notified Body. All work will be subject to assessment by IO or IO representatives, and Protection Important Activities or Safety Relevant work will be subject to ASN audit. Most of the components are classified with Quality Level 1.

7.9 Regulated Construction

As ITER is classified as a nuclear facility (INB-174), and is subject to strict regulation of work and quality; the Project is under the jurisdiction of the Autorité de Sûreté Nucléaire (ASN).

Activities identified as Protection Important or Safety Relevant (French Order of 7 February 2012) will be subject to additional surveillance. Relevant experience to the French Order is a requirement.

It is important to note that not all Tokamak Assembly activities will be Protection Important or Safety Relevant, and the level of surveillance for these activities will be as indicated by the Quality Classification System. The Contractor shall ensure at any point in time and throughout the whole assembly and installation process that the IO requirements are properly propagated and verified including the complete chain of sub-contracted services and works.

7.10 Welding

Welding is a key activity and the joining processes are a significant part of the In-vessel assembly work. Experience in the implementation of high quality welding processes, supported by rigorous quality control standards and compliance with numerous construction (pressure vessel) codes is required.

The main welding technologies envisaged are:

- Manual TIG welding;
- Micro-TIG welding;
- Laser welding
- Small bore orbital welding
- Capacitor Discharge Stud Welding;

7.11 Staging

The main in-vessel purpose built tools that will be provided by IO during Phase 1 for the In-vessel assembly are:

- In-vessel staging (IVS)
- Through-port transfer system (TPTS)
- In-vessel tower crane (IVTC)
- In-vessel nacelle (IVN)

The IVS is a reconfigurable set of personnel access platforms that fill the entire volume of the vacuum vessel. There are 5 levels of staging allowing manual access to all parts of the inner wall of the vessel. Stairs provide access between the various levels. The IVS can be manually installed or removed in sections in a relatively short time (approximately 6 hours to install staging in one vacuum vessel sector) to allow flexibility in the IVS configuration. Personnel access onto the IVS is via the lower ports or the equatorial ports. The IVS is designed for a floor loading of 200 $kg.m^{-2}$.

The TPTS is a materials handling system to bring payloads from the equatorial port cell into the vacuum vessel. Payloads of up to 5t mass can be handled. The TPTS uses 4 mobile chain hoists to horizontally transfer and raise/lower payloads.

The IVTC is a remotely operated mobile crane that can translate around the full 360° of the vacuum vessel. It moves on rails installed in the base of the vacuum vessel. The IVTC has an arm to which payloads of up to 5t can be attached.

The IVN is a personnel access system that works in a similar way to a cherry-picker. There is a man basket for two personnel. The IVN is placed on the same rails as the IVTC and can translate around the full 360° of the vacuum vessel. The extendable arm of the IVN allows the man basket to be positioned such that the personnel in the basket can reach any position on the VV inner wall. Two IVNs will be available.

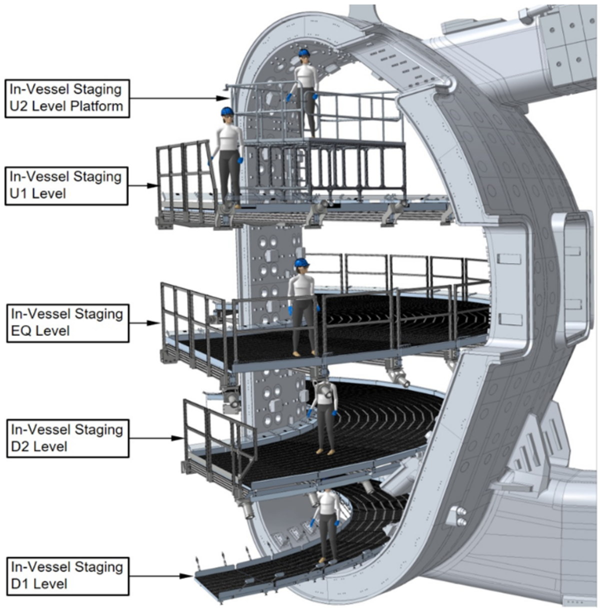

Figure 16: In-vessel staging

7.12 Cleaning

The High Vacuum and UHV conditions required for operation of the Tokamak systems necessitates the achievement and maintenance of strict levels of cleanliness throughout the assembly process. The ITER facility integrates a dedicated cleaning facility, B17, where the components will be cleaned to UHV standards by the respective Contractor. Cleanliness standards and cleaning processes will be specified by IO, which the Contractor will be required to implement. Relevant experience is a requirement.

7.13 Inspection and Non-Destructive Examination

The Contractor is responsible for performing and documenting the specified inspections and tests necessary to guarantee the quality of their work, and for qualifying all such processes and the operators performing the work. Relevant experience in the implementation of a range of standard NDE techniques is required, including:

- Vacuum Leak Testing;
- Visual Inspection;
- Ultrasonic Testing;
- Radiographic Testing;
- Dye-Penetrant Testing;
- Eddy Current Testing;

- Magnetic Particle Inspection.

Qualification of operators and techniques shall be in accordance with the relevant codes and harmonised standards, and will be performed by the Contractor as required.

7.14 Instrumentation Installation

Several thousand sensors and cables are distributed over the VV, providing measurements essential for the operation of the machine. These are very high precision components that require delicate installation to ensure they are accurate, and have the durability to last the life of the machine.

Suitably Qualified and Experienced Personnel (SQEP) are required to perform this specialist work which includes the following:

- high precision mechanical fitting;
- precision small bore pipe fitting
- strain gauge installation (resistance and fibre Bragg grating);
- small diameter Mineral Insulated (MI) cable installation;
- fibre splicing and connector termination;
- feedthroughs – electrical, fiber-optics and mechanical.

7.15 Metrology/Photogrammetry

Metrology systems such as laser tracker or photogrammetry are the only viable tools for controlling the dimensions of the In-vessel components, and given the tight alignment tolerances to be achieved, the system will have to be operated at the limit of its capabilities to deliver the required precision.

Survey work will comply with the ITER Metrology Handbook, and will be subject to verification and audit by IO.

Extensive experience of precise large volume metrology and knowledge of best practice techniques is required.

7.16 Lifting and Handling

The Contractor will be responsible for planning the lifting and handling operations required to complete, and support the assembly of components from the point of delivery (B17, B13) to the Pit. The scope includes the development of lifting plans.

7.17 Reverse Engineering, Customisation and Precision Machining, Workshop

The customisation of interfaces will be necessary to accommodate assembly and manufacturing tolerances, particularly for components with precise alignment requirements.

The assembly schedule requires the customisation of significant numbers of components on short time-scales, and the Contractor will be responsible for providing, or ensuring access to, adequate machining facilities to meet the schedule, as well as developing the technical requirements. The Contractor will perform all the activities necessary for the customisation process, including:

- Dimensional control and reverse engineering;
- Analysis and presentation of data, provision of models and drawing to define the custom machining to be performed;

- Machining of parts;
- Cleaning of parts to UHV or other standards as required;
- Packing and logistics.

To support the assembly activities, the Contractor will provide, or ensure access to, a suitable general workshop facility in close proximity to the site to enable the fabrication and modification of items such as fixtures and jigs, piping, racking, temporary covers, etc. This workshop will be staffed by competent technicians, and have an acceptable selection of hand tools, machine tools, and welding equipment. Experience in reverse engineering and precision machining of custom parts is required.

7.18 Tooling Maintenance, Storage and Preservation

The Contractor shall provide and operate facilities close to site for the maintenance and repair of IO and Contractor tooling, and shall be responsible for the transport of the tooling between site and workshop.

Space shall also be provided for storage of tooling during the contract under conditions sufficient to guarantee the integrity and continued function of the tools. Relevant experience is required.