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EXTERNAL REFERENCE / VERSION

Technical Specifications (In-Cash Procurement)

Design and Prototyping of X-ray Optics assembly for ITER XRCS-Core

This document specifies the scope of design and prototyping of the x-ray spectrometer, including crystal assembly, crystal housing, and associated alignment components, for the ITER XRCS-Core diagnostic system.

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1 Preamble

This Technical Specification is to be read in combination with the General Management Specification for Service and Supply (GM3S) – [Ref 1] that constitutes a full part of the technical requirements.

In case of conflict, the content of the Technical Specification supersedes the content of Ref [1].

2 Purpose

This document specifies the scope of design and prototyping of the X-ray optics assembly for ITER XRCS-Core, including crystal assembly, calibration source and associated alignment components, for the ITER XRCS-Core diagnostic system, for which IO holds responsibility under a Service Provider Agreement (SPA), LGA-2025-A-051, with USDA.

3 Acronyms & Definitions

3.1 Acronyms

The following acronyms are the main one relevant to this document.

Abbreviation	Description
CRO	Contract Responsible Officer
DA	Domestic Agency
DSM	Diagnostic Shield Module
GM3S	General Management Specification for Service and Supply
HOPG	Highly Oriented Pyrolytic Graphite
IO	ITER Organization
IO-TRO	ITER Organization Technical Responsible Officer
ISS	Interspace Support Structure
PIA	Protection Important Activity
PIC	Protection Important Component (component critical for nuclear safety)
PRO	Procurement Responsible Officer
RH	Remote Handling
SIC	Safety Importance Component
SRD	System Requirement Document
SPA	Service Provider Agreement
XRCS	X-Ray Crystal Spectroscopy

3.2 Definitions

Contractor: shall mean an economic operator who has signed the Contract in which this document is referenced.

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4 Applicable Documents & Codes and standards

This is the responsibility of the Contractor to identify and request for any documents that would not have been transmitted by IO, including the below list of reference documents.

This Technical Specification takes precedence over the referenced documents. In case of conflicting information, this is the responsibility of the contractor to seek clarification from IO.

Upon notification of any revision of the applicable document transmitted officially to the contractor, the contractor shall advise within 4 weeks of any impact on the execution of the contract. Without any response after this period, no impact will be considered.

Ref	Title	IDM Doc ID	Version
[1]	General Management Specification for Service and Supply (GM3S)	82MXQK	1.4
[2]	Sub-System Requirement Document sSRD-55.E5: X-Ray Crystal Spectroscopy Core (XRCS Core)	WYX93Z	2.4
[3]	Defined requirements for PBS 55 - Diagnostics	NPEVB6	2.0
[4]	PRELIMINARY ANALYSIS OF THE IMPACT OF THE INB ORDER - 7TH FEBRUARY 2012	AW6JSB	1.0
[5]	Provisions for Implementation of the Generic Safety Requirements by the External Actors/Interveners	SBSTBM	2.2
[6]	ITER Procurement Quality Requirements	22MFG4	6.3
[7]	IS-31-55-027 Interface sheet between Diagnostic 55.E5 XRCS-Core and Vacuum System	8DE2FW	1.0
[8]	IS-55.E5-55.Q2-001 Physical & Functional Interfaces between XRCS-Core and Diagnostic Equatorial Port 02	6Q6B59	2.0
[9]	ITER Dimensional Metrology Handbook	VYJ7U2	2.1
[10]	Codes and Standards for ITER Mechanical Components	25EW4K	5.0
[11]	ITER Vacuum Handbook	2EZ9UM	2.5
[12]	System Design Description (DDD) 55.E5 X Ray Crystal Spec Core	E6CMJT	1.1
[13]	ITER CAD Manuals	29FVC2	Folder

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5 Scope of Work

This section defines the specific scope of work for the service, in addition to the contract execution requirement as defined in Ref [1].

5.1 General Introduction

The primary function of XRCS-Core diagnostic is to diagnose ion temperature and plasma rotation profiles in the ITER core plasma, which will be achieved by measuring the X-ray spectra emitted by the impurity ions. It is designed to collect X-ray light from the plasma through components located in equatorial port 2 using detectors at the back of ISS with multiple lines of sights, as shown in Figure 1. The system is housed in EQ#2 and features a novel dual-reflection configuration, optimized to fit the available space while reducing radiation exposure by positioning the detectors further back in the interspace. To enhance x-ray throughput and misalignment tolerance, Highly Oriented Pyrolytic Graphite (HOPG), which has a mosaic structure of microscopic crystallites, instead of a perfect crystal reflector, is applied as the pre-reflector. The diagnostic system includes Upper, Middle, and Lower pre-reflectors within the Diagnostic Shield Module #2 (DSM#2) to provide sufficient coverage of the ITER plasma. A vacuum environment extends through the front-end of the detector sensors. Figure 1 illustrates the x-ray pathway, from the vacuum extensions to the spectrometer box, located behind the Bioshield, which houses the crystal spectrometers and alignment subsystems.

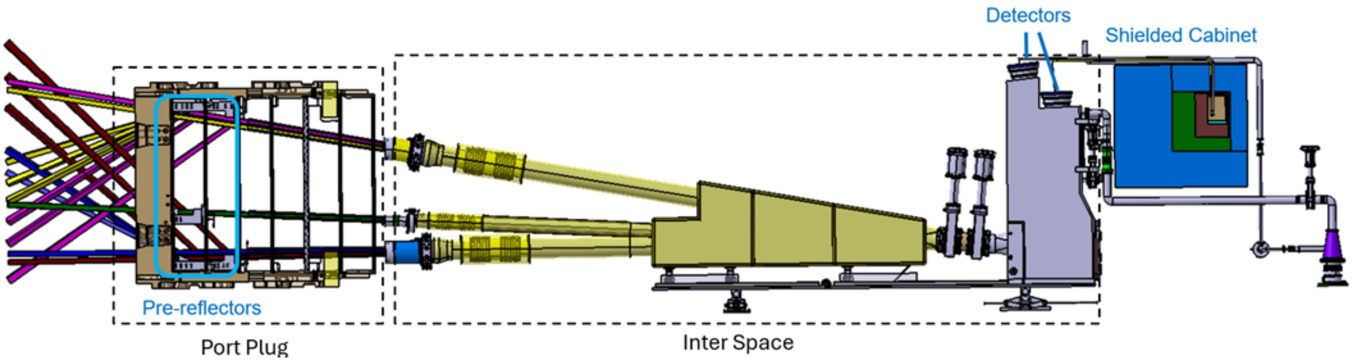

Figure 1. XRCS-Core System Overview

The scope of this contract includes addressing these challenges is broken down as below.

5.2 Scope of work #1: Design of Crystal Assembly and Tuning Mechanism

This task covers the complete mechanical design of the crystal assembly, including six spherically bent germanium crystals, crystal mounts, adjustable support with the integration of actuators that enable adjustment of both the orientation and position of the crystals. The actuators shall support remote operation, allowing precise and flexible alignment without requiring physical access. The mechanical interfaces of the assembly shall ensure sufficient stability and compatibility with the surrounding components, maintaining reliable performance throughout the system's operational lifetime. All selected components shall be suitable for the application in Ultra-High Vacuum (UHV) and environmental conditions in the ITER Port Cell, including radiation, magnetic fields, and other relevant operational constraints.

A PDR-level design concept of the crystal assembly is shown in Figure 2. IO will provide the 3D model including the designed lines of sight (LoSs), which are the interface to define the

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position of the crystals. The support structure should have no interference to the LoSs. The assembly shall accommodate six crystals, each equipped with two-axis positioning adjustment driven by piezoelectric motors and one temperature monitor. In addition, an overall lifting mechanism shall be applied to the top support plate carrying all crystals, in order to compensate for the relative displacement between the port plug and the ISS. The contractor shall assess the feasibility of this concept and, if necessary, propose an alternative solution, subject to CRO approval.

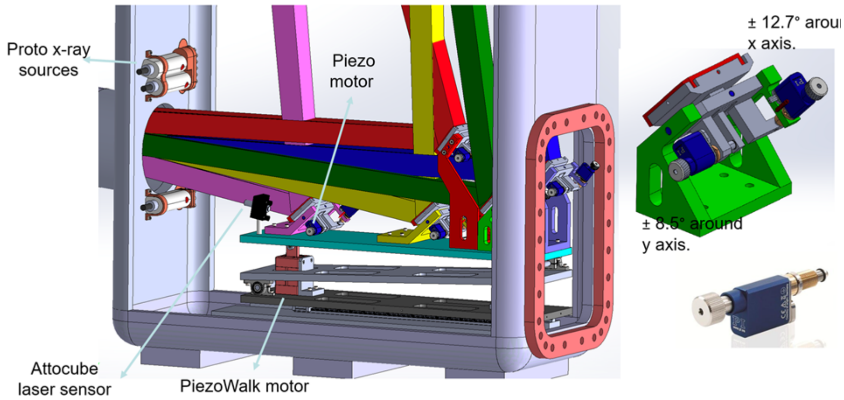

Figure 2: PDR design of crystal assembly

The design shall be based on commercially available off-the-shelf actuator components. The cable routing and electrical connections of all actuators shall be carefully evaluated to ensure compatibility with the local environmental conditions and assembly constraints.

The two-axis positioning adjustment shall meet the following performance requirements:

- **Pitch rotation:** adjustment range of at least ±10°, with positioning accuracy better than 0.01°
- **Radial linear translation:** adjustment range of at least ±5 mm, with positioning accuracy better than 0.1 mm

The overall lifting mechanism shall provide:

- **Vertical translation:** adjustment range of at least ±10 mm, with positioning accuracy better than 0.1 mm

The Contractor shall carry out the detailed design of the crystal assembly including the tuning mechanism and support IO in completing the integration of the design model into the ITER ENOVIA system.

Deliverables

- Technical report describing the mechanical design concept and evaluating the adjustment performance, including the components list and technical specification of commercial components
- 3D CAD models and manufacturing drawings of the crystal assembly and components

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5.3 Scope of work #2: Design of Crystal Alignment and Calibration System

A dedicated alignment and calibration system for the crystal assemblies shall be designed. The alignment system is used to detect the relative displacement between the crystal assembly (in the ISS) and the pre-reflectors (in the PP). The calibration system is used to assess the crystals' condition to ensure proper reflection of the selected X-ray signals.

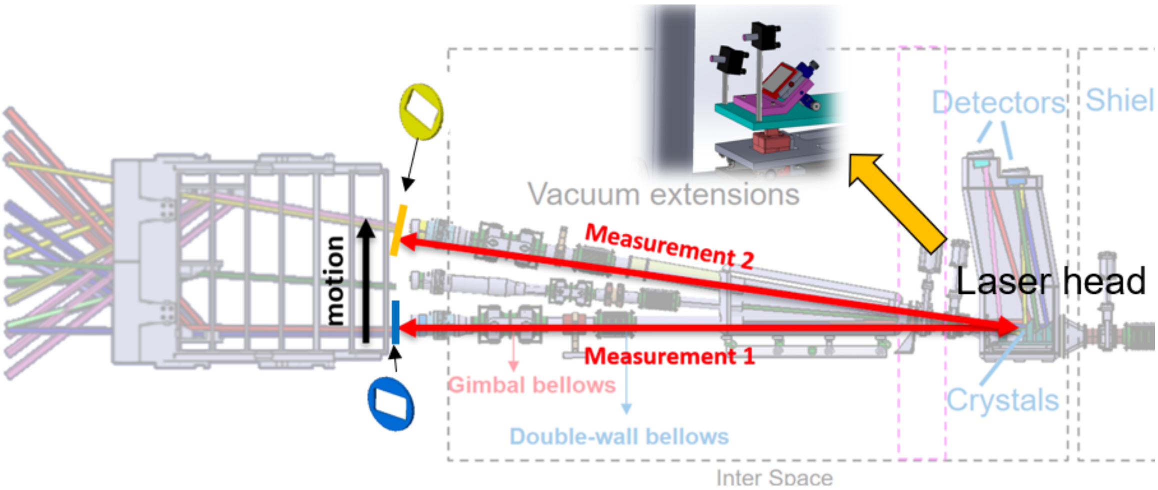

Figure 3: Conceptual design of crystal alignment System

A conceptual design of the alignment system is provided in Figure 3. The system comprises a relative displacement monitoring subsystem and a bellows adjustment mechanism. IO will provide the 3D model of the conceptual design, and the necessary models to define the interfaces.

The relative displacement monitoring subsystem shall provide measurement of the relative displacement between the port plug and the spectrometer housing during ITER operation. The measurable displacement range is ±20mm, with the precision better than 0.5mm. Sensor used in the subsystem shall be compatible with the local operating environment, including magnetic fields up to 200 mT and neutron fluxes up to 10^8 n/cm^2·s.

The bellows adjustment tool should adapt the DN150 bellows and DN100 bellows, and enable controlled adjustment of the relative position between the two ends of the bellows over a range of ±30 mm in both the axial and lateral directions.

The Contractor shall evaluate the feasibility of the proposed concept and, if deemed necessary, submit an alternative technical solution for CRO review and approval. Upon approval of the selected solution by CRO, the Contractor shall carry out the detailed design of the alignment system and support IO in completing the integration of the design model into the ITER ENOVIA system.

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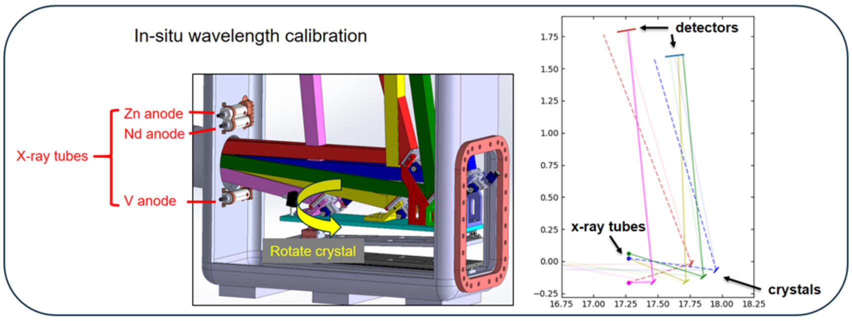

Figure 4: Conceptual design of crystal calibration System

A conceptual design of the wavelength calibration system is provided (see Figure 4), including three vacuum compatible X-ray tubes. The X-ray tubes should provide the characteristics X-ray lines at 5.414 keV (Cr Kα1), 6.49 keV (Mn Kβ1,3) and 9.89 keV (Ge Kα1). The in-vacuum components should meet the ITER VQC requirements as defined in [11] .

The contractor shall evaluate its feasibility and, if necessary, propose an alternative strategy, subject to CRO approval. Once the strategy is approved, the contractor shall proceed with the detailed design.

Deliverables

- Technical report describing alignment system and detailed configuration
- Technical report describing the X-ray tube design concept and detailed configuration.
- Operation instruction of the alignment system and the x-ray calibration system
- 3D CAD models and manufacturing drawings of alignment system and wavelength calibration components

5.4 Scope of work #3: Prototyping and Integration Testing

A complete prototype shall be fabricated, assembled, and tested. The prototype shall comprise:

- One (1) half-size HOPG pre-reflector assembly;
- Six (6) full-size germanium analyzing crystals;
- One (1) full-size crystal mounting assembly, including all adjustment and tuning mechanisms;
- One (1) alignment system;
- One (1) calibration system; and
- One (1) dummy crystal housing to support assembly, alignment, transportation, and testing activities.

The HOPG pre-reflector shall have an active area not smaller than 40 mm × 70 mm.

The germanium analyzing crystals shall be spherically bent to a nominal radius of curvature of approximately 2.0 m, with detailed configuration to be provided in the kick-off meeting. The actual radius of curvature of each crystal shall not deviate from the nominal value by more than ±0.2%. The crystal set shall consist of:

- Four (4) crystals of 50 mm × 50 mm; and

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- Two (2) crystals of 25 mm × 50 mm.

The crystal mounting assembly shall be fabricated at full scale in accordance with the design developed under Scope of Work #1. The assembly shall include full interfaces compatible with the Commercial off-the-shelf actuators, which will be provided by IO.

The alignment and calibration systems shall be fabricated in accordance with the design developed under Scope of Work #2. The calibration system shall incorporate an X-ray source capable of generating the 5.414 keV Cr $K\alpha_1$ emission line.

The objective of the prototype study is to validate the integration of all major subsystems, demonstrate the performance of the two-reflection crystal configuration and its agreement with theoretical and simulation predictions, verify the functionality and operability of the alignment and calibration systems, demonstrate the adjustment capability and repeatability of the crystal mounting assembly, and identify potential design improvements and operational considerations prior to final implementation.

Testing Requirements

A comprehensive testing program shall be conducted, including at minimum:

X-ray Performance Testing

Performance tests shall be carried out using the calibration X-ray source. The tests shall evaluate:

- Spectral response and effective bandwidth;
- Crystal alignment performance;
- Two-reflection optical performance;
- Comparison between measured results and simulation predictions; and
- Repeatability and stability of the system.

Alignment and Calibration System Demonstration

The alignment and calibration systems shall be fully demonstrated. Testing shall determine:

- Achievable displacement measurement accuracy;
- Measurement repeatability;
- Calibration procedure and reproducibility;
- Alignment sensitivity and adjustment resolution; and
- Operational procedures for routine use.

Magnetic Compatibility Testing

All actuators and other relevant components shall be tested to demonstrate compatibility with the expected installation environment, including operation in magnetic fields up to approximately 200 mT.

Vacuum Compatibility and Outgassing Testing

Outgassing testing shall be performed on materials and components intended for installation in the ITER vacuum environment. Testing shall provide evidence supporting compliance with applicable ITER vacuum compatibility requirements.

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A detailed prototyping and testing plan shall be submitted to IO for review and approval prior to the commencement of fabrication and testing activities. Fabrication and testing shall not begin until approval has been obtained.

Upon completion of all activities, a comprehensive test report shall be submitted documenting the test configurations, procedures, measurements, analyses, results, conclusions, and recommendations.

<u>Deliverables</u>

- **Prototype Fabrication and Test Plan**
  - Detailed fabrication approach;
  - Assembly procedures;
  - Test procedures;
  - Test equipment list;
  - Acceptance criteria;
  - Schedule and milestones.
- **Prototype Design Package**
  - Manufacturing drawings;
  - Assembly drawings;
  - Bill of Materials (BOM);
  - Alignment and calibration procedures.
- **Fabricated Prototype Assembly**
  - One complete integrated prototype including:
    - HOPG pre-reflector assembly;
    - Germanium crystal assemblies;
    - Crystal mounting assembly with actuators;
    - Alignment system;
    - Calibration system;
    - Dummy crystal housing.
- **X-ray Performance Test Report**
  - Test setup and methodology;
  - Measured spectral performance;
  - Effective bandwidth evaluation;
  - Comparison with simulation and theoretical predictions;
  - Uncertainty analysis.
- **Alignment and Calibration Validation Report**
  - Alignment accuracy measurements;
  - Calibration results;
  - Repeatability assessment;
  - Operational performance evaluation.
- **Magnetic Compatibility Test Report**
  - Test procedures;
  - Magnetic field conditions;
  - Functional performance under magnetic field exposure;
  - Compliance assessment.
- **Outgassing and Vacuum Compatibility Report**
  - Test methodology;
  - Material characterization;
  - Measured outgassing results;

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- Assessment of suitability for ITER vacuum service.

- **Final Prototype Demonstration Report**
    - Summary of all testing activities;
    - Integrated system performance assessment;
    - Design validation conclusions;
    - Identified risks and recommendations;
    - Proposed improvements for final design implementation.
    - Maintenance recommendations and troubleshooting guidance.

5.5 Scope of work #4: Structural Analysis and Verification

A dedicated structural analysis shall be performed for the crystal assembly, including the crystal mounts, alignment mechanisms, supporting structures. The analysis shall evaluate the effects of expected thermal loads, mechanical loads, transportation loads, and vibrational environments on the structural integrity, dimensional stability, and alignment of the X-ray optics.

The assessment shall include, as a minimum:

- Static structural analysis under operational and handling load conditions;
- Thermal analysis considering the anticipated operating environment and heat loads;
- Modal analysis to identify the natural frequencies of the assembly;
- Vibration response analysis for applicable operational and transportation conditions;
- Evaluation of crystal deformation, displacement, and alignment stability under the specified load cases; and
- Assessment of structural margins and compliance with the defined design requirements.

To validate the analytical results, representative thermal and vibration tests shall be performed on the prototype assembly or an equivalent test article. The test programme shall verify the predicted structural behaviour, alignment stability, and integrity of the optical assembly under the specified environmental conditions.

The objective of this task is to demonstrate that the optical assemblies maintain their structural integrity, alignment accuracy, and functional performance throughout the defined operational, maintenance, transportation, and installation conditions. The results of the analysis and validation activities shall provide evidence supporting the design qualification of the crystal assembly and shall serve as input to the XRCS-Core System Integrity Report and the overall system performance assessment.
Given the expectation that chits related to the contract scope may be raised during the FDR, a final conclusion report is required to address these comments and support the timely closure of the FDR.

<u>**Deliverables**</u>

- **Structural Analysis Report**
    - Finite element models and modelling assumptions;
    - Static, thermal, modal, and vibration analyses;
    - Predicted stresses, displacements, and alignment deviations;
    - Structural margins and compliance assessment;
    - Conclusions and recommendations.

- **Structural Qualification and Integrity Assessment Report**
    - Summary of analysis and test results;

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  - Demonstration of alignment stability and structural integrity;
  - Assessment of compliance with project requirements;
  - Inputs and recommendations for inclusion in the XRCS-Core System Integrity Report and the overall system performance assessment.

- **Conclusion report**
  - Design and analysis to respond FDR chits;
  - Report to summary the design and analysis for closing the involved chits.

5.6 Service duration

The maximum expected duration for this activity is **14 months**. The service duration is governed by deliverables associated to due dates which are referenced in Section 8.

6 Location for Scope of Work Execution

Contractor can perform the work at their own location, with visits on-site for meetings as and when necessary and requested by IO.

7 IO Documents

Under this scope of work, IO will deliver the input data listed below at the latest during the KOM.

Document Title	Doc ID	Expected date
3D Models of optical and alignment components of XRCS-Core	DET number to be defined	Kick-off
3D Models of surroundings systems	DET number to be defined	Kick-off
55.E5 - Ex-vessel System Load Specification (SLS)	ITER_D_7SZ74A	Kick-off
Specification of XRCS-Core crystals	N/A	Kick-off

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8 List of deliverables and due dates

The Supplier shall provide IO with the documents and data required in the application of this technical specification, the GM3S Ref [1] and any other requirement derived from the application of the contract.

A minimum, but not limited to, list of documents is available hereafter with associated due dates:

#	Document Title	Further Description	Expected date (T0+x) *
D#01	Design description of crystal assembly	Technical report describing the mechanical design concept and evaluating the adjustment performance, including the components list and technical specification of commercial components.	T0 + 3 months
D#01-bis	Model and drawings of crystal assembly	3D CAD models and manufacturing drawings of the crystal assembly and components and support IO designer to introduce the model in IO ENVIA.	T0 + 3 months
D#02	Design description of alignment and calibration systems	Technical report describing alignment system and detailed configuration Technical report describing the X-ray tube design concept and detailed configuration. Operation instruction of the alignment system and the x-ray calibration system	T0 + 4 months
D#02-bis	Model and drawings of alignment and calibration systems	3D CAD models and manufacturing drawings of alignment system and wavelength calibration components and support IO designer to introduce the model in IO ENVIA.	T0 + 4 months
D#03	Prototype Fabrication and Test Plan	Report specifying: Detailed fabrication approach; Assembly procedures; Test procedures; Test equipment list; Acceptance criteria; Schedule and milestones; Manufacturing drawings; Assembly drawings; Bill of Materials (BOM); Alignment and calibration procedures.	T0 + 6 months
D#04	Fabricated Prototype Assembly	Below components at contractor site: HOPG pre-reflector assembly; Germanium crystal assemblies; Crystal mounting assembly; Alignment system; Calibration system; Dummy crystal housing.	T0 + 8 months
D#05	Prototype Demonstration Report	Summary of all testing activities defined in SoW #3; Integrated system performance assessment; Design validation conclusions; Identified risks and recommendations; Proposed improvements for final design implementation. Maintenance recommendations and troubleshooting guidance.	T0 + 10 months
D#06	Structural Qualification and Integrity Assessment Report	Summary of analysis and test results as defined in SoW #4; Demonstration of alignment stability and structural integrity; Assessment of compliance with project requirements;	T0 + 12 months

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		Inputs and recommendations for inclusion in the XRCS-Core System Integrity Report and the overall system performance assessment.	
D#07	Conclusion report of XRCS-Core optical assembly design and prototyping demonstration	Conclusion report of XRCS-Core optical assembly design, including inputs for addressing the FDR chits involved this scope	T0 + 14 months

* T0 = Commencement Date of the contract.

Note:

Supplier is requested to prepare their document schedule based on the above and using the template available in the GM3S Ref [1] appendix II (click here to download).

These criteria shall be the basis of acceptance by IO following the successful completion of the works:

- The deliverables will be in the form of reports as indicated in "List of Deliverables".
- The deliverables will be posted in the Contractor's dedicated folder in IDM.
- The IO-TRO is the Approver of the delivered documents.
- The Approver can name one or more Reviewers(s) in the area of the report's expertise.
- The Reviewer(s) can ask for modifications to the report, in which case the Contractor must submit a new version.
- The acceptance of the document by the Approver is the acceptance criterion.

9 Quality Assurance requirements

The Quality class under this contract is QC-2 for the tasks involved in the components to be installed in the ITER vacuum, and is QC-3 for the other tasks, [Ref 1] GM3S section 8 applies in line with the defined Quality Class.

10 Safety requirements

No specific safety requirement related to PIC and/or PIA and/or PE/NPE components apply.

11 Special Management requirements

Requirement for [Ref 1] GM3S section 6 applies in full.

11.1 Contract Gates

The contract gates are defined in [Ref 1] section 6.1.5, this scope of service calls for the following technical gates:

- KOM meeting
- Close-out

11.2 Work Monitoring

To review progress, technical issues, interfaces and schedules, the ITER Organization will hold Progress Meetings. In addition, formal exchange of documents transmitted by email will be used to provide detailed information on the progress of the work.

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The main purpose of the Progress Meetings is to enable the ITER Organization, the Diagnostics Division and the Technical Responsible Officers to:

- Early detect and correct issues that may cause delays;
- Review completed and planned activities and assess progress;
- Enable rapid and consensual resolution of unexpected problems;
- Clarify doubts and prevent misinterpretations of the specifications.

In addition to the Progress Meetings, if necessary:

- Additional meetings to address specific issues to be resolved may be requested;

For all Progress Meetings, a document describing tasks done, results obtained, and blocking points must be submitted. Each report will be stored in the ITER IDM in order to ensure traceability of the work performed.

11.3 Meeting Schedule

The work will be managed by means of Progress Meetings and through the formal exchange of documents and transmitted by emails which provide detailed progress.

Progress meetings will be convened by either the IO CRO or the supplier CRO. They will be held as needed, and at a minimum, once per month via videoconference.

11.4 CAD design requirements

This contract requires for CAD activities, [Ref 1] GM3S section 6.2.2.2 applies

12 Appendices

None.