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Technical Specifications (In-Cash Procurement)

Technical Specification for DMS Optical pellet diagnostics design and prototype

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Table of Contents

1 Abstract

This document describes the technical work required to develop a prototype of an optical diagnostic for the Shattered Pellet Injectors of the ITER Disruption Mitigation System. The tasks will require specialist input in the fields of **Optical, Mechanical and Opto-mechanical Engineering and Design, Rapid Prototyping, Image Processing and Experimental Validation.**

2 Background and Objectives

ITER is a new nuclear fusion experiment that is presently under construction at Cadarache, near Marseille, France. This device will study the potential of controlled nuclear fusion to provide safe, clean and virtually limitless energy for humankind. To protect the machine from the consequences of uncontrolled plasma disruptions during high power and/or high current operations, a Disruption Mitigation System (DMS) will be installed [1].

ITER DMS system consist of 27 injectors in total. 24 injectors are located and distributed around the machine on the equatorial level in port plugs #2, #8 and #17. Three injectors are incorporated into the upper port plugs #2, #8 and #14. An example of an equatorial port (only ISS part) containing two DMS systems (left and right) with a total of 12 injectors is shown in Figure 1.

The DMS is based on the Shattered Pellet Injector (SPI) technology. This works on the basic principle of a cryogenic pipe gun: gas is fed into a pipe, which is surrounded by a cryogenically cooled mass at a temperature below the triple point of the gas, to form an ice pellet. A high gas pressure pulse, released from a reservoir behind the pellet, will shear off the frozen material and accelerate it through a pellet guide tube towards a deliberately tilted plate to shatter the pellet into fragments, which enter the plasma and ablate as a result of the high plasma temperature. The shatter process itself depends on several parameters including the pellet velocity, its orientation and integrity prior to the moment it hits the shatter plate. Therefore, it is important to observe the pellets as they travel towards the plasma in order to monitor the DMS performance, to commission and to assist the alignment of the system, and to improve the SPI technology and reliability. To fulfil this requirement a diagnostic based on optical observation is required. Figure 1 shows the part of the DMS design in a port cell for which a prototype diagnostic should be developed under this Contract. As a minimum, this Optical Pellet Diagnostic (OPD) must be capable of measuring the following parameters either directly or inferred from the measured data:

- successful launch of the pellet
- detection of the pellet passing the OPD to provide an activation signal to the fast shutter
- integrity of pellet (i.e. pellet intact or broken in macroscopic pieces)
- pellet size
- pellet velocity
- pellet trajectory information (orientation and direction of velocity vector)

Since the integrity of the pellet strongly influences the shatter process, a suitable diagnostic to monitor the pellet along its travel toward the shatter unit is essential. The diagnostic has a key role in during the DMS commissioning in PFPO-1 and -2. During these activities the procedures for pellet formation, dislodging and acceleration have to be tested and validated. The OPD will have to provide essential information to confirm the reliable successful launch of pellets.

The present ITER DMS design foresees the following pellet parameters:

- Pellet velocity range: 130-800 m/s.
- Pellet sizes (DxL): 28.5mm x 57mm and 19mm x 38mm(c.f. Appendix 1 for preliminary requirements)

A proof-of-principle of the OPD incorporating all original requirements has been developed within the ITER DMS Task Force [2]. An initial sketch of the concept is described in Appendix 2. It uses optical components such as mirrors, lenses and fibre optics to capture two orthogonal images of the pellet as it passes the observation chamber, and relays these images to high-speed and high resolution video capture and signal processing equipment behind the bio-shield. The setup should be capable to measure all required parameters. However, the maturity and feasibility of the concept must be assessed and developed further so that it can be fully incorporated into the baseline DMS design. This development work is the scope of this technical specification.

One equatorial DMS system consist of 6 injectors placed in the ISS area with all the service systems necessary for 6 injectors to work, located mainly in the PCSS and some at a back part of ISS behind the bio shield. As far as the design of the OPD is concerned, one can consider all injectors having the same geometries except that one set of injectors are an exact mirror image from the other set.

The three injectors in the upper ports are identical. The general layout of the auxiliary systems is similar to the ones in the equatorial port with simplification for only one injector. The injector design is also similar to a single left variant of the equatorial level design (left side compatible).

The design of the left side injectors (as viewed towards the torus) shall be considered as a reference design for the entire family of the DMS injectors and the right system can be seen as a variant design and only limited adaptations should be necessary when non-symmetrical parts or modules are used.

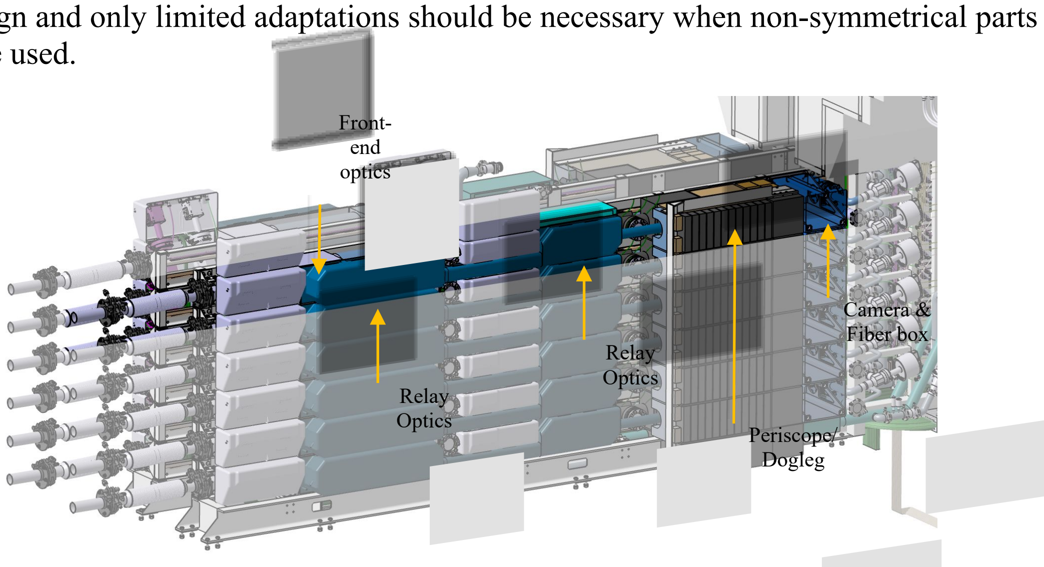

Figure 1: Part of the DMS in the port cell showing the location of the [illegible]ellet Diagnostic in the pellet flight line. The transparent box indicates one SPI injector.

3 Definitions

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

Acronym	Meaning
ALARA	As Low As Reasonably Achievable
CAD	Computer Aided Design
C-RO	Contractor's Responsible Officer
CRO	IO's Contract Responsible Officer
DA	Domestic Agency
DET	Data Exchange Transfer
DFW	Diagnostic First Wall
DIR	Design Integration Review
DMS	Disruption Mitigation System
DSM	Diagnostic Shielding Module
EP	Equatorial port
FDR	Final Design Review
FP	First Plasma
HFE	Human Factors and Ergonomics
HIRA	Hazard Identification and Risk Assessment
HoF	Human Organizational Factor
IO	ITER Organization
ISS	Interspace Support Structure
ORE	Occupational Radiation Exposure
PCSS	Port Cell Support Structure
PDR	Preliminary Design Review
PFPO-1	Pre-Fusion Plasma Operation 1
PI	Port Integrator
PIA	Protection Important Activity
PIC	Protection Important Component
PP	Port Plug
RH	Remote Handling
RO	Responsible Officer
SDDR	Shutdown Dose Rate
VV	Vacuum vessel

Contract: Contract signed between IO and the entity in charge of performing the work defined in the present technical specification.

Contractor: Legal entity to which the contract is awarded and which is responsible for performing the work defined in the present technical specification.

4 References

[1] M. Lehnen *et al.*, Proc. of the 27th IAEA Fusion Energy Conf., 2018.
[2] D. Dunai *et al.*, presentation at PDR of DMS, (6VTBQU)
[3] ITER Vacuum Handbook, (2EZ9UM)*
[4] ITER Tritium Handbook, (2LAJTW)*
[5] ITER Plant Control Design Handbook, (27LH2V)*
[6] ITER Thermavip User Manual, (YHUGQM)*
[7] 14 - Imaging reference system status + demo (7R9GBQ)
[8] Order dated 7 February 2012 relating to the general technical regulations applicable to INB – EN (7M2YKF)
[9] Provisions for Implementation of the Generic Safety Requirements by the External Actors/Interveners (SBSTBM)
[10] Procedure for the management of Deviation Request (2LZJHB)
[11] Procedure for Management of Nonconformities (22F53X)

References are also inserted throughout the text.

* The IO-CRO can provide to the Contractor(s) this document if required.

5 Scope of Work

The work is broken down into the following tasks:

- Development of an optical scheme based on results of a previous mock-up and compatible with given CAD models of the system integration.
- Development of front-end mirror/optics module and mechanical integration into the existing design taking into account installation and maintenance aspects of the OPD and the full DMS compatible with overall ITER DMS design and environment. This shall also include the removal and re-installation without the loss of the previously achieved optical alignment. After installation there should be a way of assessing and if necessary adjusting the alignment. In case of damage or accidental loss of the alignment on the base parts (internal components which are non-removable) a method should be developed for the realignment using the commissioning tools (set of alignment lasers and masks etc). In case of damage or loss of alignment of the removable part, the corresponding components/sections should be replaced with spare parts. Damaged/misaligned parts should be realigned/repaired on the workbench in addition to the maintenance procedure.
- Development of the front-end optics and redirecting mirror (a mirror, which is located in front of the optical window) so that the vacuum optical window is accessible for in service maintenance/inspection or replacement. The alignment has to be maintained despite of any of these activities.
- Development of a focussing optics module within the given space reservation (permanent area, no removal or inspection for other DMS related maintenance procedures shall be required).
- Development of relay optic modules in designated areas with possibility of their removal either partially or as one single component. Design of relay optics between front-end optics and detectors within given space reservation of the ITER DMS design.
- Detectors design and development as a prototype compatible with the ITER environment.
- Design and development of lighting compatible with the ITER environment (e.g. with radiation hard fibres, lenses, mirrors etc.).

- Definition and development of an algorithm to provide in real time the information on a successful pellet launch and to actuate other plant. (For e.g. the Central Interlock System or to close a fast shutter).
- Definition and provision of detector recording and strategy for post-pulse analysis.
- Development of an algorithm to automatically derive the key parameters such as pellet velocity, integrity, flight path trajectory.
- Mock-up design and integration of all functional components with ITER latest design
- Development and manufacturing of one prototype
- Development and manufacturing a data collection system compatible with ITER CODAC [7]
- Development a fibre routing from DMS port plug area(s) to diagnostic building including several wall penetrations and all required inter-connectors for all ports
- Integration of the prototype fast camera based on a streak type camera solution together with the control of three high definition slow camera interfaces and data transfer to fit inside one ITER instrumentation cubicle for the entire DMS system for one equatorial level (6 injectors=6 fast cameras+18 slow cameras) along with the associated PCs, triggering module, other signal interfaces and all the power supplies and lighting module and adequate storage of the excess of a fibre line up to 5m per injector (One full prototype and 5 non-functional mock-ups shall be integrated inside one cubicle)
- Testing and design validation
- Cost assessment for production of one complete optical diagnostics for one injector

<u>Generally required experience and competencies:</u>

The work must be completed by persons with:

- Demonstrated experience in delivering concept designs for optomechanical or multidisciplinary systems

Persons with experience in the following areas would be advantageous:

- Design of optomechanical systems
- Design of Ultra-High Vacuum (UHV) systems
- Design and operation of optical diagnostics in fusion experiments
- Similar tasks in the ITER environment such as radiation and neutron bombardment

6 Estimated Duration

The Contract is expected to run for 24 months from its starting date, defined by the date of the last Contract signature, for the single prototype development

The work will generally be undertaken by the Contractor at their own premises, or at subcontractors' premises where needed (for example fabrication workshops and testing facilities). The Contractor may be required to travel to the IO headquarters periodically.

7 Work Description

The Contractor shall carry out or oversee the work outlined in detail in the following sections.

Table 7-1: Task breakdown structure

#	Task description	Sub tasks	Description
Task 1	Define baseline optical monitoring layout based on results of a proof-of-principle development compatible with the latest ITER DMS design solution	T1.1	Definition of an optical layout based on results of the proof-of-principle development compatible with latest ITER CAD models
		T1.2	Definition of an optical scheme and components (mirrors, lenses, etc.) for analysis related to tolerance optimization, replacement ability and mechanical tolerances of a base supporting structure. (Optical scheme should be tolerant for local deflections or be flexible for easy access/replacement of some key components.)
		T1.3	Optical design and optimisation (grouping elements, compensators definition, tolerance optimisation for small series production with minimal alignment requirements (plug and play module based design)
Task 2	Design front end opto-mechanical setup	T2.1	Optical mechanical design of collection optics part (in VV, redirection mirror ex-vessel optics part is acceptable)
		T2.2	3D integration into DMS system with some components under torus vacuum considering an ITER port plug configuration (ITER vacuum windows, integration/assembly sequence)
Task 3	Design a collection optics relay line	T3.1	Optical mechanical design of relay optics part (in ISS through the BIO shield up to slow CMOS camera boxes, redirection mirror ex-vessel optics part in one or two modules)
		T3.2	3D integration into DMS system considering an ITER port plug configuration (ITER vacuum windows, integration/assembly sequence, doglegs for neutron/gamma shielding)
Task 4	Design of a receiver optical box	T4.1	Design of a focusing imaging group (coupled with detectors or made as standalone part in front of the camera box, depending on design choice) for coupling the image to the detectors
		T4.2	Design of a camera box with CMOS cameras and optical transmission line (to communicate with streak cameras in the diagnostic building) coupling/focusing optics (lenses or mirrors) within given space (CATIA models)
		T4.3	Design of an alignment quick fixation mechanism (3-point fixation) based on ITER conceptual design (models will be provided from IO). Installation and replacement of any box should be cross-compatible (any receiver optical box should work with any injector; 3 variants one each for left and right based for equatorial ports and one for the upper port would be acceptable)

		T4.4	3D integration and design of an integrated receiver module (left, right and upper port injector variants compatible)
Task 5	Definition and implementation of detectors	T5.1	Detector(s) and detector schemes
		T5.2	Image detector coupling
		T5.3	Design of an electrical scheme compatible with ITER environment in accordance with implementation areas
Task 6	Definition and implementation of adequate lighting	T6.1	Lighting and lighting schemes
		T6.2	Light coupling
Task 7	Definition of detector recording and analysis strategy	T7.1	Offline recording and analysis strategy
		T7.2	Pellet flight path reconstruction strategy
		T7.3	Real-time recording and analysis strategy
Task 8	Assessment of environmental impact	T8.1	Vacuum compatibility
		T8.2	Magnetic field impact on hardware
		T8.3	Radiation and neutron impact on hardware
Task 9	Prototype development	T9.1	Design documentation
		T9.2	Alignment strategy development
		T9.3	Detailed design 3D CAD model
		T9.4	Manufacture and assembly of prototype
		T9.5	Adaptation to test prototype on SPI test bench in DMS support lab and/or other existing SPI systems
Task 10	Transmission fibre line development	T10.1	Transmission line development to connect Optical receiver box to a diagnostic building data acquisition system (streak type cameras) and to records low and fast cameras compatible with the ITER CODAC environment. Tools to be provided to visualise and analyse the recorded data.
		T10.2	Detailed design 3D CAD model
		T10.3	Manufacturing and assembly of prototype
Task 11	Validation testing	T11.1	High level test plan and detailed test procedure
		T11.2	Tests and results
Task 12	Cost assessment for production of one complete optical diagnostics for one injector	T12.1	Cost assessment for one unit standalone production and price per unit for small series ~30 units

7.1 Task 1 - Define baseline optical monitoring layout based on results of a mock-up development compatible with ITER latest design development

7.1.1 Subtask T1.1 Definition of an optical layout compatible with latest ITER DMS CAD models

Based on results from proof-of-principle development and latest DMS models define the optical layout to guarantee a 2 side view on the pellet and a streak camera scanning light read out. The design shall be separated in groups based on different environmental zones (in-vessel and ex-vessel) along with different groups based on ease of maintenance and assembly/alignment. The possible groups could be: imaging collection light group, several optical relay groups for transferring light to a camera/detector box (including dog leg group) and focusing group for cameras/optical fibre. List can be extended with supplementary compensation/alignment elements or/and beam splitters if any.

7.1.2 Subtask T1.2 Definition of an optical scheme and components (mirrors, lenses, etc)

Proposed optical layout should be analyzed and optimized to work with given mechanical integration without imposing high tolerances on the mechanical parts of the DMS equipment. The design should incorporate a compensation strategy based on minimal number of compensation elements located at the camera box level (behind the bio shield). Initial alignment might impose some customization on the base plates on the DMS structure side but stay within the given volume from the models. Definition of an optical scheme and components (mirrors, lenses, etc) should be based on tolerance optimization, replacement ability and mechanical tolerances of a base supporting structure.

7.1.3 Subtask T1.3 Optical design and optimisation

Optical scheme should be robust over the course of operation to produce an image of the pellet with acceptable degradation while experiencing a mechanical deflection/deformation of the DMS structure within a margin of +/- 3 mm at any location. Mechanical groups based on optical design layout should use a non-adjustable installation strategy for easy removal to maintain Occupational Radiation Exposure (ORE) at a minimum. Modularity principal is advised so components could be used in multiple locations. As an example left system and right systems could share same groups of compatible/exchangeable elements. Cross injector compatibility, meaning any component can be considered a spare part for the same component at any other injector, is also required as a way of design and assembly simplification which can play a role on the later stages of small series production for a total set of all DMS injectors. Optical design such a grouping elements, compensators definition should be based on tolerance optimisation for small series production with minimal alignment requirements, plug and play module based design.

7.2 Task 2 - Design front end opto-mechanical setup

7.2.1 Subtask T2.1 Optical mechanical design of collection optics part (in VV, redirection mirror ex-vessel optics part is applicable)

Development of an opto-mechanical assembly based on the existing proof-of-principle design and the latest DMS injector design. Assembly should contain a two-view mirror unit (to achieve two orthogonal views on the pellet), back plate light diffuser(s) for an in vessel part of collection optics and ex-vessel redirecting mirror unit coupled with focusing imaging optics. The focusing part could be a part of a camera box or be considered as a part of relay optical line. In-vessel part should fit into the opening behind the optical vacuum window assembly and be easily removable/maintainable (in case of damage or darkening) from the vacuum window side. It should contain if required all the necessary features to be coupled with external redirecting/focusing optical unit fixed outside of the vacuum window. Alignment should be easily achievable by using mechanical features from both sides of existing vacuum window interface (not the vacuum window itself).

7.2.2 Subtask T2.2 3D integration in vacuum environment considering an ITER port plug configuration (ITER vacuum windows, integration/assembly sequence)

The OPD for the DMS has a limited space for integration (given by CAD models) and has a limited physical access. In-vessel part should be compatible with ITER primary vacuum and shall comply with the requirements of the ITER Vacuum Handbook (03 v2.5) according to Vacuum Quality Class (VQC) 1A [3]. In addition, it should have a simple and ORE friendly interface in case of maintenance/removal. The ex-vessel part should be integrated inside the given space restriction from the side of the human access corridor and be optimised for and easy removal/reinstallation. In addition, it should allow an easy access for vacuum window in service inspection when required.

7.3 Task 3 - Design a collection optics relay line

7.3.1 Subtask T3.1 Optical mechanical design of relay optics part (in ISS through the bio shield up to CMOS cameras boxes, redirection mirror ex-vessel optics part in one or two modules)

Development of a relay optics line to transmit an image of a pellet (double view projection) and light for pellet illumination. Relay optics should be developed in multiple modules, each module is an independent group of optical elements pre-assembled and aligned together so they could be easily replaced or removed for the maintenance of the DMS system behind the optical path.

7.3.2 Subtask T3.2 3D integration in vacuum environment considering an ITER port plug configuration (ITER vacuum windows, integration/assembly sequence, doglegs for neutron/gamma shielding)

Optical scheme of the entire optical layout should be optimized such that each block of relay optics has a low requirement for alignment precision during installation as a unit (+/- 3mm positioning). The base of a camera box and a dogleg unit shall use the same metal plate with better controlled flatness and better (3 point) interface for a quick removal/reinstallation process and hence having a better precision/alignment capability. Dogleg and imaging/focusing optics are considered as part of the relay optics line, and 3 point fixation is adjustable so it can be tweaked to match performances across the all 27 injectors within DMS system at any level. Average optical performance should be sufficient in this case for the successful data recovery and in the same time give a cross platform spare part compatibility for the entire DMS set-up.

7.4 Task 4 - Design of a receiver optical box

7.4.1 *Subtask T4.1 Design of a focusing imaging group (coupled with detectors or made as standalone part in front of the camera box, depending on design choice) for coupling the image to the detectors*

Focusing imaging group could be considered as a part of a relay optics line or as a part of a camera box module (preferable solution considering reduction number of independent elements, ORE, maintenance). The main function of the focusing imaging group is to prepare an image to be processed by several detectors. Three frames (images) with CMOS cameras placed in-situ in the camera box. Some portion of the image to be transferred with a portion of plasma light on to the optical communication fibre and be processed by streak type camera in the shielded cabinet in the diagnostic hall.

7.4.2 *Subtask T4.2 Design of a camera box with CMOS cameras and optical transmission line (to communicate with steak cameras in the diagnostic building) coupling/focusing optics (lenses or mirrors) within given space (CATIA models)*

Camera box should contain CMOS cameras and all the necessary beam splitters and supplementary optical elements if required with in-situ decoders and communication and power interfaces as well as an interface for a portion of the light for a streak type camera be projected on to an optical interface with optical fibre communication line.

7.4.3 *Subtask T4.3 Design an alignment quick fixation mechanism (3-point fixation) based on given by ITER conceptual design (models from ITER). Installation and replacement of any box should be cross compatible (Any receiver optical box should work with any injector, might have 2 variants left and right based on chosen strategy. Note: The upper port system can be seen as a single left variant.)*

Development of a 3-point adjustable mounting system with a quick release based on the proposed ITER design (new design will be shared with DET) for the dogleg unit and a camera box unit. Strategy for the assembly of any optical diagnostics of any injectors is to have all the interfacing/fixation elements. Full scheme of the alignment and pre-alignment procedure

7.4.4 *Subtask T4.4 3D integration and design of an integrated receiver module (left and right injector variants compatible).*

Development of a receiver (camera box) module being compatible with easy quick release and 3-point fixation mechanism and being compatible with a right hand and left hand variants or if not swappable (left/right) easily convertible from one to another.

7.5 Task 5 - Definition and implementation of detectors

7.5.1 Subtask T5.1 Detector(s) and detector schemes

List of suitable detectors (e.g. fast cameras, photo multipliers, avalanche photo diodes etc.) and combinations of detectors (e.g. slow cameras together with fast camera, three cameras solution with short exposure time to take three independent frames/images) including their sensitivity ranges and time resolutions. Camera(s) should be compatible with existing ITER CODAC interface [09]. All the components should be compatible with the environmental conditions mainly magnetic fields, in particular no component shall require magnetic shielding.

7.5.2 Subtask T5.2 Image detector coupling

Design the optical setup in order to couple the frontend optics, as developed in Task 1, to the detectors considering the required image quality and time resolution based on at least two different methods: one, utilising direct imaging (e.g. field transfer via field lenses) and another one using imaging light guides or arrays of individual light guides. The setup shall consider the ITER environment in terms of physical and environmental restrictions. The optical setup should in addition enable the registration of scattered plasma light during a disruption with three single channels for three different wavelengths in the visible light range to measure line intensities of hydrogen, and neon. The detector needs to be able to separate the associated spectral lines, utilising interference filters. An assessment of the light/signal level of these spectral lines during a plasma and a typical disruption shall be provided.

7.5.3 Subtask T5.3 Design of an electrical scheme compatible with ITER environment in accordance with implementation areas.

Development of all required electronics according to its location in ITER environmental areas. DMS equipment is located in several ISSs in equatorial (02, 08 and 17) and upper (02, 08 and 14) ports and inside the diagnostic building in the designated shielded corners of building 11. Communication and power supply for all the electronic modules should cover certain distances, routing, harnessing depending on the instrumentation cubicle locations and take in to account integration aspects (amount of intermediate connectors, cable types etc).

7.6 Task 6 - Definition and implementation of adequate lighting

7.6.1 Subtask T6.1 Lighting and lighting schemes

In order to observe the pellet with a detector, it has to be actively and sufficiently illuminated. Various configurations for the applied light source(s) are possible. The configuration should consider the environmental condition (e.g. vacuum, neutron flux, etc.). As light type for this illumination, white (broadband) light as well as monochromatic light should be considered. The source should have sufficient margin to provide the required maximum intensity through its lifetime including neutron damage effects and loss of transmission for the transmitting fibres used for the illumination as well as for those used to transmit the signal back to the detectors.

7.6.2 Subtask T6.2 Light coupling

The illumination is an important part of the optical setup. Development of an appropriate method and instruments for light coupling up to the object in the vacuum is required. The chosen illumination concept could be compatible with the focussing and collection light optics and hence be integrated (preferred solution) or have its own independent set of optics.

7.7 Task 7 - Definition of detector recording and analysis strategy

7.7.1 Subtask T7.1 Offline recording and analysis strategy

The recorded 2-D and 1-D data should be analysed after completion of a plasma pulse either by an adequate computer program or for validation purposes manually by an operator or. An algorithm should be developed to extract the pellet velocity and trajectory information automatically. The requirements to implement this software into the ITER data analysis platform should be determined. The software should be developed in accordance with the requirements for ITER plant system I&C software specifications (c.f. section 4.4 in [5]). For manual data analysis, it is necessary to have video and imaging display software available either using existing tools such as thermavip [6] or by developing a dedicated programme.

7.7.2 Subtask T7.2 Pellet flight path alignment monitoring

The continuously recorded data, i.e. data obtained outside of a plasma pulse, of the current flight path alignment will have to be available in a live view to the operator or plant monitoring software in order to assist with the alignment of the pellet flight line (c.f. section 4.4 in [5]). The exposure times of the detectors can be higher than for the pellet integrity and trajectory measurements, since the mechanical alignment of the pellet is done on a relatively slow time scale. However, the capability of a single, short exposure image in the axial direction of the pellet passing the diagnostic would be beneficial and should be considered in the design.

7.7.3 Subtask T7.3 Real-time recording and analysis strategy

The diagnostic shall have Real-Time analysis and data broadcast capabilities. Part of the recorded information e.g. pellet detected, will be have to be available in Real-Time. The main purpose of real time digital signals is to actuate a fast shutter to block the propellant gas behind the pellet. The cycle time for this analysis should be in the order of a 0.5ms or less after the pellet has passed the diagnostic chamber. Whether it is of advantage to extract this information from a 2D-image or a dedicated fast single/multiple channel recording unit should be determined as part of this subtask.

7.8 <u>Task 8 - Assessment of environmental impact</u>

7.8.1 Subtask T8.1 Vacuum compatibility

The components exposed to vacuum should be compatible with UHV requirements at ITER (c.f. ITER Vacuum Handbook [ITER_ID_2EZ9UM]).

7.8.2 Subtask T8.2 Magnetic field impact on hardware

The magnetic field varies in the ITER environment depending on the component location. The material choices for the used frontend components as well as any electronic component will need to be assessed considering the magnetic field at the location of the hardware. The IO-CRO will provide data for the expected magnitude and direction of the ambient magnetic fields.

7.8.3 Subtask T8.3 Radiation and neutron impact on hardware

During the nuclear operational phase of ITER (called FPO), components close to the vacuum vessel will be subject to high levels of radiation and neutron fluxes. In liaison with the IO-CRO, the material choices for the front-end components to be used as well as any electronic component and their impact on reliability, maintenance and lifetime must be assessed in regards to compatibility with ITER requirements.

7.9 Task 9 - Prototype development

7.9.1 Subtask T9.1 Design documentation

In order to assess whether the design fulfils the technical requirements of the contract, a design description document based on the system requirement document (to be provided by the IO-CRO) must be produced. A requirement compliance matrix must be provided to link the two documents and used to check that all requirements have been fulfilled by the proposed design.

7.9.2 Subtask T9.2 Alignment strategy development

Development of an alignment strategy complying with the cross compatibility requirement, low tolerance requirement on the optical relay group elements for installation, assembly and maintenance. A workbench setup is required to have a unique way of aligning all the used modules and to guarantee the compatibility with all DMS cross-ports systems. Development of the DMS alignment strategy documentation and tooling for future manufacturing and commissioning purposes shall also be provided.

7.9.3 Subtask T9.3 Detailed design 3D CAD model

The 3D-design and manufacturing drawings must be provided. This will be followed by a hold point for IO-CRO approval to proceed with manufacturing.

7.9.4 Subtask T9.4 Manufacture and assembly of prototype

Upon release of the holdpoint by IO, the manufacturing directly through contractor or sub-contractor (any sub-contractor must be named and fulfil the QA requirements as outlined in section 13) can commence. The manufacturing process has to be in accordance with the Quality Plan.

7.10 Task 10 - Transmission fibre line development

7.10.1 Subtask T10.1 Transmission line development to connect Optical receiver box to a diagnostic building data acquisition system (streak type cameras)

Development of a transmission line to connect a receiver box (camera box) situated in a port cell ISS level of 3 equatorial ports and 3 upper ports (EQ02, EQ08, EQ17, UP02, UP08 and UP14) to a diagnostic building data acquisition system streak type camera/detector. Every path from different port cells features similar assembly disassembly approaches and routing having in total two coupling connectors on both sides plus one or two intermediate connectors on the run, two pass-through areas for wall penetrations in between different sectors/buildings. Note: The proposed design solution needs to be compatible with the leak rate requirements through penetrations.

7.10.2 Subtask T10.2 Detailed design 3D CAD model

The 3D-design and manufacturing drawings must be provided. This will be followed by a hold point for IO-CRO approval to proceed with manufacturing.

7.10.3 Subtask T10.3 Manufacturing and assembly of prototype

Manufacturing directly through contractor or sub-contractor (any sub-contractor must be named and fulfil the QA requirements as outlined in section 13). The manufacturing process has to be in accordance with the Quality Plan.

7.11 Task 11 - Validation testing

7.11.1 Subtask T11.1 High level test plan

The plan shall describe a series of tests to verify that all requirements are fulfilled and to address the main unknowns and risks in the design.

The plan shall list any logistical arrangements related to testing (e.g. identification of a suitable test facility, procurement of additional test equipment). Note that some tests might require transport and assembly of the equipment in another facility e.g. for tests on real cryogenic pellets if pellets cannot be formed at the Contractor's facilities. The Contractor might be asked by the IO-CRO to perform these off-contractor-site tests on request and shall make (optional) provisions in the contract to allow them.

Alternatively, a test plan, which has to be approved by the IO-CRO, could include a comparable method (e.g. static objects representing pellets or dynamic fast pneumatic pistons) to successfully perform the test. The latter will rely on a detailed document describing how the test results can be transferred to real fast flying cryogenic pellets.

The test procedures should be clear and robust in order to give unambiguous results in particular with regard to the feasibility of the concept and precision of the measurements. Before commencing the tests, the test procedures should be approved by the IO-CRO. All recorded test results, video files of each test shot, and all supporting data such as equipment calibration certificates should be collated and provided to the IO.

7.11.2 Subtask T11.3 Tests

All testing should be carried out following the agreed test procedure. Sufficient supervision should be provided to guarantee successful completion of the tests and any deviation from the test procedure should be documented and agreed by the IO-CRO.

The test results will be summarised, conclusions described and the outlook given.

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7.12 Task 12 - Cost assessment for production of one complete optical diagnostics for one injector

7.12.1 Subtask T12.1 Cost assessment for one unit standalone production and price per unit for small series ~30 units

A detailed cost breakdown for the prototype including design and materials shall be provided. In addition a cost assessment should be performed for one unit standalone production and for a small series of about 30 units to cover a full setup of all DMS systems. The latter shall include economies of scale, state potential cost optimization / savings, and quantify those in reference to the prototype cost.

8 Responsibilities

ITER Organization:
The ITER Organization will provide the necessary information and access to the adequate ITER files for executing this work when needed following the work plan.

Contractor:
The Contractor appoints a responsible person, the Contractor's Responsible Officer (C-RO), who shall represent the Contractor for all matters related to the implementation of this Contract.
The Contractor will provide results according to the scope of the work outlined above and agreed between the corresponding Contact Persons, and will fulfil the work plan and conditions of present Contract. The Contractor shall allow access to its premises for selected IO staff to witness the commissioning and testing of the diagnostic.

9 Deliverables and due dates

The Contractor shall submit all relevant data necessary to demonstrate the performance and outcome of its deliverables to the IO upon request by the IO-CRO at any time during the course of the tasks and subtasks. The deliverables, due dates and acceptance criteria are given in Table 8-1.
Each test requires a unique reference number attributed to all data generated for this event. The raw data should be provided in a standard video format (AVI or MJPEG are acceptable) for each event together with results from post processing and validation of the post-processing method.
A full description of the experimental set-ups shall be included. This will include manufacturing drawings, technical specifications, method statements, operational guidelines, commissioning procedures, etc.
Any hardware procured under this contract shall remain the property of IO and shall be clearly marked as property of the IO. At the conclusion of this Contract, the IO may request the return of this hardware.

Table 8-1: Deliverable, due date and acceptance criteria

#	Task description	Sub tasks ID	Deliverable Description	Due Date	Acceptance
D1	Define baseline optical monitoring layout	D1.1	A written individual document or part of an overview document and presentation containing the definition of an optical layout based on defined in mock-up development pellet integrity monitoring strategy compliant with ITER integrated CAD design solution (starting from the in-vessel pellet observation unit up to a camera/fibre unit behind bioshield)	T0+2 months	D1.1: Upload of the report to the IDM, compliance with all reviewer's comments and approval by the IO-CRO.

		D1.2	A written individual document or part of an overview document and presentation containing the optical scheme proposal for optimisation containing the definition of all used groups of elements (mirror, lenses etc) with given target tolerances based the proposed optical layout		D1.2: Upload of the report to the IDM, compliance with all reviewer's comments and approval by the IO-CRO
		D1.3	A written individual document or part of an overview document and presentation containing the results of an optical design and optimisation (grouping elements, compensators definition, tolerance optimisation for small series production with minimal alignment requirements, plug and play module based design)		D1.3: Upload of the report to the IDM, detailing the design in a standard raytracing format (utilising either Zemax or CODE V) and including a description of the expected performance and/or suitable analytical calculations, compliance with all reviewer's comments and approval by the IO-CRO

D2	Design front end optical setup	D2.1	Overall front end optical design suitable for all listed monitoring tasks and integration/maintenance requirements.	T0+4 months	D2.1: Upload of a report to the IDM detailing the design in a standard raytracing format (utilising either Zemax or CODE V) and including a description of the expected performance and/or suitable analytical calculations and drawings. Compliance of the report with all reviewer's comments and approval by the IO-CRO.
		D2.2	Detailed optical design integration with the specified vacuum interface in 3D CAD.		D2.2: Provision of 3D CAD design file (compatible with CATIA V5) and a design description document being submitted to the IDM, reviewed and approved by the IO-CRO.

D3	Design a collection optics relay line	D3.1	Optical mechanical design of relay optics part (in ISS through the BIO shield up to CMOS cameras boxes, redirection mirror ex-vessel optics part in one or two modules)	T0+6 months	D3.1: Upload of a report to the IDM detailing the design in a standard raytracing format (utilising either Zemax or CODE V) and including a description of the expected performance and/or suitable analytical calculations and drawings. Compliance of the report with all reviewer's comments and approval by the IO-CRO.
		D3.2	3D integration in vacuum environment considering an ITER port plug configuration (ITER vacuum windows, integration/assembly sequence, doglegs for neutron/gamma shielding)		D3.2: Provision of 3D CAD design file (compatible with CATIA V5) and a design description document being submitted to the IDM, reviewed and approved by the IO-CRO.

D4	Design of a receiver optical box	D4.1	Design of a focusing imaging group (coupled with detectors or made as standalone part in front of the camera box (depending on design choice) for coupling the image to the detectors	T0+8 months	D4.1: Upload of a report to the IDM detailing the design in a standard raytracing format (utilising either Zemax or CODE V) and including a description of the expected performance and/or suitable analytical calculations and drawings. Compliance of the report with all reviewer's comments and approval by the IO-CRO.
		D4.2	Design of a camera box with CMOSs cameras and optical transmission line (to communicate with steak cameras in the diagnostic building) coupling/focusing optics (lenses or mirrors) within given space (CATIA models)		D4.2: Provision of 3D CAD design file (compatible with CATIA V5) and a design description document being submitted to the IDM, reviewed and approved by the IO-CRO.

		D4.3	Design an alignment quick fixation mechanism (3-point fixation) based on given by ITER conceptual design (models from ITER). Installation and replacement of any box should be cross compatible (Any receiver optical box should work with any injector, might have 2 variants left and right based on chosen strategy)		D4.3: Provision of 3D CAD design file (compatible with CATIA V5) and a design description document being submitted to the IDM, reviewed and approved by the IO-CRO.
		D4.4	3D integration and design of an integrated receiver module (left and right injector variants compatible)		D4.4: Provision of 3D CAD design file (compatible with CATIA V5) and a design description document being submitted to the IDM, reviewed and approved by the IO-CRO.
D5	Definition and implementation of detectors	D5.1	Detector(s) and detector scheme(s), a list of potential detectors, detector combinations and their interaction together with their individual advantages and disadvantages considering all relevant monitoring tasks	T0+10 months	D5.1: Upload of the report to the IDM, compliance with all reviewer's comments and approval by the IO-CRO

		D5.2	A solution and a report of an image detector coupling solution, including detailed optical and conceptual mechanical designs of a direct imaging detector coupling and of a concept using imaging light guides.		D5.2: Report, submitted to the IDM, reviewed and approved by the IO-CRO detailing the conceptual design and the optical model. Provision of a 3D CAD design file (compatible with CATIA V5) showing the mechanical design in and a design description document, uploaded to the IDM, complying with all reviewer's comments and approved by the IO-CRO
		D5.3	Design of an electrical scheme compatible with ITER environment in accordance with implementation areas considering the ITER specific space (Port Cells) and environmental constrains (Magnetic field, radiation and neutrons)		D5.3: Upload of the report to the IDM, compliance with all reviewer's comments and approval by the IO-CRO

D6	Definition and implementation of adequate lighting	D6.1	At least one design concept with in-vacuum integrated light source and two independent concept designs for ex-vacuum light source providing adequate illumination taking into account the listed tasks (required time resolution, detector sensitivity etc.) and an assessment of advantages and disadvantages with a conclusion on the preferred solution (Hold point for IO-CRO input).	T0+11 months	D6.1: Upload of the report to the IDM, detailing the deliverables listed, the conceptual design, the optical design and rendering of achievable 2D images of pellet considering light characteristics. Compliance with all reviewer's comments and approval by the IO-CRO and provision of the 3D-CAD model (compatible with CATIA V5).
		D6.2	Detailed design of the light source and coupling		D6.2: Provision of detailed mechanical design in 3D CAD design file (compatible with CATIA V5) and a design description document, uploaded to the IDM, complying with all reviewer's comments and approved by the IO-CRO.

D7	Definition of detector recording and analysis strategy	D7.1	Document describing the data recording and offline analysis requirements of each detector type, the algorithm for automatic determination of pellet parameters and assessment of the applicability to the ITER environment. Recommended implementation and proof of principle tests and report.	T0+13 months	D7.1: Upload of the report to the IDM, compliance with all reviewer's comments and approval by the IO-CRO.
		D7.2	Description of the pellet flight path alignment strategy. Recommended implementation and proof of principle tests and report.		D7.2: Upload of the report to the IDM, compliance with all reviewer's comments and approval by the IO-CRO.
		D7.3	Summary of the feasibility study on possible Real-Time analysis and data provision.		D7.3: Upload of the report to the IDM, compliance with all reviewer's comments and approval by the IO-CRO.
D8	Assessment of environmental impact	D8.1	Overview and assessment of the overall applicability of the proposed design solution considering the specific ITER vacuum requirements and consequences for reliability, accuracy, maintenance and lifetime.	T0+14 months	D8.1: Upload of the report to the IDM, compliance with all reviewer's comments and approval by the IO-CRO.
		D8.2	Overview and assessment of the overall applicability of the proposed design solution considering the specific ITER magnetic environment and consequences for reliability, accuracy, maintenance and lifetime.		D8.2: Upload of the report to the IDM, compliance with all reviewer's comments and approval by the IO-CRO.

		D8.3	Overview document and assessment of the overall applicability of the proposed design solution considering the specific ITER neutron and radiation environment and consequences for reliability, maintenance and lifetime.		D8.3: Upload of the report to the IDM, compliance with all reviewer's comments and approval by the IO-CRO.
D9	Prototype development	D9.1	System requirements document, design description document, Requirement compliance matrix for DMS optical diagnostic (hold point for IO-CRO input).	T0+18 months	D9.1: Upload of the report to the IDM, compliance with all reviewer's comments and approval by the IO-CRO
		D9.2	Document describing the alignment strategy and tooling/mechanisms required for implementation		D9.2: Upload of the report to the IDM, compliance with all reviewer's comments and approval by the IO-CRO
		D9.3	Detailed 3D CAD design (after release of hold point after T6.2 by IO-CRO).		D9.3: Detailed mechanical design in 3D CAD design file (compatible with CATIA V5) and as built drawings. Design description document uploaded to the IDM, reviewed and approved by the IO-CRO.

		D9.4	Manufacturing and assembly of optical and mechanical prototype		D9.4: Upload to the IDM of a report showing the completed prototype and detailing the component assembly sequence, and approved by the IO-CRO
D10	Transmission fibre line development	D10.1	Document describing the transmission line setup and implementation.	T0+20 months	D10.1: Upload of the report to the IDM, compliance with all reviewer's comments and approval by the IO-CRO.
		D10.2	Detailed 3D CAD design (after release of hold point after T6.2 by IO-CRO).		D10.2: Detailed mechanical design in 3D CAD design file (compatible with CATIA V5) and as built drawings. Design description document uploaded to the IDM, reviewed and approved by the IO-CRO

		D10.3	Manufacturing and assembly of optical and mechanical prototype		D10.3: Upload to the IDM of a report showing the completed prototype and detailing the component assembly sequence, and approved by the IO-CRO
D11	Validation testing	D11.1	High level test plan. Detailed test procedure and results log template	T0+23 months	D11.1: Upload of a document to the IDM summarising the test plan, compliance with all reviewer's comments and approval by the IO-CRO.
		D11.2	Completed test results log. Test dossier		D11.2: Provision of all video files in a standard video file format (MJPEG) for 2D and all data in ASCII format.
D12	Cost assessment for production of one complete optical diagnostics for one injector	D12.1	Document describing the cost assessment for one unit standalone production and price per unit for small series ~30 units. (including economies of scale, state potential cost optimization / savings, and quantify those in reference to the prototype cost)	T0+24 months	D12.1: Upload of the report to the IDM, compliance with all reviewer's comments and approval by the IO-CRO

T0 is the date of the kick-off meeting for the Contract.

Deliverables and due dates relating to each service are listed under its relevant section above.

10 Acceptance Criteria (including rules and criteria)

The IO-CRO shall review the deliverables and reply, within the 15 following days, a commented version of the deliverables. The Contractor shall perform all the necessary modifications or iterations to the deliverables and submit a revised version. The Contract will be considered completed after ITER has accepted the last deliverable.

11 Specific requirements and conditions

- The work will be mainly performed at the Contractor's premises. Some tests might be carried out at a facility with an operational SPI system.
- Kick-Off Meeting (KOM) will be organised within 2 weeks from contract signature.
- Progress and working meetings shall be organized at the ITER Organization Headquarters or remotely by video conference. The contract cost will include all costs related to the contract including the presence of Contractor staff at the ITER Organization Headquarters for such meetings. The Contractor should plan to visit the IO site for five meetings (KOM, three progress/design review meetings and intermediate or final report presentation).
- Agenda and relevant information will be sent by the C-RO at least 2 days before the meeting.
- Minutes of meetings will be drafted by the C-RO and communicated to the IO-CRO for review/validation.
- Documentation developed shall be retained by the Contractor for a minimum of 5 years and then may be discarded at the direction of the IO.
- All reports shall be submitted in electronic format, readable either with Adobe Acrobat Reader or Microsoft Word.
- The Contractor shall request formal approval from the IO for any and all deviation from the requirements defined in this specification.
- The units of the international system (SI) should be used (kg, N, m, etc.). All values shall be given with their units.
- The official language of the ITER project is English. Therefore all input and output documentation relevant to this Contract shall be in English. The Contractor shall ensure that all the professionals in charge of the Contract have an adequate knowledge of English, to allow easy communication and adequate drafting of technical documentation. This requirement also applies to the Contractor's staff working at the ITER site or participating in meetings with the IO.

12 Progress Monitoring / Meeting Schedule

A high-level project plan will be created by the Contractor soon after the kick-off meeting for acceptance by the nominated IO-CRO for this work. As a minimum, this should include the scope of the Contract, the deliverables and how they will be achieved, a project schedule and a risk register.

The detailed planning of the services and the progress of the deliverables listed in this specification will generally be monitored by means of progress meetings. If required, exchange of emails will be used to informally provide detailed progress. These meetings will be regularly organised by the contractor or requested by the IO-CRO with the purpose

1. to detail the forthcoming deliverables and their schedule,
2. to review the progress on ongoing deliverables, the technical problems, the interfaces and the planning.

It is expected that progress meetings will be held as frequently as required, generally bi-weekly, lasting 30-60 minutes.

The main purpose of the progress meetings is to allow the IO-CRO and the Contractor to:

1. Detect and correct early any issue that might cause delays;
2. Review the completed and planned deliverables and assess the progress made;
3. Permit fast and consensual resolution of unexpected problems;
4. Clarify any doubts and prevent misinterpretations of the specifications.

<u>Note:</u> For specific hold points as listed in Table 1 dedicated meetings shall be held before proceeding with the following task.

Except where otherwise stated, the documentation forming the deliverables (except for CAD models) will be stored in the ITER documentation management system (IDM).

In summary, the following meetings and submission of progress reports should be considered:

Scope of meeting	Point of check: progress or final report	Place of meeting
Kick-off meeting	Work program	IO site or video conference
Progress meetings	Progress check and further work definition approximately every 2 weeks in line with the completion of tasks and starting of the next task	IO site or video conference
Design Review Meeting	Final optical and mechanical design of OPD	IO site or video conference
Site visit*	Progress check, IO may wish to visit to see the progress in the experimental work.	Contractor's site
Intermediate report presentation	Intermediate reports and other deliverables as listed in section 9.	IO site or video conference
Contract completion	Final check of reports on all deliverables (24 months after signature)	IO site or video conference

*IO staff or representatives may wish to visit the contractor's site in order to witness the testing performed. The timing of these visits will be agreed between the Contractor and IO-CRO. The Contractor will take the measures required to allow IO staff to witness the tests as required.

13 Quality Assurance (QA) requirements

The contractor shall have a quality management system implemented in accordance with ISO 9001:2015 standards. For the tendering phase, the participants shall present a copy of their valid ISO 9001:2015 certificate or equivalent recognized by IO. This certification shall be maintain valid during contract implementation.

Prior to commencement of any work under this Contract, a Quality Plan must be provided to IO for approval written in accordance with "Requirements for Producing a Quality Plan" (ITER_D_22MFMW). This is a separate document, which comprises:
1) A statement of those involved in the activity and their approximate role and contribution in time;
2) A statement of what work will be subcontracted and who will responsible for checking this.

It is noted that Contractor's personnel visiting the ITER project will be bound by the rules and regulations governing safety and security. The Contractor shall have and maintain the necessary equipment and licences to run the software tools required to carry out the engineering analyses and produce the deliverables in accordance with the tools adopted by the IO.

Deviations and Nonconformities are to be managed as per the references [10] and [11].

14 CAD Design Requirements (if applicable)

For the contracts where CAD design tasks are involved, the following shall apply:
The Supplier shall ensure that all designs, CAD data and drawings delivered to IO comply with the Procedure for the Usage of the ITER CAD Manual (2F6FTX), and with the Procedure for the Management of CAD Work & CAD Data (Models and Drawings 2DWU2M).
Drawing Registration in the IO system shall be performed according to the Procedure for the Management of Diagrams and Drawings in pdf Format Using the SMDD Application (KFMK2B).
The reference scheme is for the Supplier to work in a fully synchronous manner on the ITER CAD platform (see detailed information about synchronous collaboration in the ITER P7Q3J7 - Specification for CAD data Production in ITER direct contracts). This implies the usage of the CAD software versions as indicated in CAD Manual 07 - CAD Fact Sheet (249WUL) and the connection to one of the ITER project CAD data-bases. Any deviation against this requirement shall be defined in a Design Collaboration Implementation Form (DCIF) prepared and approved by DO and included in the call-for-tender package. Any cost or labour resulting from a deviation or non-conformance of the Supplier with regards to the CAD collaboration requirement shall be incurred by the Supplier.

15 Safety requirements

ITER is a Nuclear Facility identified in France by the number-INB-174 (“Installation Nucléaire de Base”).
For Protection Important Components (PIC) the French Nuclear Regulation must be observed, in application of the Article 14 of the ITER Agreement.
In such case the Suppliers and Subcontractors must be informed that:

- The Order 7th February 2012 applies to all the components important for the protection (PIC) and the activities important for the protection (PIA).
- The compliance with the INB-order must be demonstrated in the chain of external contractors.
- In application of article II.2.5.4 of the Order 7th February 2012, contracted activities for supervision purposes are also subject to a supervision done by the Nuclear Operator.

For the Protection Important Components, structures and systems of the nuclear facility, and Protection Important Activities (as per *ITER D PSTTZL*) the contractor shall ensure that a specific management system is implemented for his own activities and for the activities done by any Supplier and Subcontractor following the requirements of the Order 7th February 2012 [8]

Compliance with *ITER_D_45P8YK Defined requirements PBS 18 DMS* is mandatory.
Note: DMS Design activities are PIA
Refer the Quality class and Safety Class as per the SRD document (BEJQWA)

16 Conflict of Interest

The IO plans to hold a Call for Tender for the manufacturing of the DMS at the later stage in future. The selected Contractor for this Contract will be allowed to participate in the future tender, however, the candidates for this Contract should note the following conditions:
1) The selected Contractor shall develop the design which will ensure the future competition of manufacturing tender (e.g. design manufacturable by multiple suppliers or so). The detailed conditions will be clarified at the call for tender stage.
2) Any results from this Contract will be owned by the IO who may disclose them to the tenderers at the next Call for Tender.
The IO may reject any offer not in compliance with the above principles or terminate the Contract if the selected Contractor cannot comply with them.

Appendix 1 – Preliminary Requirements for Optical Pellet Diagnostic

The requirements in the table below are provided as a starting point for the development of a complete System Requirements Document for this diagnostic (see Deliverable 1.1). The Contractor will update this document during the contract, with further input from the IO.

These initial requirements relate to the design solution for use in ITER DMS described in [08] Results from the mock-up development and will be updated by the Contractor according to the result of this study. The design of the mock-up does not necessarily need to comply with all of these requirements, but any non-compliance shall be documented and must not affect the validity of the validation testing. For example, requirement 20 calls for ITER standard primary vacuum flanges. The mock-up may use industry-standard flanges, as long as the concept design (with ITER standard flanges) fits within the overall keep-in envelope.

#	Requirement text
	General requirements
1	The system SHALL measure pellet velocities for a range of 130-800m/s.
2	The system SHALL measure pellet velocity with error "e" (m/s) below the following limit, over the whole range of pellet velocities in requirement #1. $\lvert e \rvert < 0.000109 s/m * v^2$ where "v" (m/s) is the true velocity of the pellet. *This corresponds to an error, t_{error}, of ±0.5ms in inferred arrival time at a point 4.2m from the centre of the diagnostic, which is the approximate distance to the plasma edge. To achieve this, the error of the velocity must be less than [$t_{error}*v^2/(distance - t_{error}*v)$], which can be approximated with above formula. This is roughly an error of e=1.1m/s at v=100m/s, e=27m/s at v=500m/s and e=70m/s at v=800m/s.*
3	The system SHALL be capable of recording still images of the pellet as it passes through the diagnostic chamber, at a frame rate of 30 fps or higher. *This corresponds to three separate images of a pellet with a length of 57mm, travelling at v=500m/s as it passes the diagnostic chamber.*
4	The system SHALL be capable of determining the orientation of the trajectory with an accuracy, which is to be agreed mutually between the IO-CRO and C-RO. *This number is expected to be in the order of a few degrees, but remains to be confirmed.*
	Optical requirements
5	The system SHALL be capable of producing still images of the pellet and videos of the pellet passing the diagnostic chamber with resolution 5 pixel/mm or higher.
6	The system SHALL be capable of recording minimum of three still images of the pellet with exposure/shutter time 60ns or less. *This corresponds to a 500m/s pellet travelling less than 0.03mm (i.e. ⅓ of a pixel at 10px/mm) within the exposure time.*
7	The system SHOULD be capable of producing an image containing two separate views at nominally orthogonal midplanes.
8	The system SHALL be capable of producing an image containing two separate views with a difference of their angles of incidence in a plane perpendicular to the flight path by no less than 60°.
9	The system SHALL provide its own light source.
	Control, & Data Acquisition requirements

10	The system SHALL be capable of producing a still image of a pellet arriving at the diagnostic any time between 1ms and 100ms after a trigger signal is received.
11	The system SHALL be capable of creating a timestamp of the recorded image data accurate to within 0.1ms of the time of image capture.
12	The system SHALL be capable of transmitting the recorded image data and timestamp to the central control system in a suitable format.
13	The system SHOULD be capable of transmitting processed information to the central control system within 1ms of capture.
14	The system SHALL be capable of transmitting the recorded image data and timestamp to the data storage within 5min after the pulse.
15	The system and data acquisition SHALL be compatible with [7] ITER_D_7R9GBQ - 14 - Imaging reference system status + demo
	Environmental requirements
16	In-vacuum and vacuum boundary materials and components shall be compatible with the ITER Vacuum Handbook [3] and ITER Tritium Handbook [4].
17	The system SHALL fit within the overall physical envelope provided (ITER Data Exchange Transfer number TBC).
18	The system SHALL be capable of operating in a magnetic field of a few hundred milli-Tesla. The precise numbers and direction of the ambient magnetic field will be provided by the IO-CRO.
19	The system SHALL be capable of operating during neutron fluxes and withstanding irradiation of up to limits, which will be provided by the IO-CRO. .
20	The system SHALL be capable of operating at least for 20 years with no planned maintenance.

Appendix 2 – Link to a mock-up design results

This section gives an outline technical description of the basic concept for the Optical Pellet Diagnostic. It served as a reference and a starting point for the design tasks for the mock-up development. Combined with the results of mock-up development should be used as a starting point for the prototype development defined in this technical specification. It is anticipated that a design that is fundamentally similar, with some further development, could meet all system requirements. However, **it is the responsibility of the Contractor to review the suitability of the conceptual design presented below, identify any significant technical issues or risks, and propose an alternative concept if necessary.**

Figure A2.1 shows the overall layout of equipment inside the optical box. A pellet is shown travelling along its nominal trajectory (dark blue cylinder) as it passes through the midplane of the optical diagnostic. The optical components (fibre optic bundles, mirrors, windows and lenses) provide two orthogonal views of the pellet at this position. Ultra-high vacuum sealing is provided by the ITER standard diagnostic flange (shown directly above the pellet) and two ITER standard vacuum flanges on the upstream and downstream sides of the flight line itself (not shown). Additional mirrors also provide downstream views to check alignment of the flight line with downstream flight tube components. The various optical paths inside the diagnostic are shown in Figure A2.2 in green and red, with housing and other components omitted for clarity.

Figure A2.3 shows the optical paths and related optics used for pellet imaging. The virtual object plane is oriented at 45° to the nominal axis of light reflected from the first mirror downstream of the viewing lens assembly, so that both pellet images (direct view and reflected view) are in focus.

Figure A2.4 shows the optical paths and related optics used for aligning the flight line in the vertical plane. Figure A2.5 shows the optical paths and related optics used for aligning the flight line in the horizontal plane (the lens assembly is omitted in this figure). Due to the arrangement of the mirrors required for horizontal and vertical views, the two views have slightly different focal lengths. However, it is expected that the optics can be arranged such that both views use identical lens assemblies (probably, a modified lens assembly will be required for pellet imaging, since the required focal length is significantly different).

The optical pellet diagnostic is shown in context with neighbouring equipment in Figure A2.6 to Figure A2.8. An upstream valve and a downstream bellows define the space constraints in the axial direction. In the orthogonal plane, space is limited by the optical diagnostics of adjacent flight lines vertically above and below, and by other equipment and operator access corridors (not shown) to either side. Figure A2.8 also shows the location of the target plane on the downstream component ("closure plate") which will be used to check alignment.

Images are transmitted via fibre-optic cables from the lens assembly to capture and recording equipment in an adjacent cell. Appropriate technologies must be selected for this equipment, taking into account requirements such as physical space, environmental conditions (e.g. magnetic field and neutron irradiation), and interface with central control system.

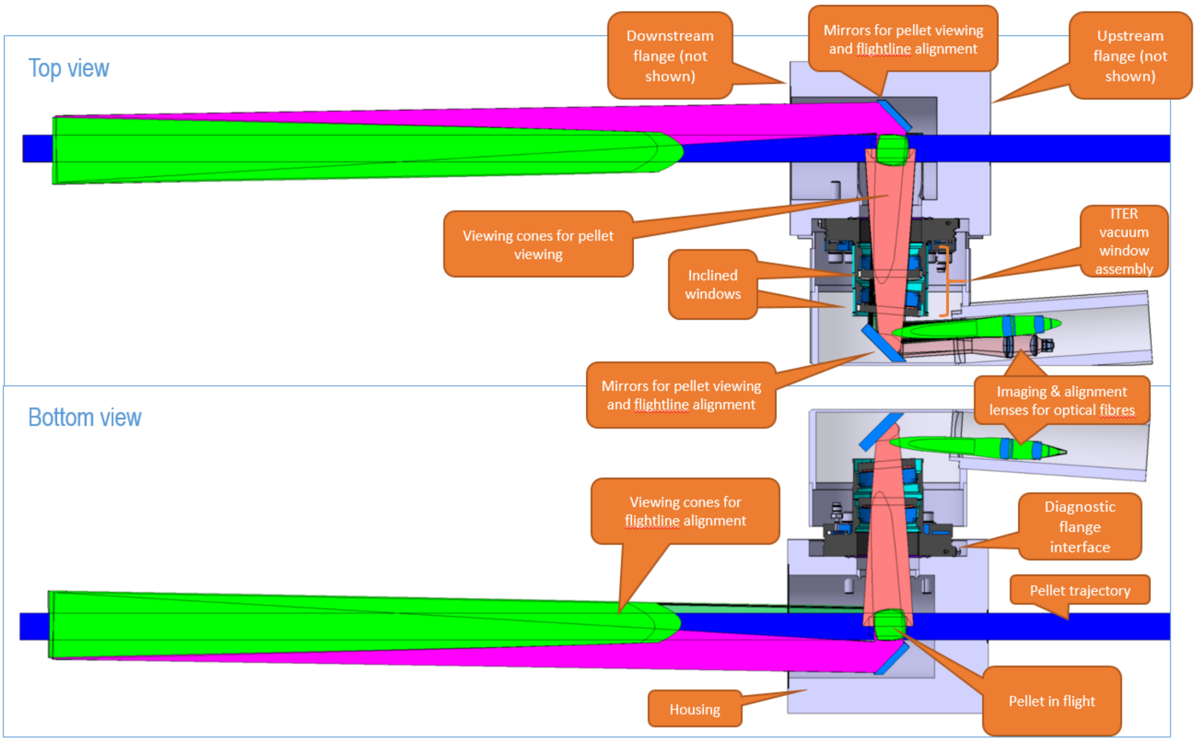

Figure A2.1: Section view through pellet flight path (blue) and vacuum window.

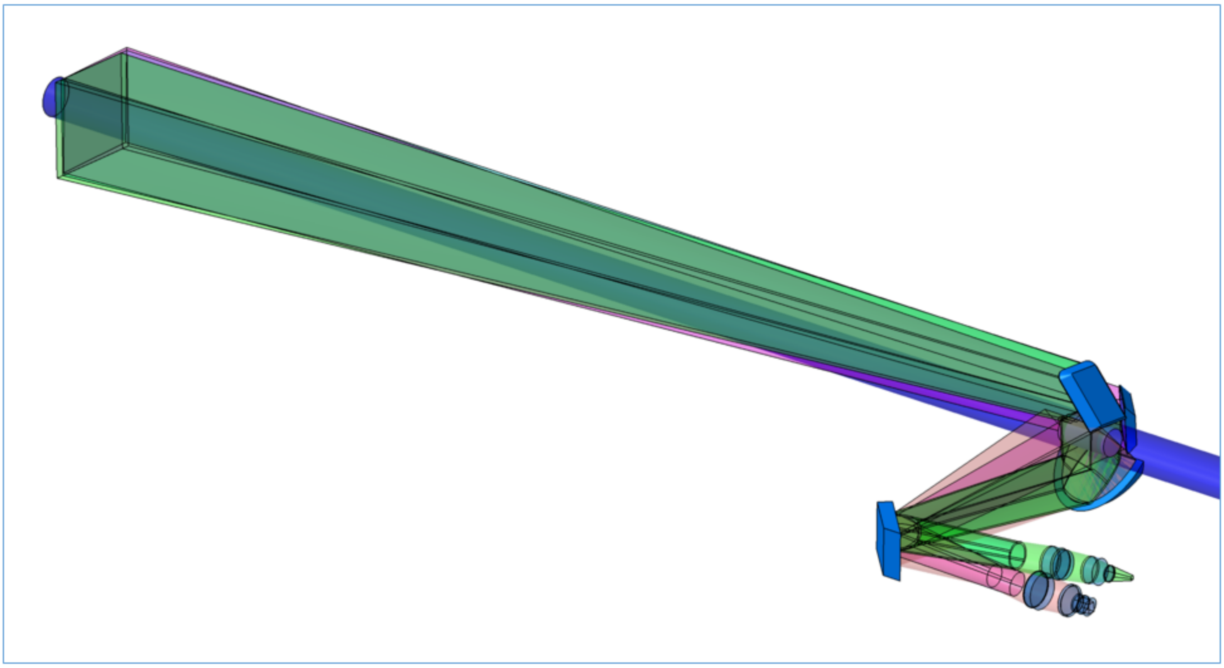

Figure A2.2: 3D view of internal viewing cones and optics.

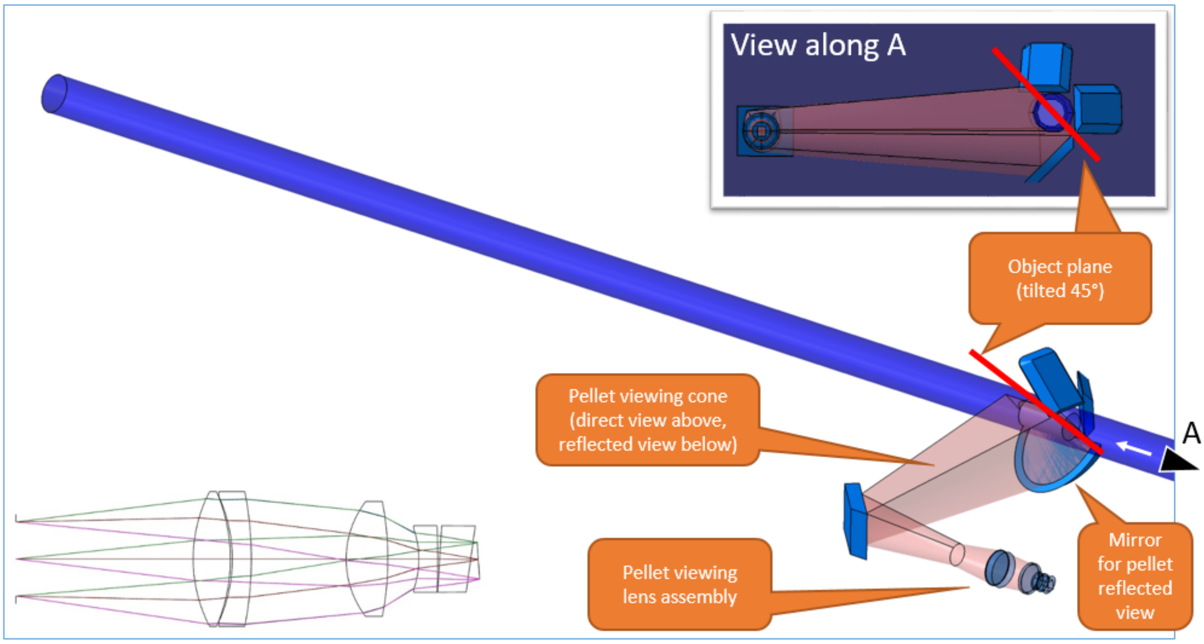

Figure A2.3: Internal viewing cones and optics (pellet view).

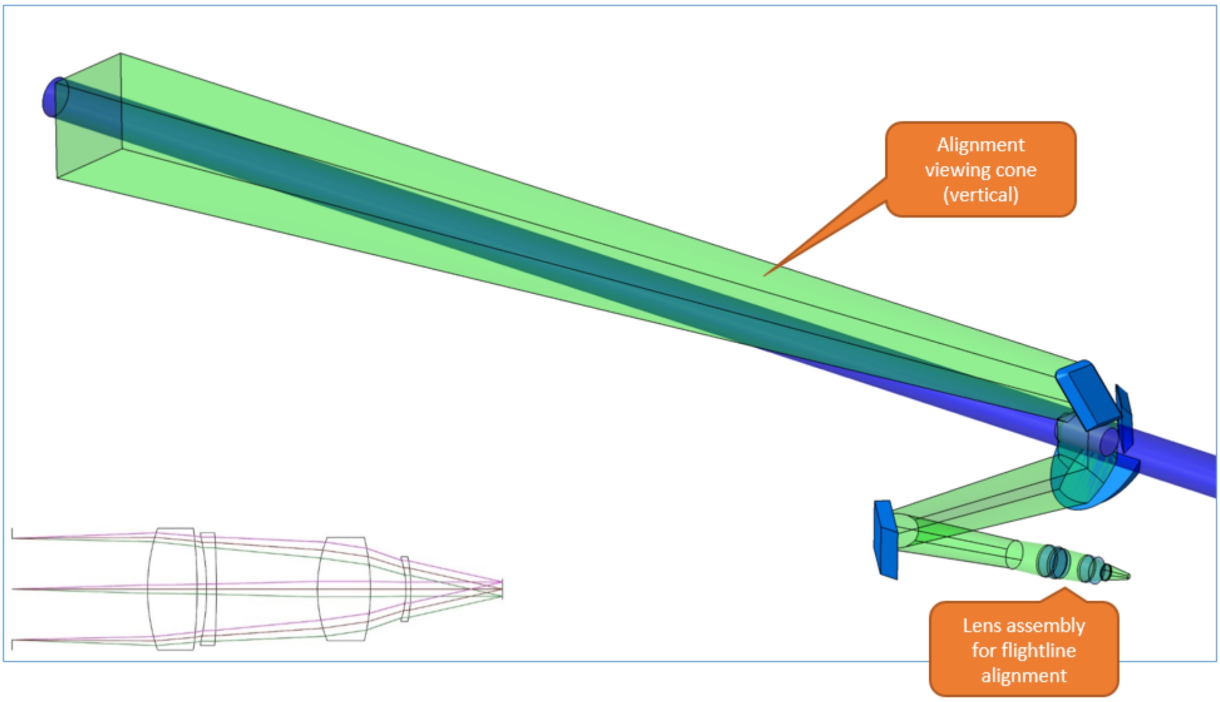

Figure A2.4: Internal viewing cones and optics (flight line vertical alignment view).

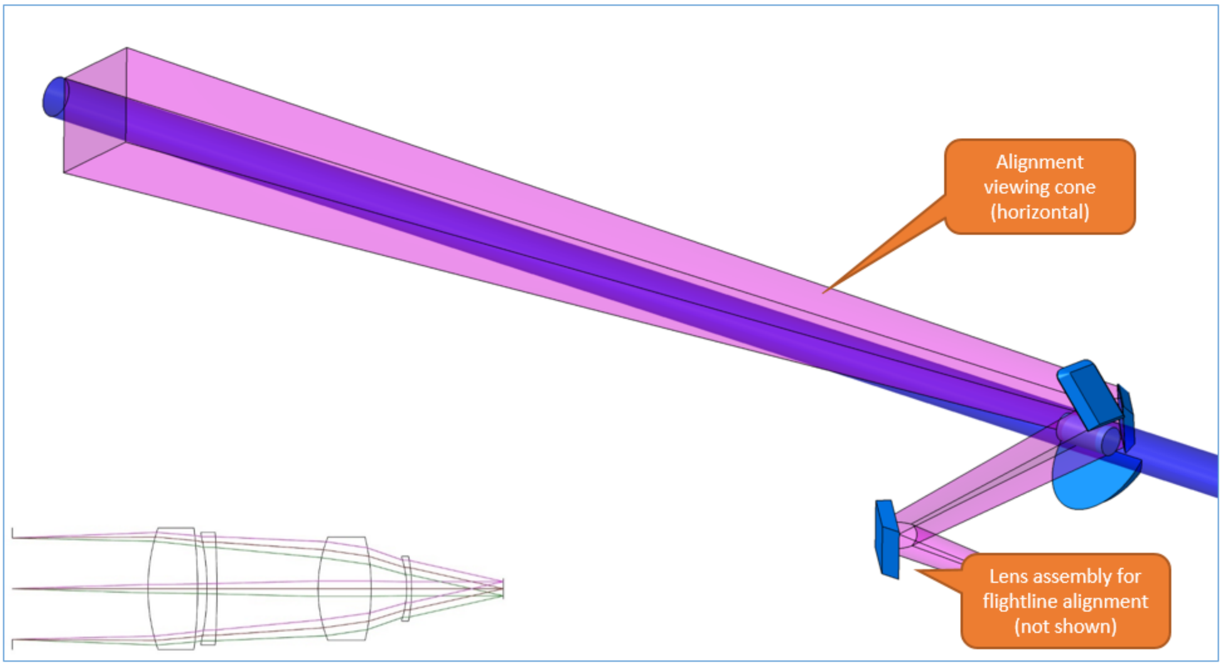

Figure A2.5: Internal viewing cones and optics (flight line horizontal alignment view).

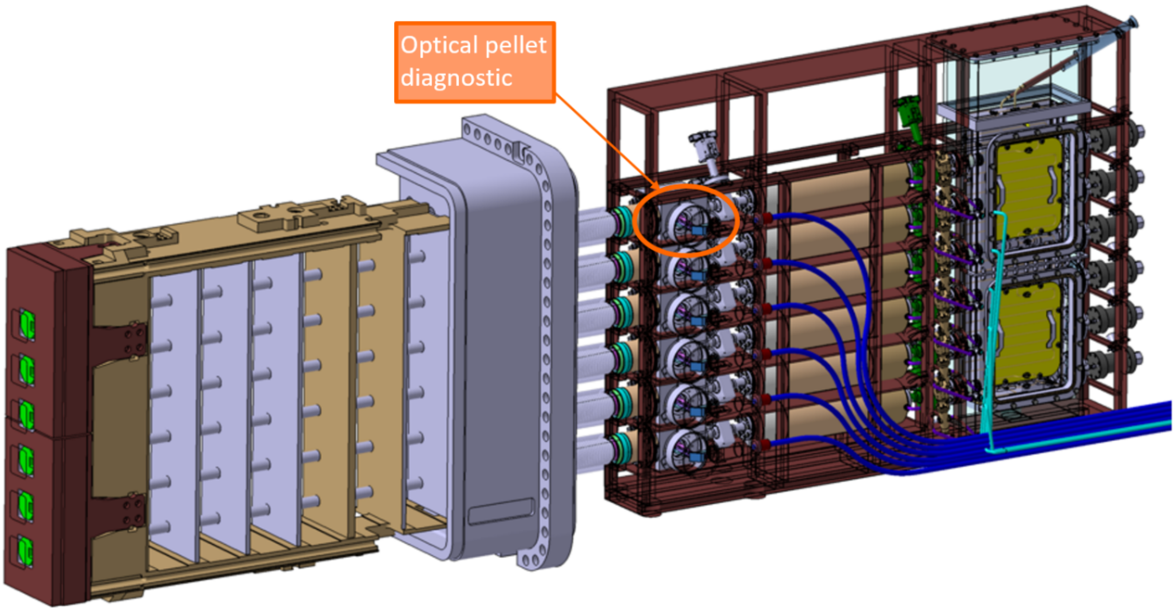

Figure A2.6: Optical pellet diagnostic in context with SPI injector (pre-PDR design).

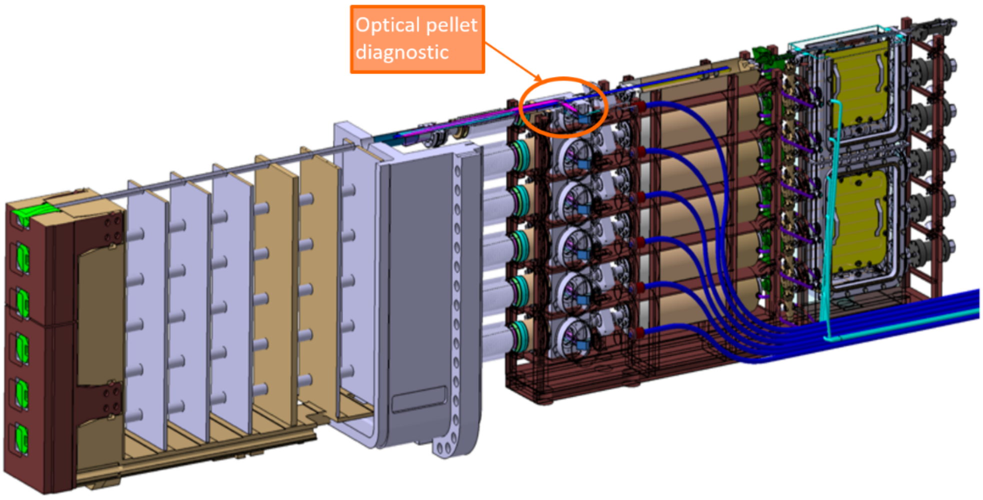

Figure A2.7: Optical diagnostic in context with SPI (cut through upper flightline).

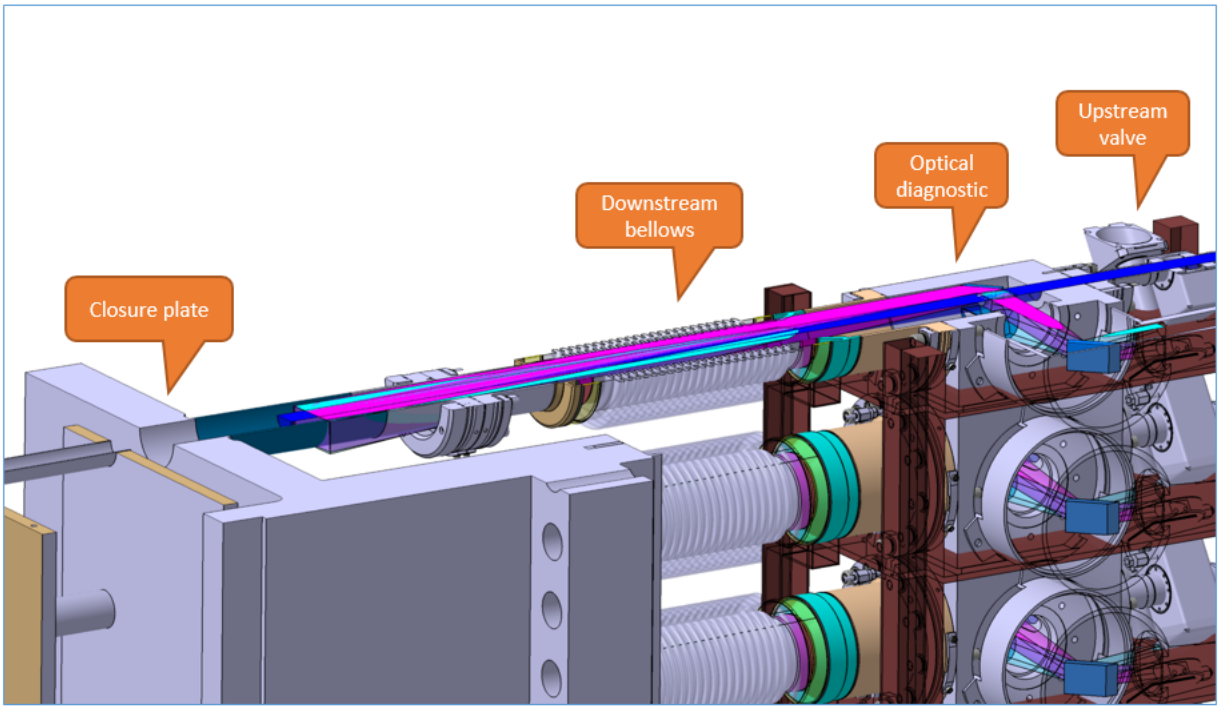

Figure A2.8: Detailed view of the neighbouring components of the optical diagnostic.