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Technical Specifications (In-Cash Procurement)

Technical Specifications for the development of a Mechanical Pellet Launcher

The scope of this contract is to perform an assessment of the feasibility of a mechanical pellet launcher (MPL) to dislodge and accelerate cryogenic pellets without the use of propellant gas, to design, manufacture and assemble a test stand with MPL and to perform tests to characterise the performance of the MPL.

This is a contract within the DMS Task Force technology activities.

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1 Purpose

This document describes the technical work required to design, manufacture and test a system that allows the fully-mechanical release and acceleration of cryogenic pellets as they are required for the ITER Disruption Mitigation System (DMS). This work is part of the programme of the ITER DMS Task Force (TF) to establish the design specifications and technology basis of the ITER DMS.

2 Background

The strategy to mitigate plasma disruptions in ITER is based on massive material injection. This will be provided by the injectors of the DMS. The technology used by the DMS is Shattered Pellet Injection (SPI). This technology and its performance is presently assessed through an extensive programme established within the DMS TF that comprises experiments at various tokamaks, extensive modelling efforts and a technology programme to develop DMS components according to ITER requirements and assess their performance. The work described in this document is part of the technology programme of the DMS TF (c.f. [1]).
The present design of the ITER DMS foresees the injection of cryogenic pellets consisting of hydrogen (protium), neon and mixtures of these two gases. A total of 27 injectors are distributed over three equatorial and three upper port plugs. An example of the system in equatorial port #02 with 12 injectors is shown in **Figure 1**. The envisaged pellets have a diameter of 28.5 mm and a length of 57 mm. These pellets will be formed through desublimation of various gases (H, Ne or H/Ne-mixtures) in the cold head cooled by supercritical helium. The present design foresees a fast gas valve to release propellant gas (H) for pellet dislodging and acceleration. This method is used by all presently operating SPI systems. After acceleration, the pellet will make its way to the shattering chamber in free flight passing a propellant suppression chamber, the optical pellet diagnostics, and various shutters and vacuum valves. At the shattering unit, possibly established through an inclined plane, the pellet disintegrates into smaller fragments that then enter the plasma and ablate.
The space restrictions in the ITER port plugs and port cells do not allow the propellant gas to be held back by a large expansion volume as it is done in present tokamak SPI experiments. This is a critical issue, since the propellant gas expands with velocities larger than the pellet velocity and, therefore, significant quantities of this gas can arrive at the plasma before the fragments. This can lead to premature initiation of the plasma disruption and may severely reduce the mitigation efficiency of the DMS. The presently foreseen propellant suppression

chamber has a volume of only 50 l (e.g. to be compared to 1000 l for the JET SPI system) and can only delay the gas flow towards the plasma. A fast shutter that closes right after the pellet passes by, blocking the propellant gas exiting the retention volume, may mitigate the lack of a large expansion volume. The development of such a fast shutter that requires closing within 1 ms is presently pursued through another contract by the IO. However, there is a risk that the shutter performance is not compatible with the requirements for the DMS in particular regarding high reliability. To mitigate this risk, the work described here aims on solving the propellant gas issue by developing a system that can accelerate the pellets by purely mechanical means to the required velocities without compromising the pellet integrity.

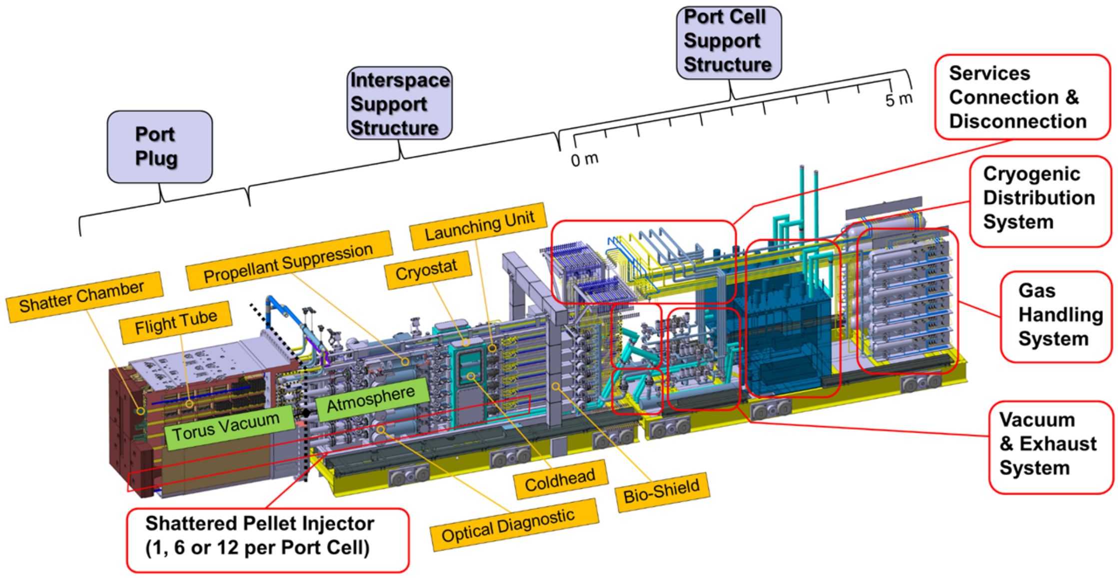

Figure 1 *– Present design of the DMS injectors in equatorial port plug #02. The location of the actuator of the MPL is marked as 'Launching Unit'. Also, note the propellant suppression chamber presently foreseen to delay the propellant gas flow. The fast shutter is not integrated in this design.*

3 Scope

The scope of this contract is to perform an assessment of the feasibility of a mechanical pellet launcher (MPL) to dislodge and accelerate cryogenic pellets without the use of propellant gas, to design, manufacture and assemble a test stand with MPL and to perform tests to characterise the performance of the MPL.

The detailed requirements and tasks are described in Section 7.

4 Definitions

C-RO - Contractors Responsible Officer

DMS	- Disruption Mitigation System
DMS TF	- DMS Task Force to coordinate DMS design validation tasks
IO	- ITER Organization
IO-CRO	- ITER Organization – Contract Responsible Officer
MPL	- Mechanical Pellet Launcher
QA	- Quality Assurance
SPI	- Shattered Pellet Injection

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

5 References

[1] T. Luce *et al.*, Progress on the ITER DMS design and integration. Preprint: 2020 IAEA Fusion Energy Conference, Nice, TECH/1-4Ra.

6 Estimated Duration

The contract duration is 18 months starting at the date of Contract signature.

7 Work Description

The Contractor shall carry out the work outlined in detail in the following sections. The work is broken down into two major parts. The first part is a study to demonstrate the feasibility of launching cryogenic pellets purely mechanically within the specifications of the ITER DMS. The second part focuses on preparing a test stand with reduced requirements (see Sect. 7.2 for details) for extensive testing of the concept. The tasks and their deliverables are summarised in Table 9-1.

7.1 Task 1 – Feasibility study

A conceptual design of a complete system to accelerate pellets of the ITER DMS size purely mechanically shall be developed, including all components required to operate the device (e.g. power supplies, vacuum and gas supply, etc.). Calculations or simulations shall be performed showing that the performance of such a system is compliant with the requirements listed in Table 7-1.

Parameter	Requirement
Pellet diameter	28.5 mm
Pellet length	57.0 mm
Pellet material	H, Ne and H/Ne-mixtures
Pellet temperature[1]	≤ 5 K (H and H/Ne pellets) and ≤ 8 K (Ne pellets)
Pellet velocity	controllable over the range of 150-500 m/s for H pellets
Lifecycles	> 5000 (assessment of achievable lifecycles to be performed by the contractor)
Time of pellet release after receiving trigger	< 10 ms
Maximum jitter for pellet release	< 1 ms
Maximum variation in pellet velocity (Δv/v)	< 10%
Ambient magnetic field	~0.5 T
Physical Space Allocation	The size of the MPL shall be compatible with the space restrictions in the port cell. For guidance, the actuator size shall not exceed a height and depth of 0.2 m and a length of 0.7 m.

Table 7-1: Technical requirements for a MPL as part of the ITER DMS.

7.2 Task 2 – Test of the MPL concept

7.2.1 Task 2.1 – Detailed design of the test stand

The MPL developed and assessed as described in Section 7.1 shall be scaled down in size to allow designing a test stand to assess experimentally the performance of the MPL concept. The size shall be chosen such that all relevant mechanisms can be tested to allow the extrapolation of the basic design features to the ITER DMS pellet sizes and to confirm the functionality of

[1] Note that possible heat loads on the pellet from any mechanical structure of the MPL to release and accelerate the pellet shall not compromise the pellet temperature, size, and integrity.

the ITER-like system assessed as per Section 7.1 while achieving high enough repetition rates for extensive parameter scans and assessment of reproducibility.

The test stand shall allow the formation and launching of cryogenic pellets. A detailed design of this test stand shall be developed, including all required hardware and auxiliary components to operate the test stand and to perform all relevant measurements to assess the characteristics of the launched pellets. These diagnostics shall include an optical diagnostic based on fast cameras to determine pellet velocity, integrity and orientation. The requirements for the test stand are summarised in Table 7-2. The diagnostics must be designed to allow sufficient resolution to demonstrate that the requirements are met.

The final design shall be reviewed and approved by IO in a dedicated progress meeting.

Parameter	**Requirement**
Pellet diameter	optimised but not to be less than 12 mm
Pellet length / diameter	≥ 1.5
Pellet material	H, Ne and H/Ne-mixtures
Pellet temperature	Minimum temperature at least 7 K (temperature variation must be feasible to vary shear strength)
Pellet velocity	controllable over the range of 150-700 m/s for H pellets
Lifecycles	> 200 Assessment of achievable lifecycles should be included in the final report, taking assessment of wear into account.
Time of pellet release after receiving trigger	< 10 ms
Maximum jitter for pellet release	< 1 ms
Maximum variation in pellet velocity (Δv/v)	< 10%

Table 7-2: Technical requirements for the experimental test of the MPL concept.

7.2.2 Task 2.2 – Manufacturing, assembly, commissioning

All components shall be manufactured and assembled. The functional test shall include cool-down confirming that the cold head and the cold zone where the pellet is formed reach the required temperature. The gas and vacuum systems as well as all diagnostic systems shall be commissioned. The performance of the MPL shall be tested without pellets, documenting that the mechanical acceleration, the reaction times, the expected power supply characteristics, etc. are met. Finally, all components shall be assembled and pellet formation shall be demonstrated.

7.2.3 Task 2.3 – MPL performance tests

The MPL performance tests aim at demonstrating the MPL functionality and at characterising the system with respect to the achievable operational range for the pellet parameters as specified in Table 7.2. This includes variation of the MPL settings to assess the achievable velocity range for different pellet compositions (H, Ne and Ne/H mixtures) and cold head temperatures. Statistically relevant numbers of repeats shall be foreseen to assess reproducibility of the results and to characterise the variation on the pellet parameters. The pellet orientation (tilting) and trajectory, as well as any possible rotation shall be documented. The test results shall be used to assess the validity of the ITER MPL design as developed for Task 1.

The MPL must work such that the integrity of the pellet is not compromised and that pellet debris (ice dust, small fragments) is minimised and is not flying ahead of the pellet. In particular, the formation of gas during the dislodging and acceleration process must be minimised since it could reach the plasma before the pellet itself. The Contractor shall make provision to adapt the design of the MPL and remanufacture essential components if pellet breakage and debris occur.

All data related to the MPL and its power supply, pellet formation data, pellet diagnostic data as well as pressure measurements must be recorded automatically and provided as time traces with sufficient resolution to assess and characterise the processes.

After the tests, the MPL shall be disassembled and the state of all movable parts shall be documented. An assessment of the wear and the resulting impact on the achievable MPL lifetime for ITER shall be performed, possibly including proposals on design improvements.

8 Responsibilities

ITER Organization:

The ITER Organization will provide the necessary information and access to the ITER files required for the execution of this work when needed following the implementation 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 implementation plan and conditions of the present contract. The Contractor shall allow access to its premises for selected IO staff to witness the commissioning and testing of the components.

9 List of 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 any time during the course of the tasks.

Any hardware procured under this Contract shall remain the property of the IO and shall be clearly marked as property of the IO. At the conclusion of the contract, the IO may request the return or transfer of this hardware to the IO.

All data recorded during the MPL tests and all design drawings shall be submitted to the IO at the end of the contract. Upon request of the IO-CRO, the contractor shall submit numerical data relevant to demonstrate the performance and outcome of the deliverables to the IO anytime during the course of the work.

All work shall be done in close collaboration with the ITER DMS task force. Changes in the work plan can be implemented upon mutual agreement between IO-CRO and C-RO.

The Contractor shall submit all deliverables to the ITER Organization as described in Table 9-1.

Deliverable	Task description	Deliverable Description	Due Date

Deliverable	Task description	Deliverable Description	Due Date
D1	Task 1 – Feasibility study	Report on the conceptual design and its expected performance as described in Section 7.1. Relevant 3D CAD design files (compatible with CATIA V5)	T0 + 2 months
D2.1	Task 2.1 – Detailed design of the test stand	Report on the final design of the test stand and the MPL as described in Section 7.2.1. Relevant 3D CAD design files (compatible with CATIA V5)	T0 + 4 months
D2.2	Task 2.2 – Manufacturing, assembly, functional test	Report on the manufacturing, assembly and the functional test results as described in Section 7.2.2.	T0 + 12 months
D2.3	Task 2.3 – MPL performance tests	Report on all MPL performance tests as described in Section 7.2.3 and submission of all test data and design drawings to IO.	T0 + 18 months

T0 is the date of the Contract signature.

Table 9-1: Deliverables and due dates.

10 Acceptance Criteria

The IO-CRO shall review the deliverables and provide, within the 15 following working 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 the IO has accepted the last deliverable.

11 Specific requirements and conditions

- The work will be performed at the Contractor's premises.
- If requested by the IO-CRO, IO personnel shall be granted access to the Contractor's premises to witness the experiments.

- The 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 ITER Headquarters for two meetings (KOM and 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 Work Monitoring / Meeting Schedule

The work shall be monitored by regular progress meetings according to the provisional schedule below.

Type of meeting	Scope	Place of meeting
Kick-off meeting	Work programme.	ITER Headquarters or video

		conference
Progress meetings	Progress check and further work definition approximately every 4 weeks in line with the completion of tasks and starting of the next task.	Video conference or Contractors' site
Technical Meetings	Clarification of technical details as required.	Video conference or Contractors' site
Contract completion	Final check of reports on all deliverables.	ITER Headquarters or video conference

The Contractor shall be prepared to participate in DMS TF meetings and present material related to this contract.

13 Quality Assurance (QA) requirements

Prior to commencement of any activities under this Contract, a Quality Plan (QP) as per procurement requirements for producing a *Quality Plan (ITER_D_22MFMW)* shall be prepared by the Contractor and main sub-contractors and submitted to the IO for approval, describing how they will implement the ITER *Procurement Quality Requirements (ITER_D_22MFG4).* Among the detailed information in the quality plan, the following should be included:

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 sub-contracted and who will be responsible for checking this.

Sub-contractors not performing critical quality activities (i.e. activities that if not performed correctly may affect safety, functionality or reliability) may be exempted from the requirement to supply quality plans, subject to agreement by the IO.

The Contractor shall have implemented a quality management system in accordance with ISO 9001:2015 (or equivalent standard recognized by IO). The Contractor shall present a copy of valid ISO 9001:2015 certificate or demonstrate the implementation of an equivalent quality management system (IO acceptance of equivalency is required).

14 CAD Design Requirements

All CAD models or drawings relevant for the operation or experimental exploitation of the test bench and/or required for the replication of the diagnostics at an external organisation must be supplied in a format compatible with CATIA-V5.

15 Safety requirements

15.1 General safety requirements

ITER is a *Nuclear Facility* identified in France by the number-INB-174 ("Installation Nucléaire de Base").

For Protection Important Components (PIC) and in particular Safety Important Class components (SIC-1 or SIC-2), the *French Nuclear Regulation* must be observed, in application of the article 14 of the *ITER Agreement*.

In such case the suppliers and sub-contractors 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 the Contractor shall ensure that a specific management system is implemented for his own activities and for the activities done by any supplier and sub-contractor following the requirements of the *Order 7th February 2012*.

15.2 Contractor safety responsibilities

The Contractor will be responsible for determining which health, safety and environmental laws, regulations and procedures are applicable in their organisation and country and for ensuring compliance with these laws, regulations and procedures.