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EXTERNAL REFERENCE / VERSION

Technical Specifications (In-Cash Procurement)

DMS Fast Shutter-Technical specification

Technical specification for concept design and proof-of-principle prototyping/testing of DMS Fast Shutter.

Being Urgent, this is intended to be processed as Restricted Tender

Table of Contents

1 Purpose

This document describes the technical work required to develop the design of a Fast Shutter for the ITER Disruption Mitigation System (DMS). This will require specialist input in the fields of valve technology, electrical actuator design, mechanical engineering & design, systems engineering, rapid prototyping, experimental design validation.

2 Scope

The scope applicable to this contract is the Disruption Mitigation System (DMS), further described in section 4.

3 Definitions

DMS	Disruption Mitigation System
SPI	Shattered Pellet Injector
TRO	Technical Responsible Officer
CRO	Contract Responsible Officer
VV	Vacuum Vessel
PCS	Plasma Control System
IO	ITER Organization

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

4 Estimated Duration

The estimated duration for the contract is 12 months

5 Background

ITER is a major new device that is 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 plasma disruptions during high power operations, a Disruption Mitigation System (DMS) is required.

The current DMS is based on the Shattered Pellet Injector (SPI) technology. This works on the basic principle of a cryogenic pipe gun, as shown in Figure 1:

- a pellet consisting of protium or neon is formed inside a cryogenically cooled section of a pipe (the “barrel”),
- the pellet is kept at low temperature (~5K) being ready to be launched,
- high-pressure hydrogen gas shears off the pellet from the barrel walls and propels it down the barrel and the pellet enters a flight line to travel towards the plasma,
- just before the pellet reaches the plasma, it contacts a strike plate or tube bend (the “shatter chamber”) which causes it to shatter.

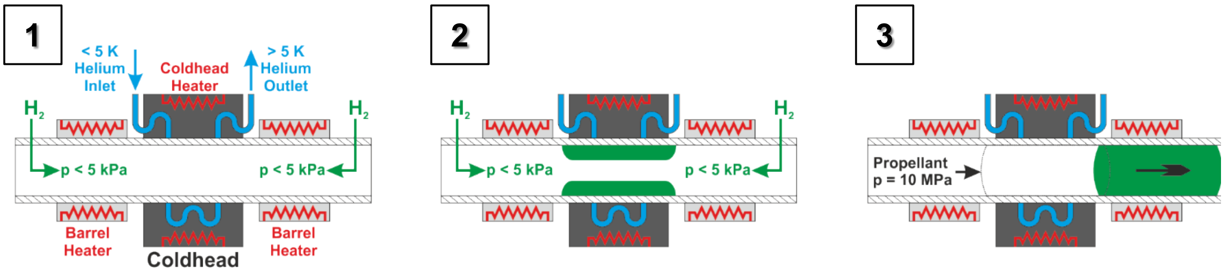

Figure 1 - Schematic pellet formation and firing sequence

It is important to avoid any contact between the pellet and internal surfaces of the flight line between the pellet leaving the barrel and striking the shatter chamber, in order to avoid pellet slowing down and minimise risk of premature pellet breakage. This means that the internal dimensions of the flight tube are relatively large, providing a bypass for propellant gas to pass the pellet, so that a significant quantity of propellant is injected into the main ITER vacuum vessel in advance of the pellet. This will cause an undesirable instability in the plasma and compromise the effectiveness of disruption mitigation. The described events are appearing in the scale of a few milliseconds.

One possible solution for this issue could be the use of a fast-acting shutter valve in the flight line, which will close after the pellet has passed through it, in order to hold back the propellant gas.

5.1 Flight line mechanical design

Figure 2 shows the layout of the flight line. The main components in the direction of pellet flight from barrel to shatter chamber are:

1. Propellant suppressor: vessel whose purpose is to retard propellant flow downstream, by providing a large expansion volume (within maximum envelope constraints) and optimised internal flow geometry
2. Optical diagnostic: mirrors and detectors mounted inside the downstream section of the suppressor whose purpose is to detect the passage of the pellet and associated parameters (velocity, trajectory, integrity)
3. Vacuum Vessel (VV) extension valve: ultra-high vacuum valve to isolate DMS injector from main ITER VV with high leak-tightness across the valve seat. Closure time of these valves are typically in the range of a few seconds. This valve will remain open after firing of DMS and cannot be actuated quickly enough to contribute to propellant gas suppression.
4. VV extension bellows: flexible element to accommodate thermal displacement of ITER machine and port plug during operations while maintaining integrity of the vacuum boundary
5. Port plug: large module with shielding, water cooling, vacuum sealing etc., cylindrical cut-outs for pellet flight paths, and pellet shatter chamber. It may be possible to create cavities inside the port plug structure to act as secondary buffer volumes / propellant expansion chambers.

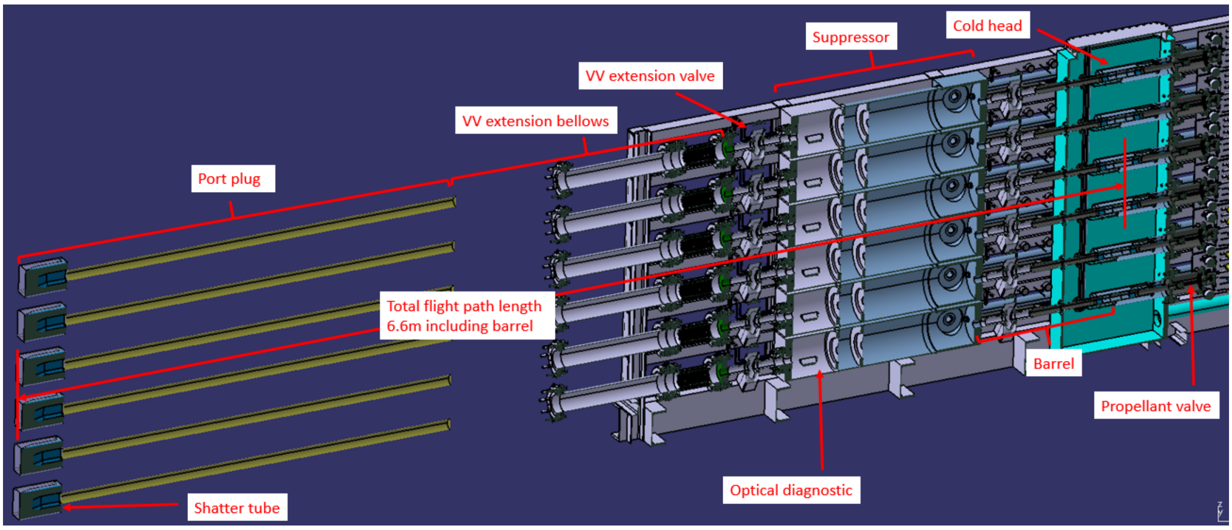

Figure 2 - Layout of pellet injector flight lines (6 injectors in parallel, some external components hidden for clarity)

It is proposed to reduce the axial length of propellant suppressor and/or VV extension bellows in order to insert the fast-acting shutter valve. For guidance, the dimensions of the shutter component should have the same outer dimensions as the existing VV extension valve if compatible with its function (overall dimensions shown in Figure 3).

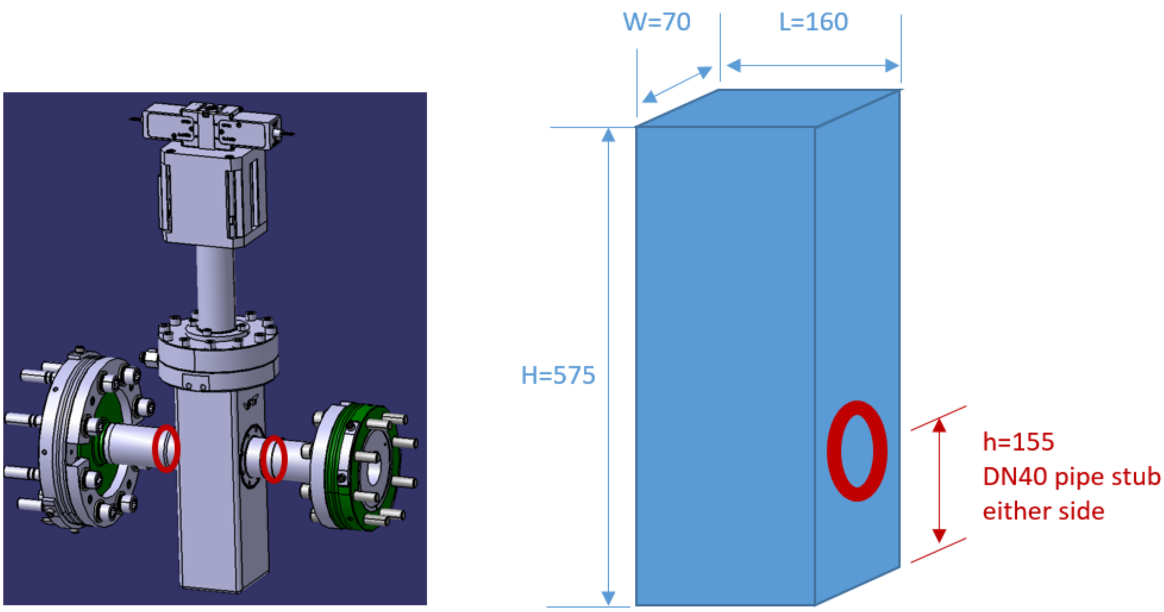

Figure 3 – Fast Shutter keep-in envelope based on VV extension valve dimensions (mm)

5.2 Pellet launch sequence

An indicative timeline for the delivery of pellet material into the VV is the following:

t=0ms: The DMS propellant valve has received a trigger from the PCS that a disruption is imminent and begins to open, pressurising the "breech" behind the pellet.

t~0.8ms: Breech pressure reaches pellet breakaway pressure ~40bar, pellet breaks away and begins to accelerate down the barrel

t~2ms: Pellet leaves barrel and enters propellant suppressor at its terminal velocity of ~900m/s. Gas begins to flow around the pellet towards the suppressor outlet and downstream, with no significant flow restriction provided by the pellet after this point t~2.6ms: Pellet passes optical diagnostic, and reaches fast shutter located at suppressor outlet.

t~7.6ms: Pellet strikes shatter tube at end of port plug (~4.5m downstream of fast shutter location), shattered fragments are injected into plasma

Figure 4 shows the mass flow profile into the ITER Vacuum Vessel during pellet launch. As the pellet leaves the barrel at t~2.6ms, there is an initial shock as the propellant starts to flow into the suppressor. This propagates downstream with sonic velocity and arrives at the VV at t~4.5ms. As the pressure develops in the suppressor, downstream mass flow rate increases.

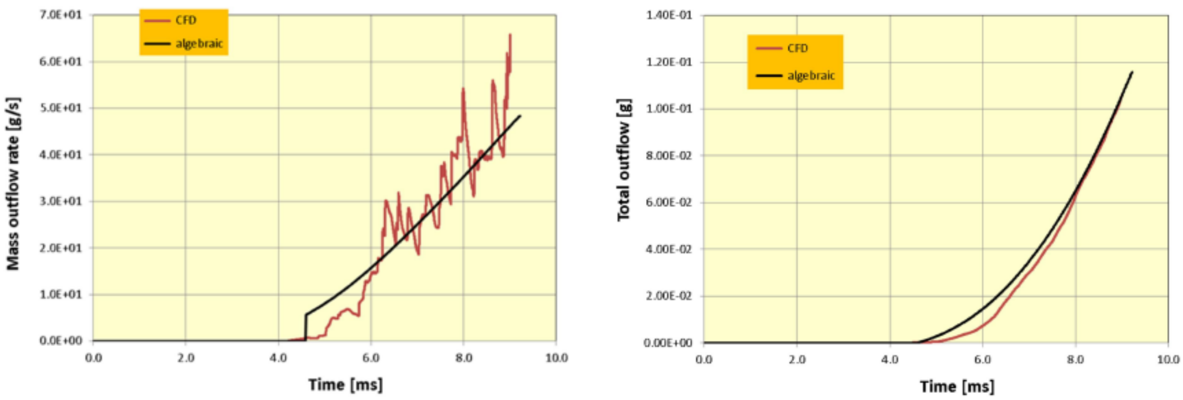

Figure 4 - Approximate mass flow rate and cumulative total mass flow to ITER VV as function of time after DMS trigger calculated using simple algebraic expression and modelled with CFD.

5.3 Need for fast closing shutter

To avoid any impact on disruption mitigation, the total propellant mass injected before pellet arrival must be limited. Allowing 1ms for detection of the pellet and transmitting the "close" signal to the shutter, and allowing some margin to account for the gas which has already passed the shutter position by this time, the shutter should be capable of moving from "fully open" to "fully closed" position in not more than 1ms after receiving the "close" signal. The shutter does not need to be fully vacuum leak-tight in the closed position, but the product of discharge coefficient and cross-sectional area at the choking plane (C_d.A) must be below 5E-07m^2 in order to limit the mass flow after closing to acceptable levels.

Note: The time values as stated above are based on a fast pellet. If the velocity of the pellet has to be lowered, the values specified might have to be adapted. Best efforts shall be undertaken to reduce the shutter closing time within the constraints described in this document.

Detailed requirements are described in Appendix A.

6 Work Description

The foreseen scope of work is outlined in this section. Each phase shall be carried out in sequence, with formal review and acceptance by IO TRO before moving on to the next phase.

1. Requirements analysis
2. Functional analysis and optioneering
3. Concept development
4. Proof-of-principle prototype
5. Test

6.1 Requirements analysis

Inputs:

Functional requirements specification, CAD model(s), supporting documents if any

Scope:

Review input data pack for clarity, consistency and completeness. Produce short feedback report listing:

- initial assessment of solution feasibility and potential technology options
- any further input data required before proceeding to phase 2

Deliverables:

- Feedback report, assessments of requirements provided (clarity, consistency, completeness, compatibility, areas of concern over technical feasibility, proposed editing/modifications of requirements as relevant)
- Review meeting (Periodicity-at the end of this phase, interim review meetings as needed, minutes of meeting & list of actions)

6.2 Functional analysis and optioneering

Inputs:

Input data pack with updates as requested during 5.1

Scope:

- Functional decomposition of shutter unit as a system
- Selection of one or more suitable technologies to perform each function
- Screening and ranking of options per function based on relevant system-level requirements
  - Workshop and/or paper exercise (Reports, Summary of discussion/MoMs)
  - with assistance from IO experts where needed in specific areas e.g. effect of neutron irradiation or fast transient electromagnetic fields, design of ultra-high vacuum systems
- Presentation of proposed system concept as written report and oral presentation, including preliminary assessment of inter-compatibility of subsystem concepts
- Preparation of design review (readiness of documents, solving the actions from the review)

Deliverables:

- Shutter system functional tree and product tree
- Optioneering report
- Design Review Documents – Concept Design Report
- Review meeting
- Closure of actions from the review meeting and the close-out report

6.3 Concept development

Inputs:

Agreed system concept for development, based on final report from 5.2

Scope:

- Development of system concept design (component sizing, material selection, scoping calculations, outline CAD model etc. as appropriate for concept level)

Deliverables:

- Concept design description report

- Outline CAD model of the concept
- Preliminary design compliance matrix (DCM) based on system requirements
- List of significant design risks / unknowns and proposed mitigation measures
- Concept design review meeting and closure of actions from the meeting (report)

6.4 Proof-of-principle prototype

Inputs:

- Accepted concept design, based on 5.3
- Outline test plan based on IO assessment of outputs from previous phase
- Requirements specification for prototype (subset of requirements for production units)

Scope:

- Detail design, manufacture and assembly of a size-relevant prototype

Deliverables:

- Prototype (working proof-of-scale prototype, ready for testing)
- Options and acceptance criteria for testing – type, location (factory or elsewhere) and durations of tests – to be validated in the testing phase

6.5 Prototype Test

Inputs:

- Prototype

Scope:

- Prepare detailed test plan (number of test runs, test log template, input parameters, pass/fail criteria, diagnostics, raw data capture etc.). The test plan should be sufficiently comprehensive to allow the assessment whether the prototype complies with the requirements in Annex 1.
- Carry out testing (factory or other location, witnessed by ITER representatives, if requested)

Deliverables:

- Test report with summary of results, updated concept feasibility assessment, conclusions and recommendations for further development
- Review meeting and closeout report

7 Responsibilities

7.1 Contractor's obligations

In order to successfully perform the tasks in these Technical Specifications, the Contractor shall:

- Strictly implement the IO procedures, instructions and use templates;
- Provide experienced and trained resources to perform the tasks;
- Contractor's personnel shall possess the qualifications, professional competence and experience to carry out services in accordance with IO rules and procedures;
- Contractor's personnel shall be bound by the rules and regulations governing the IO ethics, safety and security IO rules.

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 ITER Organization.

7.2 Obligations of the ITER Organization

The ITER Organization shall

- Nominate the Responsible Officer to manage the Contract;
- Organise regular meeting(s) on work performed;
- Provide offices at IO premises, if needed for work at ITER site.

The ITER Organization shall in addition give the possibility to the contractor to review documents on the ITER documents database (IDM). Furthermore the IO shall make all technical data and documents available to the Contractor which will be required to carry out its obligations in a timely manner.

8 List of Deliverables and due dates

The tentative timetable is as follows: (T0 is contract signature date)

Phase 1: Requirements Analysis - Feedback Report, assessments of requirements provided (clarity, consistency, completeness, compatibility, areas of concern over technical feasibility, proposed editing/modifications of requirements as relevant) - Review meeting (phase-wise, interim review meetings as needed, minutes of meeting & list of actions)	T0+2 months
Phase 2: Optioneering - Shutter system functional tree and product tree - Optioneering report - Concept Design Report - Review meeting-Planning, Closure of actions from the review meeting and the close-out report	T0+4 months
Phase 3: Concept Development - Concept design description report - Outline CAD model of the concept	T0+5 months

- Preliminary design compliance matrix (DCM) based on system requirements - List of significant design risks / unknowns and proposed mitigation measures - Concept design review meeting and closure of actions from the meeting (report)	
Phase 4: Prototyping - Prototype Delivery (working proof-of-scale prototype, ready for testing) - Options and acceptance criteria for testing – type of test and details, location of test (factory or elsewhere) and durations of tests – to be validated in the testing phase	T0+10 months
Phase 5: Test - Test report with summary of results, updated concept feasibility assessment, conclusions and recommendations for further development - Review meeting and closeout report	T0+12 months

9 Acceptance Criteria

The deliverables will be posted in the Contractor's dedicated folder in IDM, and the acceptance by the IO will be recorded by the approval of the designated IO TRO. These criteria shall be the basis of acceptance by IO following the successful completion of the services. These will be in the form of reports as indicated in Section 5 Scope of Work.

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.

10 Specific requirements and conditions

In order to complete the tasks in a timely manner the following skills are required. The acceptance criteria for the selection of the tender cover a broad range of technical capabilities, and the Contractor and its personnel shall have adequate experience in the areas as listed below:

- Valve design
- Mechanical design and analysis
- Verification and Validation
- R&D, Prototyping
- Testing, troubleshooting

11 Work Monitoring / Meeting Schedule

Work is monitored through reports (as per Section 8 Schedule of Deliverables).

The Contractor will work predominantly work off-site, and on specific occasions be invited to ITER site as required.

Regular Progress Review Meetings shall be held, e.g. on a monthly basis. A Kick-off-Meeting will be organised by the IO-CRO within 2 weeks after Contract signature to define the detailed work programme. The Contractor shall consider a provision for 3 meetings to take place on the ITER site. The Contractor should take the measures required to allow IO staff to visit the Contractor's site to witness the prototype tests.

The following meetings and submissions of progress reports should be foreseen.

Scope of meeting	**Point of check** **(progress or final report)**	**Place of meeting**
Kick-off Meeting	Work plan	ITER site or Video conference
Progress meetings	Progress status 2-4 weeks prior to date of each deliverable.	Video conference
Technical Meetings	Clarification of technical details as required	Video conference
Contract completion	Checking final report on all deliverables	ITER site or video conference

12 Quality Assurance (QA) requirements

The organisation conducting these activities shall have a quality management system certified as per ISO 9001 standard or QA Program accepted by ITER Organization.

The general requirements are detailed in ITER Procurement Quality Requirements (ITER_D_22MFG4).

Prior to commencement of the task, a Quality Plan must be submitted for IO approval giving evidence of the above and describing the organisation for this task; the skill of workers involved in the study; any anticipated sub-contractors; and giving details of who will be the independent checker of the activities (see Procurement Requirements for Producing a Quality Plan (ITER_D_22MFMW)).

Documentation developed as the result of this task shall be retained by the performer of the task or the DA organization for a minimum of 5 years and then may be discarded at the direction of the IO. The use of computer software to perform a safety basis task activity such as analysis and/or modelling, etc. shall be reviewed and approved by the IO prior to its use, in accordance with Quality Assurance for ITER Safety Codes (ITER_D_258LKL).

13 CAD 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.

14 Safety requirements (if applicable)

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 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

Note: DMS is not a PIC

Appendix A: Requirements

The following requirements are provided as a starting point for the development of a complete System Requirements Document for this component (see phase 1 deliverables).

These requirements relate to the design solution for use in ITER DMS. The design of the proof-of-principle prototype does not necessarily need to comply with all of these requirements, but any non-compliances must not affect the validity of the validation testing.

Where the following terms appear in bold type, they are assumed to have the following meanings:

SHALL: mandatory requirement or rigid constraint

SHOULD: optional requirement or flexible constraint

MAY: not a requirement or constraint, included as a suggestion or recommendation to the system designer.

PERFORMANCE REQUIREMENTS		
#	**Requirement**	**Comment**
P1	Aperture in "fully open" position **SHALL** be 40mm or larger	
P2	Product of discharge coefficient and choking plane cross-section C_d.A **SHALL** be ≤5E-07m^2 in "fully closed" position	
P3	From receiving "close" signal, shutter **SHOULD** move from "fully open" to "fully closed" position within 1 ms	
P4	Mean Cycles Between Failure (MCBF) **SHALL** be at least 10,000	
P5	Repeatability of closure time: standard deviation **SHOULD** be σ≤0.1ms from receiving "close" signal to reaching "fully closed" position	
P6	Shutter housing materials and design including any feedthroughs **SHALL** be compatible with Vacuum Quality Class 1A (max acceptable leak rate is 1E-10Pa.m3/s air equivalent)	See ITER Vacuum Handbook
P7	Shutter internal components materials and design **SHALL** be compatible with Vacuum Quality Class 1B	See ITER Vacuum Handbook
INTERFACES		
#	**Requirement**	**Comment**
I1	Shutter **SHALL** be capable of receiving a "close" signal of either 0-5V or 4-20mA	
I2	Shutter overall dimensions **SHOULD** fit within the overall envelope shown in Figure 3	
I3	Shutter upstream and downstream flight line connections at outer planes of keep-in envelope **SHALL** be DN40 Sch.40S pipe stubs suitable for	

	butt-weld using automatic welding head (tool half-width 19mm)	
ENVIRONMENTAL		
E1	Shutter **SHALL** be fully operational within an applied external magnetic field of B≤2T	
E2	Shutter **SHALL** be fully operational after exposure to 100kGy 14MeV neutron radiation	Radiation dose map ITER_D_3FM52L. Use of polymers is generally prohibited.
E3	Shutter housing **SHALL** survive an applied temperature of 300°C for 2h with no loss of leak tightness.	Fire load case. Internal shutter mechanism is not expected to operate after this event.
E4	In “fully closed” position, shutter mechanism **SHALL** be capable of withstanding a differential pressure of ≤2bar in one direction indefinitely	