Experimental Validation of the Divertor Plasma Facing Units of Vertical Targets

Call for Nomination

Purpose

The purpose of this contract is to perform an experimental validation of the Plasma Facing Units of the Divertor Vertical Targets based on the so-called tungsten monoblock concept.

Background

One of the most technically challenging components of the ITER machine is the Divertor, the main functions of which is to extract the plasma power and to shield surroundings from neutrons whilst maintaining the plasma purity. The Divertor covers the bottom part of the plasma-facing surface (210 m^2) and has to remove up to 204 MW of thermal power via a pressurized water flow. The design includes 54 divertor cassettes. Each of them includes the Cassette Body (CB) and three Plasma-Facing Components (PFCs), namely the inner vertical target (IVT), the outer vertical target (OVT), and the Dome as shown in Fig. 1.

The IVT and OVT consist of a steel supporting structure onto which the plasma-facing units (PFUs) are mounted. A PFU is a single poloidal element, which directly faces the plasma (Fig. 2).

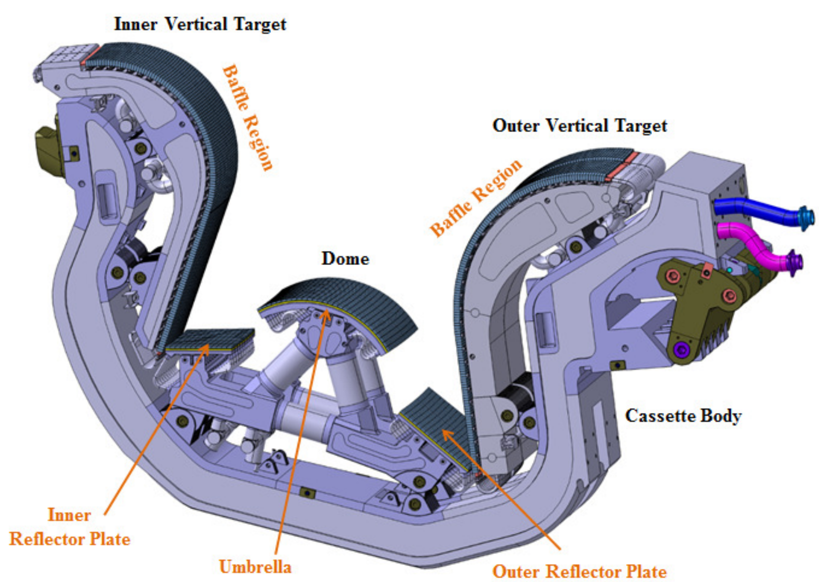

Figure 1: 3D View of the Divertor Cassette Assembly.

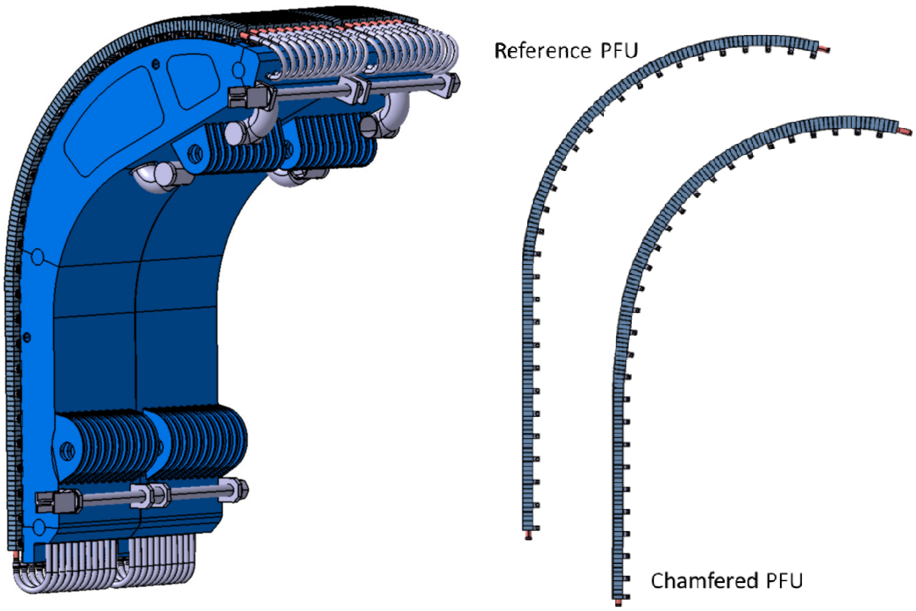

Figure 2: 3D View of the OVT (left), and individual PFUs (right).

The PFU geometry is based on the so-called "monoblocks" concept, which consists of armour blocks with a drilled hole. Then, a copper alloy (CuCrZr-IG) cooling tube is inserted into these holes, and is intimately joined to the tiles. A turbulence promoter (twisted tape) is inserted into the lower straight part of each PFU to enhance the water coolant heat removal capability.

It was recently decided to use tungsten (W) as plasma-facing material (armour) in all plasma-facing surfaces of the Divertor, including the straight part of the IVT and OVT.

The first step of the qualification programme was successful and the components could withstand and even exceed the design requirements. However, the metallographic analysis of W monoblock small-scale mock-ups has revealed in some cases the cracks and plastic strains areas in the CuCrZr tube after the High Heat Flux (HHF) tests at $20MW/m^2$.

In parallel, the results of updated supporting analysis showed high shear and bending stresses in the CuCrZr tube in the gaps between W monoblocks under design load combinations.

The 2 points above are suggesting the need of an experimental validation of the VTs plasma-facing units (PFUs), which is the objective of the experimental validation programme of this contract.

Scope of work

Up to 10 (ten) mock-ups, from different manufacturers, will be provided by the IO as free-issued items. A picture of a typical mock-up and its indicative geometry is shown Fig.3.

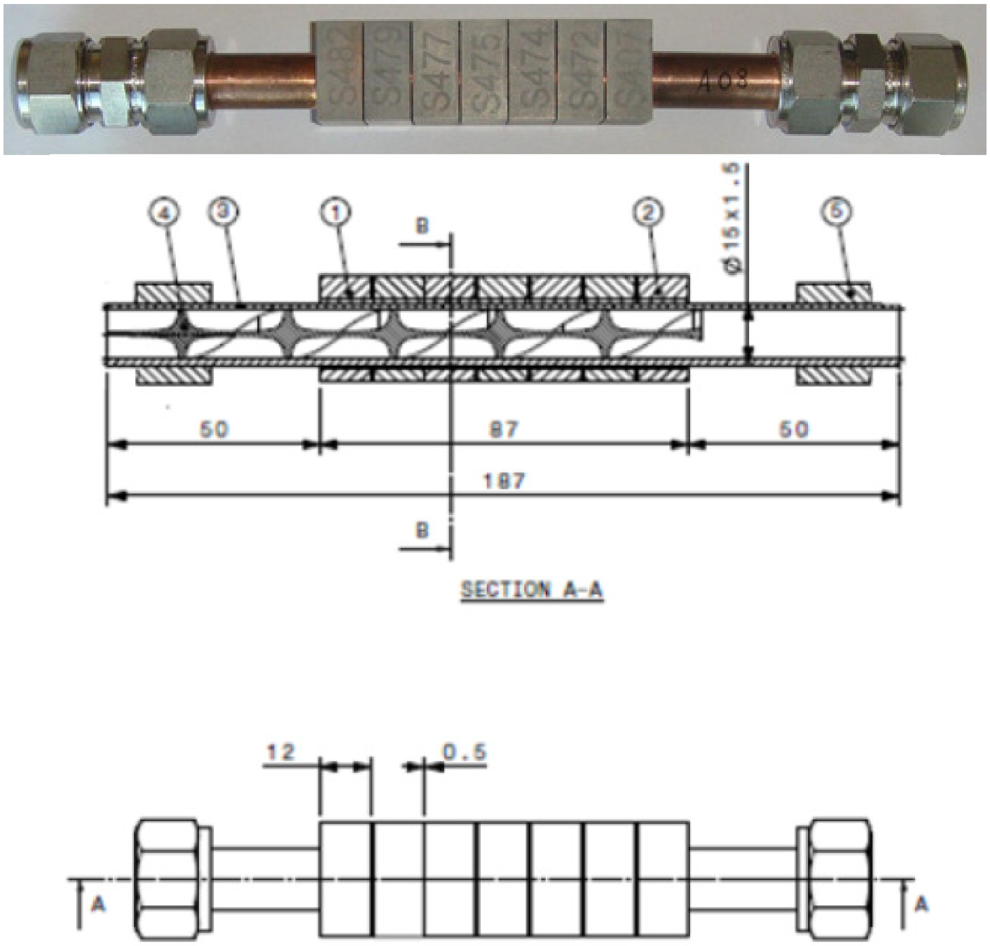

Figure 3: Typical mock-up and its indicative geometry

Where:

1) Copper interlayer
2) Tungsten monoblock
3) CuCrZr tube
4) Twisted tape (turbolence promoter)
5) Swagelok connector to the water cooling circuit

The following programme shall be performed on each provided mock-ups. It consists of the 16 steps described below. Within a step, the inspection/test shall be performed following the order indicated in the Table 1.

Table 1: Steps of the programme

Step Number	Technique of Inspection or Test
1	VI, PrT, EI, ECI, DIM, USI, HLT
2	*Insert the swirl tape* CYCLING HIGH HEAT FLUX TESTS (300 cycles @ 20 MW/m2) *Remove the swirl tape*
3	VI, EI, ECI, DIM, USI, HLT
4	*Insert the swirl tape* CYCLING HIGH HEAT FLUX TESTS (5000 cycles @ 10 MW/m2) *Remove the swirl tape*
5	VI, EI, ECI, DIM, USI, HLT
6	*Insert the swirl tape* CYCLING BENDING TESTS (1000 cycles at (nominal P)/3 *Remove the swirl tape*
7	VI, EI, ECI, DIM, HLT
8	*Insert the swirl tape* CYCLING BENDING TESTS (5000 cycles at (nominal P) *Remove the swirl tape*
9	VI, EI, ECI, DIM, HLT
10	*Insert the swirl tape* CYCLING BENDING TESTS (5000 cycles at (nominal P) *Remove the swirl tape*
11	VI, EI, ECI, DIM, HLT
12	*Insert the swirl tape* CYCLING BENDING TESTS (5000 cycles at (nominal P) *Remove the swirl tape*
13	VI, EI, ECI, DIM, HLT
14	*Insert the swirl tape* CYCLING HIGH HEAT FLUX TESTS (300 + 400 cycles @ 20 MW/m2) *Remove the swirl tape*
15	VI, EI, ECI, DIM, USI, HLT
16	DESTRUCTIVE EXAMINATION

Acronyms of the Non-Destructive Inspection Techniques used in the table

Visual inspection:	VI
Endoscopic inspection:	EI
Eddy Current inspection:	ECI
Dimensional inspection:	DIM
Pressure test:	PrT
Ultrasonic Inspection:	USI
Helium leak test:	HLT

CYCLIC BENDING TEST (STEP 6; 8; 10; 12 in Table 1)

The bending test shall be carried out with the help of hinge-type supports as indicated in the Fig. 4below. The forces P as indicated in the Figure shall be applied on the extensions of the hinged supports of the mock-up, positioned "perpendicularly" to the supports. The force to be applied depends on the distance "a" between the point of force application and the hinge-type support, and the distance "L" between the supports.

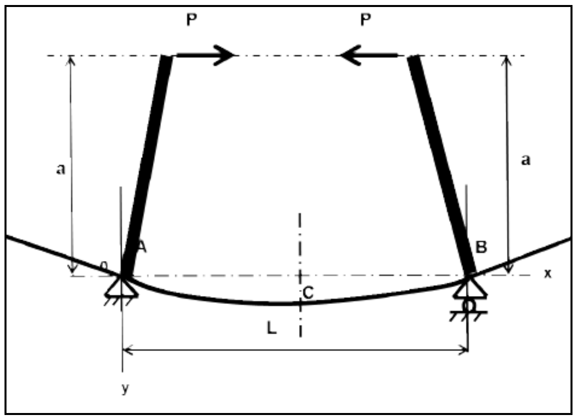

Figure 4: Principle of bending test with hinged-type supports with frame

CYCLIC HIGH HEAT FLUX TEST (STEPS 2, 4, 14 in Table 1)

The parameters of the High Heat Flux testing at 20MW/m^2 are specified below. The test protocol shall be accepted by IO.

- Initial thermal mapping at 10 MW/m^2
- Specified number of cycles at 20 MW/m^2 (10s beam on / 10s beam off)
- Final thermal mapping at 10 MW/m^2

The parameters of the High Heat Flux testing at 10MW/m^2 are specified below. Intermediate thermal mappings during 5000 cycles shall be proposed by the Tenderer and agreed with the IO. The test protocol shall be accepted by IO.

- Initial thermal mapping at 10 MW/m^2
- 5000 cycles at 10 MW/m^2 (10s beam on / 10s beam off)
- Final thermal mapping at 10 MW/m^2

The specified value for the heat flux shall be intended as "target value for the absorbed heat flux" with a flat profile. A heat flux profile is defined as "flat" when its variation is within ±5% of its average value when applied onto a flat surface.

The absorbed heat flux shall be within ±10% of the target value.

The surface temperature measurement shall be calibrated. The surface temperature measurement by Infrared (IR) camera shall be with ± 5% for the range 1000 – 2000 °C or 10% in the range

100 - 1000°C compared with the reference temperatures. The calibration procedure shall be documented in the test protocol.

The coolant parameters and water chemistry during HHF tests are given in the Table 2 below.

Table 2: Required coolant parameters and water chemistry during HHF tests

Inlet Pressure, [MPa]	Inlet Temp, [°C]	Flow velocity, [m/s]	Electrical conductivity, [µS/cm]	Oxygen content, [mg/l or ppm]
3.9	70	11	< 0.3	< 0.05

The cooling parameters shall be kept constant (within tolerances: ±5% for the inlet pressure and for the flow rate; ±10% for the inlet temperature) during the High Heat Flux testing.
A proper control of the quality of the water coolant is essential to prevent corrosion and formation of deposits or coatings in the coolant tube.

The following main measurements are required during the test and shall be recorded:

1) Surface temperature distribution by IR camera and surface temperature measured by two-colour pyrometers;
2) Water calorimetry to determine the absorbed heat flux;
3) Coolant flow rate;
4) Coolant inlet/outlet temperature and pressure;
5) Vacuum level in the vacuum chamber (shall be < 1 Pa).
6) Water chemistry (electrical conductivity, pH and oxygen content);

Timetable

The tentative timetable is as follows:

Tender submission	May	2015
Tender Evaluation	July	2015
Contract placement	July	2015
Completion	July	2017

Experience

The companies and their personnel shall have adequate experience in the following areas:

- **Relevant experience and technical and engineering capability in high heat flux testing**

- **Relevant experience and technical and engineering capability in the required non-destructive testing**

- **Relevant experience and technical and engineering capability in mechanical tests**

- **Relevant experience and technical and engineering capability in destructive examinations of metallic components:**

- **Language ability in English:**

Candidature

Participation is open to all legal persons participating either individually or in a grouping (consortium) which is established in an ITER Member State. A legal person cannot participate individually or as a consortium partner in more than one application or tender. A consortium may be a permanent, legally-established grouping or a grouping, which has been constituted informally for a specific tender procedure. All members of a consortium (i.e. the leader and all other members) are jointly and severally liable to the ITER Organization.

The consortium groupings shall be presented at the pre-qualification stage. The tenderer's composition cannot be modified without the approval of the ITER Organization after the pre-qualification.

Legal entities belonging to the same legal grouping are allowed to participate separately if they are able to demonstrate independent technical and financial capacities. Candidates (individual or consortium) must comply with the selection criteria. The IO reserves the right to disregard duplicated reference projects and may exclude such legal entities from the pre-qualification procedure.