TECHNICAL NOTE

RELATED TO THE TPD MARKET SURVEY ON

Feasibility study to manufacture Tungsten to CuCrZr gradient joints

IMPORTANT: This note is for information only. Data can be subject to change. Only the tender documentation will prevail for the related forthcoming Call for Tender.

IMPORTANT: This note is for information only. Data can be subject to change. Only the tender documentation will prevail for the related forthcoming Call for Tender.

1 INTRODUCTION

1.1 BACKGROUND TO THIS TECHNICAL NOTE

Tungsten is considered a main candidate as plasma facing material due to its high melting point and high toughness. Tungsten is intended to be in positions directly facing the fusion plasma which means exposure to an extreme and hostile environment. To initiate reaction in the fusion plasma needs to be heated up to about 150 million degrees Celsius and the fusion reactions generates neutrons with 10 times higher energy (speed) than neutrons released via conventional fission reactions. The tungsten is positioned a distance away from the plasma, but it's only ultra-high vacuum between the plasma and the tungsten surfaces.

Thus, the plasma operation exposes the Tungsten to thermal shocks and intense flux of fast neutrons. Tungsten is more ductile at high temperatures, but relatively brittle especially at low temperatures. The ductile to brittle transition temperature (DBTT, a temperature zone where above the W get significantly more ductile) can be modified by manufacturing methods. The DBTT also changes after exposure to high temperatures and neutrons.

Efficient heat transfer is essential from W plasma facing surfaces towards the coolant system. In the baseline design W is joined to CuCrZr where the Cu-alloy acts as heat sink. For ITER the inner surface of the Tokamak walls are covered with W-tiles attached to CuCrZr. The thermal expansion is higher for CuCrZr than for W and this will generate stresses at the W to CuCrZr interfaces. Due to the thermal expansion difference the W-tile size must be optimized to limit the risk of tiles falling off. Smaller tiles are favourable, but too small tile configuration leads to manufacturing constraints. Roughly 1-1.5 million W-tiles may be needed for the ITER First Wall and with high requirements on the tolerance of surface alignment for successful plasma operation. The design has to be robust enough to allow some tiles to fall off with continuous operation, but as any fusion reactor can be considered a First of Kind project this risk must be mitigated.

One approach is to manufacture W-tiles with a gradual transition from W to CuCrZr (gradient material) to avoid the narrow joint with high concentrated stresses due to thermal expansion mismatch. A gradient material allows smoother transition of stresses over larger volume.

IMPORTANT: This note is for information only. Data can be subject to change. Only the tender documentation will prevail for the related forthcoming Call for Tender.

The thickness of either W or CuCrZr varies depending on position and purpose. Typical thicknesses are 12 mm W and 22 mm CuCrZr that are joined together. Without gradient joint approach a thin Cu-compliance layer (typically 1-2 mm) is joined to W before joining to CuCrZr via Hot Isostatic Pressing to mitigate thermal stresses the CuCrZr.

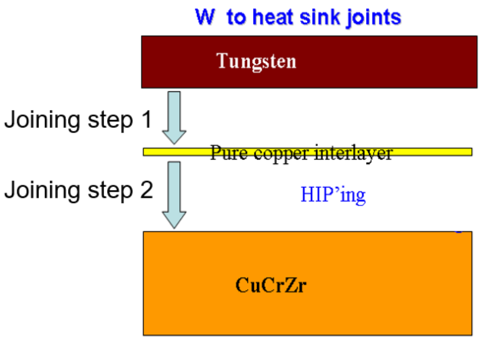

Figure 1: Illustration of conventional manufacturing route of joining W-tiles on CuCrZr developed for ITER 15 years ago.

The thickness of the gradient joint itself is part of this development project and to be proposed by the bidder. Some millimetres thick gradient joint is foreseen, but not specified in detail. However, as W is the plasma facing armour around 6-12 mm should be pure W in thickness.

The width and length (i.e. footprint) of the W tiles for the NHF (Normal Heat Flux 2 MW/m^2) First Wall Panels are expected to be in the region of 22 mm x 22 mm – 35 mm x 45 mm. The EHF (Enhanced Heat Flux 4.7 MW/m^2) W footprint is in the region of 12 mm x 12 mm. Note the higher the heat flux the smaller the tile footprint, due to the thermal stresses that are concentrated in the W/CuCrZr joint.

The W tile dimensions for this study may be selected in such a way that it is representative for the FW panels, preferably for the European NHF design. But, the smaller EHF design can be trialled as well as this study will be looking further than the ITER specific scope The dimensions of the gradient samples shall be agreed with F4E so that they can be bonded on suitable NHF mock-ups.

IMPORTANT: This note is for information only. Data can be subject to change. Only the tender documentation will prevail for the related forthcoming Call for Tender.

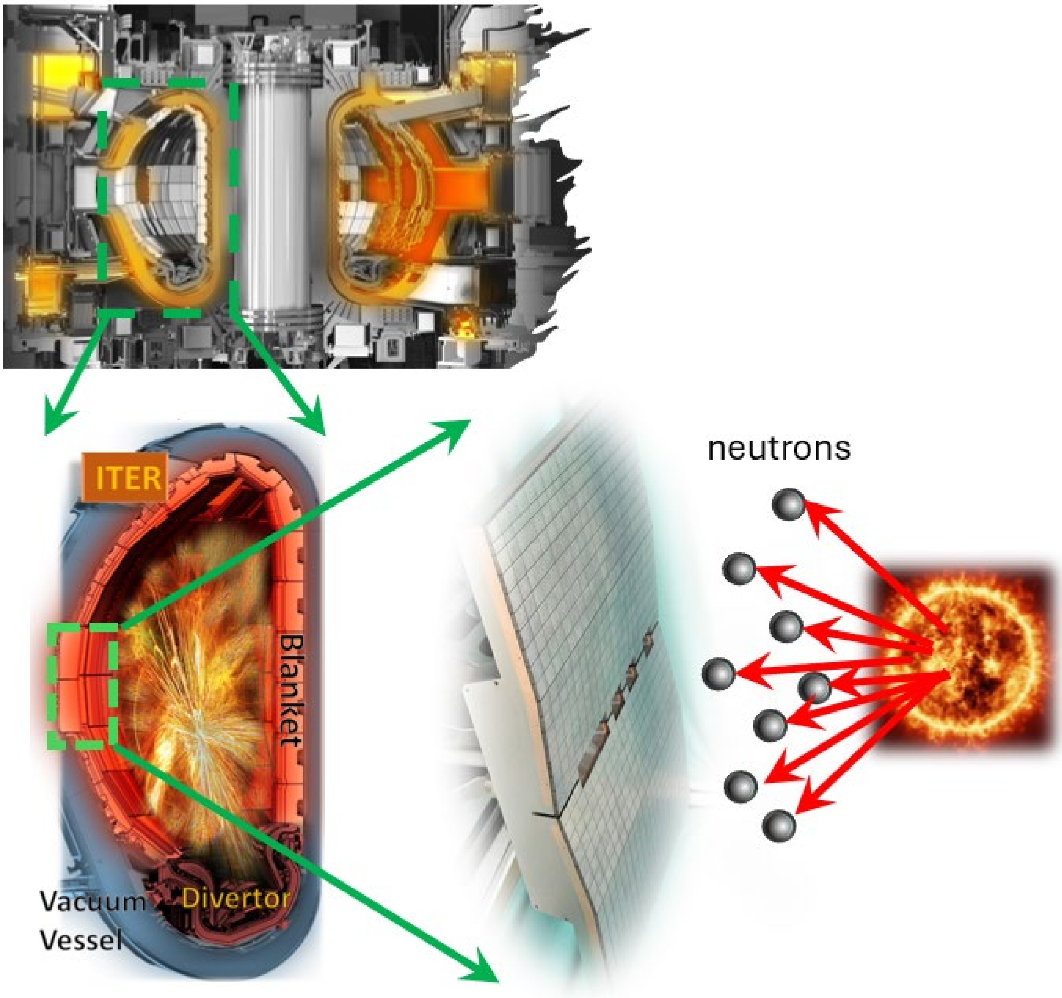

Figure 2: Illustration of plasma facing armor aligned against the fusion plasma.

1.2 SUBJECT OF THIS TECHNICAL NOTE

Fusion is a growing field, and this work has a potential to generate spin-off applications as the design of plasma facing components is demanding and the different teams are looking for solutions. This technical note is prepared based on the design of the ITER First Wall and the work to be provided has potential to be useful for applications for other fusion projects.

The subject of this technical specification is to describe the development needed to achieve a manufacturing method to obtain a W to CuCrZr material with a gradient joint area. Any specific approach to manufacture this gradient material is not imposed in detail on purpose to allow the bidder to propose a method.

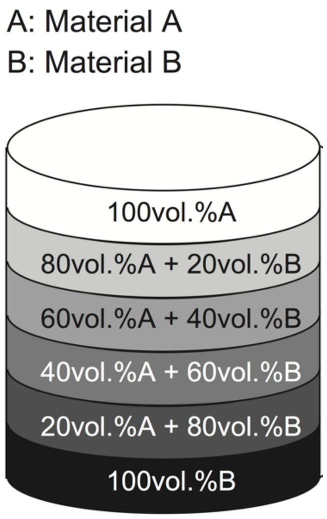

Figure 3: Stepwise approach for gradient joint.

Figure 4: Gradual composition changes gradient joint.

It is essential to assess the performance of the manufactured W top layer to map behaviour of damage due to thermal shocks and determine DBTT. This testing is usually done by applying cyclic heat flux on the top W surface by electron beam and this testing is not in the scope of this technical note. What is included in this technical specification is to supply W/CuCrZr gradient tiles and F4E will coordinate this testing as it is quite specific for comparison with existing data.

IMPORTANT: This note is for information only. Data can be subject to change. Only the tender documentation will prevail for the related forthcoming Call for Tender.

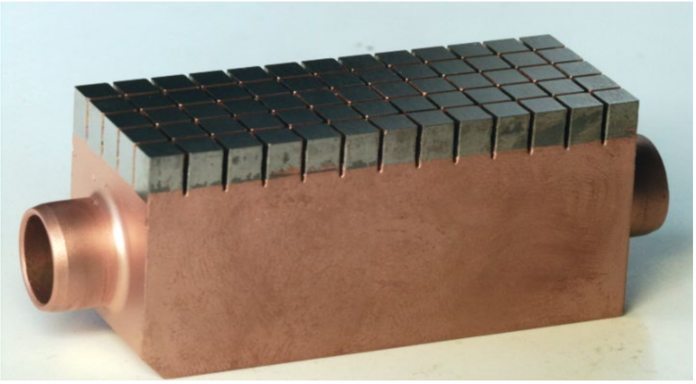

Figure 5: Tungsten tiles on mock-up used for thermal shock testing for illustration purposes (from 2007 R&D).

IMPORTANT: This note is for information only. Data can be subject to change. Only the tender documentation will prevail for the related forthcoming Call for Tender.

2 SCOPE OF WORK

2.1 GENERAL

The scope of the supply is to propose a manufacturing plan, procure raw materials based on manufacturing method (W and CuCrZr), manufacture gradient joints, and test the materials properties. Some small test specimens shall be proved for demonstration purposes and for thermal shock testing and vacuum properties testing. The main final deliverable is a technical report.

The following material specifications are provided for information as examples of the current envisaged material specifications for the ITER First Wall application:

- Divertor IVT (Inner Vertical Target) - tungsten plates (ITER_D_3FQRFH v1.2)
- CuCrZr for Heat Sink of Blanket NHF (Normal Heat Flux) First Wall Panels (ITER_D_ QSSDWJ v1.0)
- Copper Sheet Specification for Divertor PFC (Plasma Facing Component) (ITER_D_ 2DXXKQ v2.1)

They are not strict requirements for this study as the availabilities of the ITER specific grades may be limited, but it is recommended to source batches that are at least similar. F4E can provide market information about potential suppliers.

2.2 SERVICES

The following activities shall be included in the supply:

- Development of manufacturing process to produce W to CuCrZr gradient joints.
- Manufacturing of W to CuCrZr gradient joints.

  Specimens thick enough to allow grip for tensile/shear testing.
- Test to be done:
  - Microstructure analysis (SEM), grain sizes, morphology, and areas of interest.
  - Mechanical testing (hardness and tensile/shear strength).
- Provision of samples to F4E for heat flux and vacuum properties testing.

  (about 20 gradient tile specimens is sufficient to reproduce reliable results, dimensions to be agreed)
- Supervision and reporting of all the test to be performed.

Please answer the survey here LINK.

IMPORTANT: This note is for information only. Data can be subject to change. Only the tender documentation will prevail for the related forthcoming Call for Tender.