Princeton Plasma Physics Laboratory

PPPL- 4813

PPPL- 4813

ITER Diagnostic First Wall

G.D. Loesser, C.S. Pitcher, R. Feder, D. Johnson, S. Pak, M. Walsh, Y. Zhai

September, 2012

Prepared for the U.S. Department of Energy under Contract DE-AC02-09CH11466.

ITER DIAGNOSTIC FIRST WALL*

G. D. Loesser[a], C. S. Pitcher[b], R. Feder[a], D. Johnson[a], S. Pak[c] , M. Walsh[b], Y. Zhai[a]

[a]*Princeton Plasma Physics Lab, Princeton, NJ, USA*
[b]*ITER Organization, Route de Vinon sur Verdon, 13115 Saint Paul Lez Durance, France*
[c]*National Fusion Research Institute, Daejeon, Korea*

The ITER Diagnostic Division is responsible for designing and procuring the First Wall Blankets that are mounted on the vacuum vessel port plugs at both the upper and equatorial levels This paper will discuss the effects of the diagnostic aperture shape and configuration on the coolant circuit design. The DFW design is driven in large part by the need to conform the coolant arrangement to a wide variety of diagnostic apertures combined with the more severe heating conditions at the surface facing the plasma, the first wall. At the first wall, a radiant heat flux of 35W/cm^2 combines with approximate peak volumetric heating rates of 8W/cm^3 (equatorial ports) and 5W/cm3 (upper ports). Here at the FW, a fast thermal response is desirable and leads to a thin element between the heat flux and coolant. This requirement is opposed by the wish for a thicker FW element to accommodate surface erosion and other off-normal plasma events.

I. INTRODUCTION

ITER upper ports and equatorial ports contain structures largely dedicated to the support and positioning of diagnostics elements, posed to view or interact with the plasma. It is anticipated that additional elements such as the glow discharge probes (GDC) and disruption mitigation systems (DMS) will also be housed in these structures. On the plasma end of these port plugs (PP) structures are mounted DFW components whose function and responsibilities are to protect the diagnostics elements housed in the port plug structure from volumetric and radiant plasma heating and provide radiation shielding while providing plasma viewing access for the diagnostic operation. Interfaces between these items are complicated by ownership. The DFW components are being supplied by ITER directly while the interfacing components are being supplied by the domestic agencies (DA). With the many diagnostics systems housed in the fourteen upper port plugs (UPP) and eight equatorial port plugs (EPP) there are numerous variations of configurations and apertures. Each DFW may contain a unique set of apertures and cavities to provide an acceptable diagnostic environment and view of the ITER plasma conditions.

II. GENERAL REQUIREMENTS

The goal of the DFW design is summed up in the following statement: "Provide a design that allows versatility in diagnostic size and configuration while protecting the diagnostics from plasma heat loads. This design must provide adequate nuclear shielding for port cell, vacuum vessel and magnets (with combined efforts of diagnostic shielding module (DSM) and port structure). The attachment of the DFW must allow for remote handling replacement in the hot-cell."

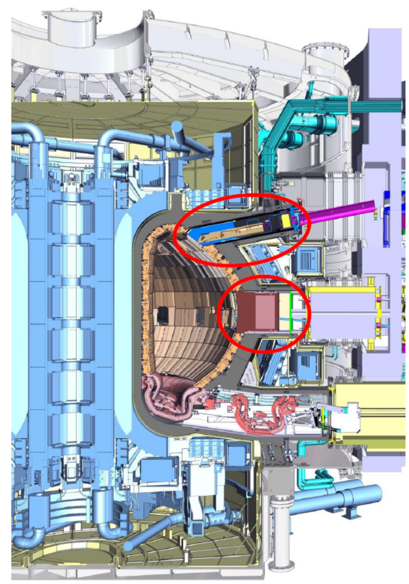

Figure 1 Diagnostic Port Plug locations on ITER, equatorial and upper port plugs, circled in red.

Many other ITER component requirements exist as well as design guidance. Requirements or guidance that have a more profound effect on the design choices are noted, the foremost being the radial position of the DFW. The design of the port plug positions the DFW surface recess 10cm compared to the wall mounted blanket shielding modules.

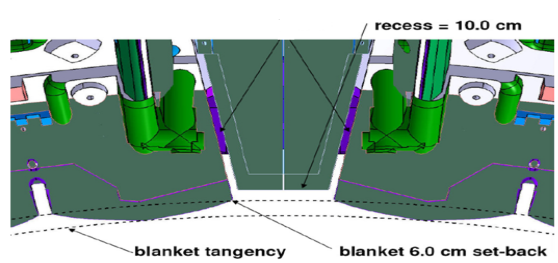

Figure 2 Elevation section of UPP recess verse wall mounted blankets

This set back is discussed in detail in "Port-Based Plasma Diagnostic Infrastructure on ITER", C. S. Pitcher (Ref 1). Despite this radial set-back (that protects the DFW from plasma interaction) uncertainty produce unexpected loads on the DFW first wall. These uncertainties are being evaluated by the ITER Physics team, which provides status and reports to the DFW design team. Due to this uncertainty, a requirement was established to have a DFW attachment design that is remotely replaceable. This lends itself to a bolted connection (described in detail later) rather than a less preferred (by remote handling) welded connection. The 10cm radial setback produces a reduced first wall thermal loading and allows for a full stainless steel (SS) construction. The exposure of this area of SS to the plasma has been evaluated to be acceptable (REF 2) for plasma impurities influx and is the basis for the presented design. The simplification of a SS first wall allows for a much cheaper design (verses typical ITER first wall of beryllium layer mounted on actively cooled copper mounted on a cooled SS structure). An option to add an additional layer of thin beryllium coatings will be considered if warranted and feasible.

Perhaps the next biggest requirement that has a large effect on the design of the DFW and attachment is the assumed fault conditions that could exist between the coolant system feeding the DFW and separate system feeding the DSM (supports the DFW).

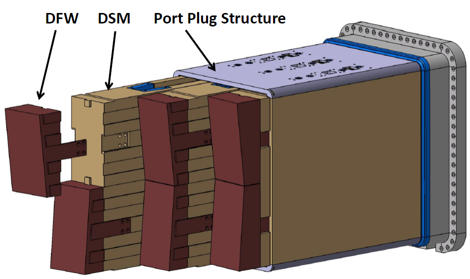

Figure 3 Equatorial Port Plug showing the assembly of DFW to the DSM, then insertion into the port plug structure.

The assumed faulted condition could result in a 100˚C thermal difference between the two mated components. This gradient must be accommodated in the design of the attachment. Additional guidelines preferred an attachment scheme for the upper and equatorial DFW's that are similar in concept and size (where appropriate). This will allow a reduction in unique RH tools and RH operations that need to be validated.

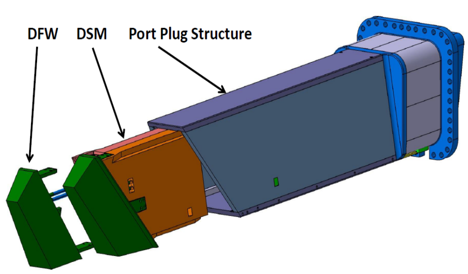

Figure 4 Upper Port Plug showing the assembly of DFW to the DSM, then insertion into the port plug structure.

To accommodate this multitude of diagnostic attachment concepts, it was determined to isolate the diagnostic attachment from DFW functions. This allows the diagnostic components to exist in the DFW overall space (within cavities), but not rely on the DFW to mechanically support or thermally control the diagnostic element. This "isolation" allows diagnostic components to be positioned far radially forward (support by the DSM) to gain better viewing angles of the plasma.

Evolution of the design for the upper DFW (UDFW) and equatorial DFW (EDFW) has considered the effects on electromagnetic (EM) loading and overall port loads and defections. Concerning this, the upper port DFW will contain a vertical separation dividing the front end of the UPP components into two parts as far radially back as 600mm from the plasma surface. Although this doubles the DFW components and complicates the coolant arrangement it has a great effect on reducing EM loads and subsequent port plug deflections. The EPP structure has also evolved to have vertical separations to reduce EM loads (REF 3). In this case, the EPP has two vertical divisions producing 3 discrete elements (drawers). In the model description below you will see the EDFW is again split along the horizontal plane producing 6 EDFW's per equatorial port. This is partly done to match the geometric break of the faceted EDFW face in the poloidal direction, but also reduces loading. Manufacturing techniques and cost to produce was weighed into the factor of design choices that were made.

III. DESCRIPTION UDFW and EDFW

The two DFW's, Upper and Equatorial, will have similar features (where practical) altered due to configuration and loading. For the purposes of this paper the EDFW will be detailed and the UDFW will describe alteration or differences due to shape. Each DFW is made of a forged 316LN IG SS. Sizes are identified in the tables below. The heating of the DFW is defined by two conditions, first wall radiant heating ($0.35 w/mm^2$) and volumetric heating that drops off exponential as a function of volume and radial distance.

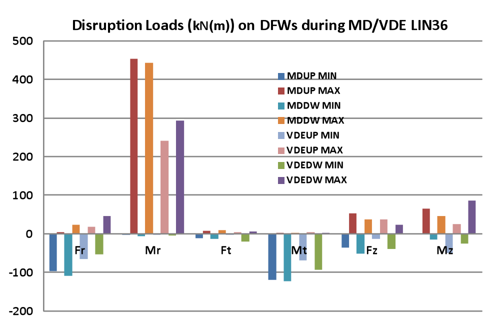

Figure 5 Summary of max/min EM loads on the EDFW for four disruption cases

For the EDFW nuclear heating peaks near the surface (as does the radiant plasma heating) at $8 w/cm^3$ and at

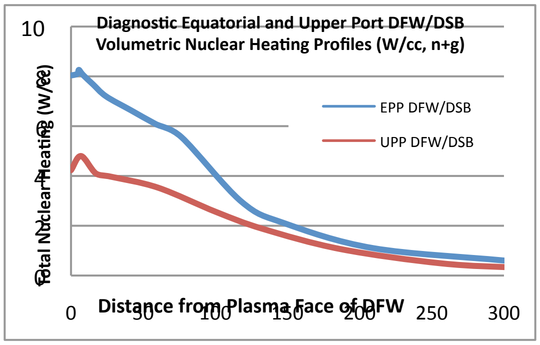

Figure 6 Volumetric nuclear heating of UPP and EPP

Optimizing the first wall thickness to stay within the design allowable and criteria established by ITER for In-vessel components (SDC-IC) yields a maximum first wall thickness of 5mm. This thickness then determines the span between first wall coolant channels (due to 4MPa coolant pressure) and the total power that needs to be dissipated. Since one total circuit is preferred per DFW, the total flow must travel thru the entire circuit.

The first wall will be machined into the face of the exposed bulk DFW. The milling will allow for coolant passages to vary in cross-section and allow curved routing to accommodate the numerous aperture configurations. The ability to alter the depth and width of the passages will allow a path that can maintain a constant cross-section and minimizes pressure drops along the path.

To provide adequate flow while maintaining the allowable thermal coolant gradient (65˚C), the first wall-milled channels must be divided into two parallel paths. This allows reasonable depth and width channels and limits flow velocity to less than 4MPS. These first wall parallel paths are recombined as the coolant enters the 1st layer of the bulk shielding gun-drilled layer.

Depending on aperture configuration, the sidewalls of diagnostic apertures may require specialized coolant close to the exposed surfaces.

This aperture sidewall coolant routing can be provided by various methods. One method is to rout first wall coolant radially back along aperture surfaces and then back to milled first wall channels in a parallel loop. In some cases the arrangement of the gun-drilled bulk shielding passages could be positioned to provide adequate cooling. The bulk cooling and heating of these blocks are provided by an array of coolant passages that are "gun-drilled" thru the long direction of each component. The drilled passages are arranged in sets (ladders) that form a group of parallel passages aligned on each end to allow for manifolding.

When alignment cannot be accommodated additional passages are needed to reconnect the misaligned passages with the flow paths. A typical circuit of the bulk coolant path is shown in figure 9. The FW paths are milled into the face while the remaining coolant path is an arrangement of parallel/series ladders in the bulk shielding of the DFW. The gun-drilled layers will typically be 15mm in diameter and can be located to an accuracy of +/-1mm.

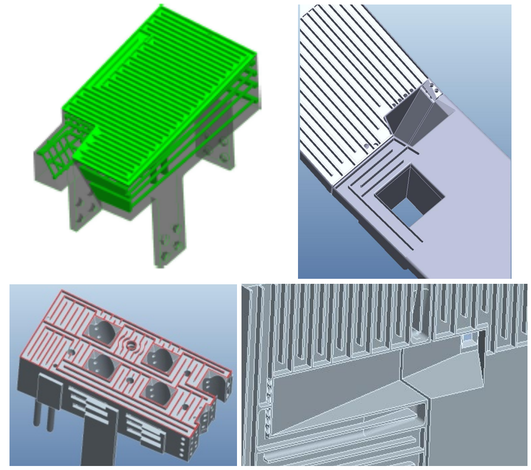

Figure 7 Arrangement of diagnostic apertures and first wall coolant arrangements

The attachment and load transfer between the DFW and DSM (in the model used in for this paper) used a set of 3 attachment legs (tabs). Each of the three tabs is secured to the DSM by a bolted arrangement into threaded bushings within the DSM. The tabs cross-section and length will be optimized for the entire set of loads for each of the EDFW and UDFW. The eight EPP ports (six EDFW's on each) will all have the same attachment tab cross-section and length.

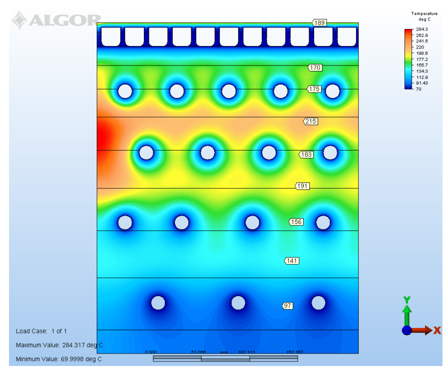

Figure 8 Typical EDFW coolant layers spatial relationship, Note first wall thickness of 5mm.

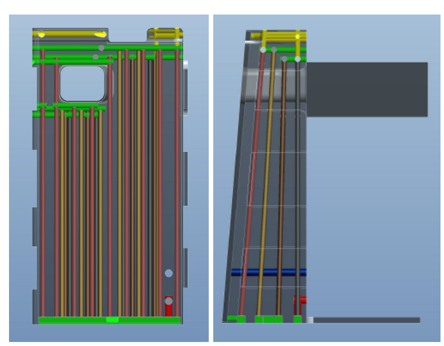

Figure 9 Typical EDFW coolant 2-D sections showing relationship of coolant layers

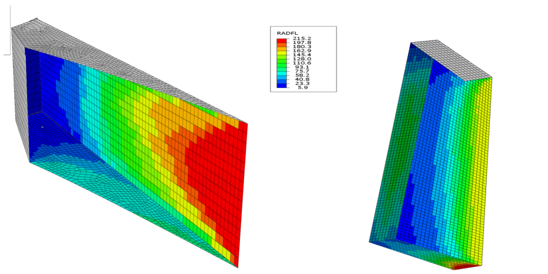

Figure 10 Surfaces of typical diagnostic apertures showing heating distribution

While the 12 UPP UDFW's will all have a unique cross-section and length (different than the EDFW).

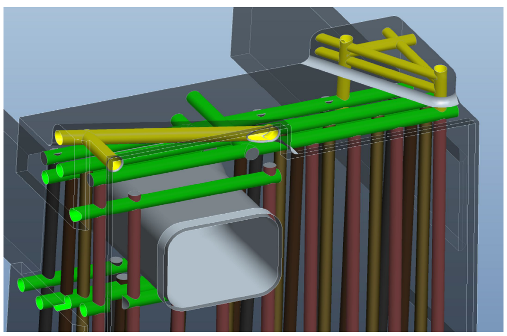

Figure 11 EDFW coolant arrangement to illustrate first wall water-cooling along aperture surfaces

The attachment tabs are not actively cooled along the length (no coolant lines running thru cross-section). The bolted region of the DFW attachment tab where it mates to the DSM will provide sufficient heat removal to limit the peak attachment tab temperature.

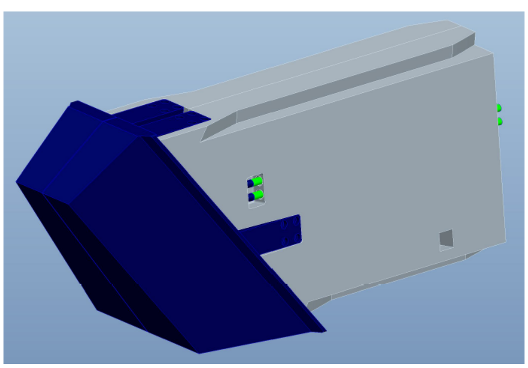

Figure 12 UPP sub-assembly of UDFW (2) and DSM

The two EDFW opposing and facing tabs on the DFW sides could be adjusted in the vertical direction to provide flexibility to the diagnostic arrangements.

EDFW (6 versions)	Range		
Volume (w/coolant)	0.102	0.125	m^3
Polodial Height	957	957	mm
Toroidal Width	320	353	mm
Radial Depth	200	353	mm
Mass	819	1001	kg

Table 1 Variation in size and mass of typical EDFW's (w/o apertures)

UDFW (2 versions mirrior images)		
Volume (w/coolant)	0.151	m^3
Polodial Height	1496	mm
Toroidal Width	344	mm
Radial Depth(1)	500	mm
Mass	1210	kg
(1) alteration TBC		

Table 2 Size and mass of typical UDFW (w/o apertures)

This option is being optimized. The primary loading component that needs to be reacted thru the DFW supports into the DSM is a radial moment (figure 5). The optimization of the tab configuration (cross-section and length) must consider this and other load paths in combination with the need to allow for a thermal gradient of (100˚C) existing between the DSM and DFW. The tabs length must be minimized to limit the peak temperature, yet maximized to produce lower bending stresses due to growth resulting from thermal gradients between DSM and DFW. This balance of tab length and cross section will be considered for all the required ITER DINA load cases with the goal of finding a single optimized solution for all.
The bolted arrangement of the DFW attachment tabs to the DSM provides for three well defined electric paths between the structures. A fourth and fifth path exists in the coolant line connection. These coolant paths are being evaluated and designed to minimize the likelihood that they will carry substantial current.

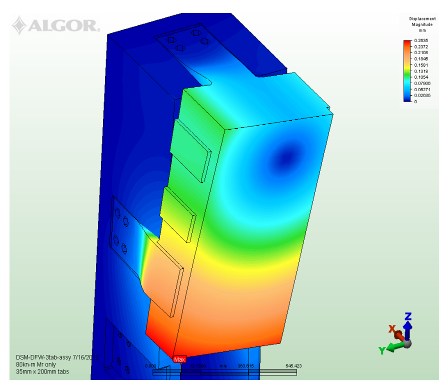

Figure 13 EDFW FEA study of deflections resulting from radial moment thru 3-tab attachment concept

The attachment tab length also locates the bolted attachment hardware onto the DSM in a region where volumetric heating of the passive cooled attachment hardware is much less a concern. A reduction of greater than an order of magnitude is achieved. This reduces the difficulties with loss of preload from the bolt heating and elongation. Since the three attachment joints double as electrical connections the attachment hardware is sized to maintain a constant preload thru the full temperature range including any fault conditions. To minimize the quantity of bolts needed to maintain the joint preload, Inconel bolts will be used that have a far greater engineering stress level (Sm) value at temperatures higher than the surrounding 316SS. To compensate for the material strength differences a bearing area in the SS threaded region. This concept of using an insert is also in line with RH practices regarding tapped holes. The bushing size allows the depth of the attachment bolts to be minimized in order to avoid interruption of diagnostic space.

The arrangement of relatively flexible DFW attachment tabs coupled with passive DSM features at the interfaces (tapers that guide the DFW onto the DSM), allows for the passive alignment of the components during remote installation.

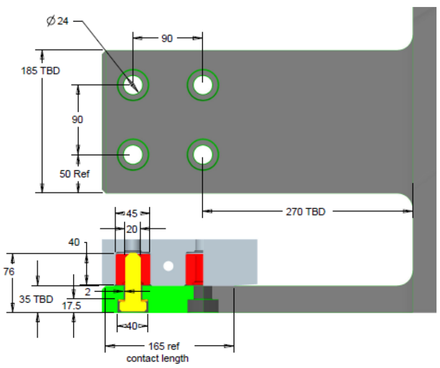

Figure 14 EDFW attachment region details

IV. CONSTRUCTION ISSUES AND R&D

The need to mill the front face of the bulk-forged block to produce a variable first wall coolant passage requires that a cover plate seal the coolant channels. Efforts thru the CDR have identified the maximum thickness of the first wall plate to approach 5mm.

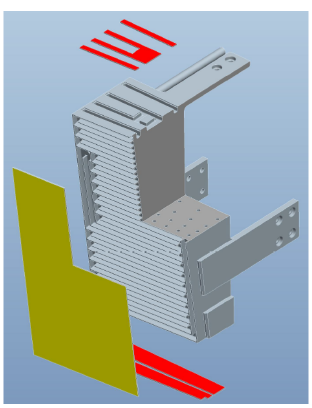

Figure 15 Equatorial Diagnostic First Wall (DFW) – no diagnostic apertures (corner cutaway)

A first wall plate, as thick as possible, is preferred to gain margin on erosion life and off-normal loading events. The ITER structural design criteria for In-Vessel Components (SDC-IC) yields a limit that can be confirmed by analysis of about 5mm. A greater thickness could be considered if testing was performed to verify the design. This may be considered by ITER IO in a parallel effort, but to date, the 5mm plate is the baseline thickness. This plate will be adhered to the gun drilled forging.

The method given the highest consideration for joining the first wall plate to the DFW bulk is brazing using a pure copper alloy. This must be a hard vacuum seal. This type joint has been used very often for many similar applications and has the lowest risk compared to other methods that would require extensive R&D. Limited R&D is planned to investigate this joint as well. The R&D will consider joint details, limitations, inspection and joint validation techniques. Additional R&D is being considered to evaluate the option of adding beryllium to the first wall face. The application process and adhesion of this thin layer to the face of the 5mm first wall plate will be investigated.

V. FUTURE EFFORTS

The USIPO has agreed to develop the DFW design thru the PDR and FDR stages for two Equatorial ports and two Upper ports. The design of each port will be based upon the latest diagnostic arrangements available and will be used as a basis / foundation for all later DFW reviews.

VI. CONCLUSIONS

A strong foundation has been established to help evolve the design of the ITER DFW. The continued development of the DFW design (thru PDR and FDR) will help the on-going diagnostic developers consider DFW friendly concepts that will reduce the need for redesign in the critical late design stages. The efforts and development of FDR for the EDFWs and UDFWs arrangements will provide a foundation for subsequent port specific design reviews

REFERENCES

1. C. S. PITCHER et al. “Port-Based Plasma Diagnostic Infrastructure on ITER” C.S. Pitcher (TOFE 2012).
2. S. LISGO et al. “Recommendations on the Selection of Port Plug Plasma Facing Materials” ITER IDM 2MSJ7L_v1_1
3. Y. ZHAI et al, "ITER Diagnostic First Wall CDR – Transient electromagnetic, static structural and thermal fatigue analysis", ITER Report, June, 2011.
4. R. FEDER et al. "Assessing the Nuclear Environment for ITER Port Plugs and Port-based Diagnostics", ITR/P5-28, IAEA FEC 2012 Conference Proceedings”

This work is supported by US DOE Contract No. DE-AC02-09CH1146. PPPL Prime Contract Number DE-AC02-09CH11466. All US activities are managed by the US ITER Project Office, hosted by Oak Ridge National Laboratory with partner labs Princeton Plasma Physics Laboratory and Savannah River National Laboratory. The project is being accomplished through a collaboration of DOE Laboratories, universities and industry.

“The views and opinions expressed herein do not

The Princeton Plasma Physics Laboratory is operated
by Princeton University under contract
with the U.S. Department of Energy.

Information Services
Princeton Plasma Physics Laboratory
P.O. Box 451
Princeton, NJ 08543

Phone: 609-243-2245
Fax: 609-243-2751
e-mail: pppl_info@pppl.gov
Internet Address: http://www.pppl.gov