Nuclear Heating In Critical Components of Alternative ITER First Wall Attachment Mechanism

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***Abstract*—A nuclear analysis was performed for an alternate ITER first wall attachment scheme to estimate the nuclear heating in critical components. With a variety of components near the first wall without direct cooling, there is concern that the operating temperatures will be above engineering limits. Using DAG-MCNP5, a 1-D analysis framework was used to estimate the nuclear heating in a detailed 3-D model of the first wall and shield attachment mechanism. The parts of the stainless steel hinge at the base of system experience nuclear heating between 1.85 and 5.07 W/cm^3. The copper yoke and Inconel-718 yoke pin experience a heat rate of 2.44 W/cm^3. If stainless steel bolts are used, the bolt heads will experience 2.9 W/cm^3, with only a small reduction from plugging the bolt access holes. If molybdenum bolts are used, the bolt head heating is increased to 3.4 W/cm^3. The heating in the hinge parts and stainless steel bolts is expected to lead to temperatures higher than engineering limits. Due to a higher thermal conductivity and melting temperature, the Mo bolts are expected to operate at acceptable temperatures.**

Keywords-3-D nuclear analysis, Monte Carlo

I. INTRODUCTION

A new hinge concept is proposed for attachment of the first wall to shield modules in ITER. A beam on the back of the first wall fits over a "knuckle" that is attached to the base of the shield module (see Figure 1(A), Figure 2 and Figure 3). The top of the first wall is attached to the shield with a copper yoke around an Inconel pin with a pair of Inconel bolts (see Figure 1(B) and Figure 3).

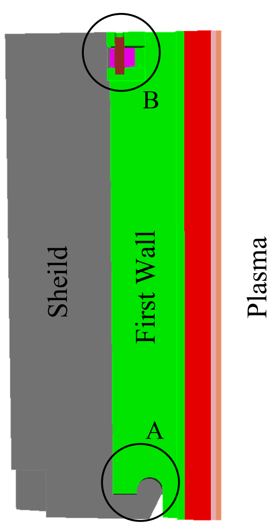

Figure 1. Cross-section through middle of Module 4 prototype showing (A) hinge and (B) yoke/pin attachment.

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There are concerns about nuclear heating and the ability to cool both the hinge components and the yoke/pin components. The hinge knuckle is cooled by conduction to the bulk of the shield module and the notch components of the hinge are cooled by conduction to the rest of the beam. The copper yoke is cooled by conduction through the bolts to the shield module and the pin is cooled by contact conduction to the yoke and the first wall beam.

II. ANALYSIS METHODOLOGY

We performed 3-D neutronics analysis of this system using DAG-MCNP5[1] with FENDL-2.1[2] continuous energy data. The calculations were performed in a 1-D/3-D hybrid r-z geometry[3]. The detailed module geometry shown in the figures was used on the inboard side with material definitions shown in Table I and without modeling the vacuum vessel. On the outboard side the three first wall layers and shield module were modeled with homogenized materials as shown in Table II, also without modeling the vacuum vessel. The regions of interest were far enough away from the I/B vacuum vessel to justify excluding it from the model, as any radiation reflected from the vacuum vessel would be shielded by the shield module. The plasma-facing surface of the I/B first wall and O/B first wall were positioned at 402.7 cm and 842 cm respectively. The 14.1 MeV neutron source was localized to an annular region between 519 and 719 cm to offset the effect of the source distribution on the first wall. The regions of interest were far enough away from the first wall that the known

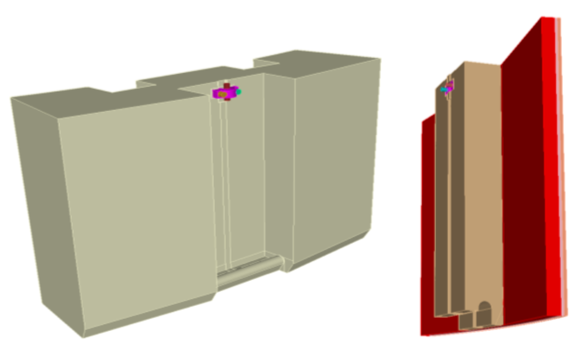

Figure 2. Three dimensional view of shield module (left) and first wall (right) showing knuckle and notch detached.

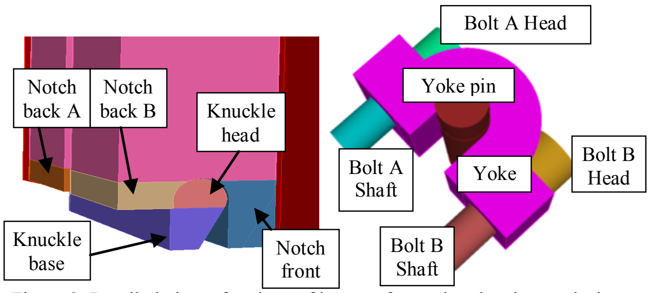

Figure 3. Detailed view of regions of interest for nuclear heating analysis.

limitations of the 1-D/3-D hybrid source distribution would not play a role in this analysis[4]. The results were normalized for a 0.567 MW/m^2 neutron wall loading expected at Module 4[5]. The results should scale linearly with the neutron wall loading for other poloidal locations.

In order to provide some information about spatial distribution of nuclear heating, the hinge knuckle was divided into two regions, both separate from the shield bulk, and the notch region of the first wall beam was divided into three regions, as shown in Figure 3. Combined neutron and photon heating results are reported for each region indicated. Similarly, in the yoke/pin region, each bolt was divided into bolt head and bolt shaft and combined neutron and photon heating results are reported.

A. Yoke bolt variations

There are two holes through all the first wall layers to provide access to the bolts that attach the yoke to the shield module. These holes provide a streaming path for radiation directly to the bolts. Therefore, in addition to the base case with Inconel-718 bolts and open access holes, three additional variations were analyzed: one with Inconel bolts and plugged holes, and two with pure molybdenum (Mo) bolts (open and plugged holes). When plugged the holes are filled with 100% SS-316.

TABLE I. MATERIAL COMPOSITIONS OF INBOARD COMPONENTS

Inboard Component	Composition
Be Tiles	100% Be
CuCrZr	66% CuCrZr 34% H2O
FW Body	80% SS-316 20% H2O
FW Mounting Beam	100% SS-316
FW Mounting Beam Cooling	100% H2O
Shield Module	70% SS-316 30% H2O
Copper Yoke	100% Cu
Inconel Bolts	100% Inconel-718
Inconel Pin	100% Inconel-718

TABLE II. COMPOSITIONS AND THICKNESSES OF LAYERS TO APPROXIMATE OUTBOARD COMPONENTS

Outboard Component	Thickness [cm]	Composition
Be Tiles	1	100% Be
CuCrZr	2.2	82.9% CuCrZr 17.1% H2O
FW steel structure	4.9	84.6 % SS-316 15.4% H2O
Shield Module	40	70% SS-316 20% H2O

III. RESULTS

The total nuclear heating of all the compenents other than the bolts are shown in Table III. Results are consistent with previous 1-D analysis for heating in steel in the first wall and shield. The heating in the front of the hinge beam is highest, at 5.07 W/cm^3, and falls off through the knuckle to 1.86 W/cm^3 in the back of the hinge beam. The heating in the copper yoke and Inconel pin are both 2.44 W/cm^3.

TABLE III. TOTAL NUCLEAR HEATING IN ALL COMPONENTS EXCEPT BOLTS

Part	Total Nuclear Heating [W/cm^3]
Knuckle Head	2.83 (±0.45%)
Knuckle Base	3.22 (±0.40%)
Hinge Front	5.07 (±0.28%)
Hinge Back A	1.87 (±0.77%)
Hinge Back B	1.86 (±0.76%)
Yoke	2.44 (±1.05%)
Yoke Pin	2.44 (±1.63%)

Table IV shows the results for heating in the Inconel-718 bolt heads and shafts for both the open and plugged hole configurations. As expected, the heating is lower in the shaft of the bolt than in the head. The SS-316 plugs do reduce the heating in the bolts, although not substantially. This is probably due to the fact that the majority of the heating comes from secondary photons and not from the primary neutrons. Plugging the holes reduces the high energy neutron fluence, but does not have a substantial impact on the secondary photon fluence near the bolts. Table V shows similar results for the Mo bolts.

TABLE IV. TOTAL NUCLEAR HEATING [W/CM^3] IN INCONEL BOLTS WITH AND WITHOUT PLUGGED ACCESS HOLES.

Part	Inconel-718 Bolts	
	Open Holes	*Plugged Holes*
Bolt A Head	2.91 (±2.36%)	2.68 (±2.79%)
Bolt B Head	2.85 (±2.40%)	2.84 (±2.82%)
Bolt A Shaft	2.10 (±2.61%)	2.00 (±5.98%)
Bolt B Shaft	2.07 (±2.53%)	2.08 (±2.95%)
Plug A/B	N/A	5.99/5.83

TABLE V. TOTAL NUCLEAR HEATING [W/CM^3] IN MOLYBDENUM BOLTS WITH AND WITHOUT PLUGGED ACCESS HOLES.

Part	**Molybdenum Bolts**	
	Open Holes	***Plugged Holes***
Bolt A Head	3.48 (±2.22%)	3.24 (±3.05%)
Bolt B Head	3.42 (±2.25%)	3.46 (±3.08%)
Bolt A Shaft	2.48 (±2.31%)	2.40 (±3.22%)
Bolt B Shaft	2.48 (±2.34%)	2.51 (±3.19%)
Plug A/B	N/A	6.02/5.85

IV. IMPACT ON THERMAL PEROFRMANCE

A simple thermal analysis suggests that the ability for heat to conduct away from the front of hinge notch and from the head of the hinge knuckle may not be adequate to maintain temperatures within acceptable margins. Similarly, the heating in the Inconcel bolt heads is larger than can be adequately removed by conduction into the shield through the contact of the bolts with the shield. Plugging the bolt access holes has a small effect on the heating in the bolts and probably does not reduce the nuclear heating sufficiently. Although the heating of the molybdenum bolts is higher, its much higher thermal conductivity and higher melting temperature suggests that there may be adequate cooling through conduction to the shield block, with or without the plugs in the access holes.

V. SUMMARY

Using the DAG-MCNP5 capability to rapidly analyze complex 3-D geometries, a rapid scoping study of a new ITER first wall attachment mechanism was performed on a realistic representation of the geometry. With primary concern for the nuclear heating rates in components with poor heat removal paths, we identified potential hot spots in the design that suggest a need for a more rigorous analysis, and probably requiring a change in the cooling strategy if this concept were to proceed.

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