Fusion Engineering and Design xxx (2015) xxx–xxx

Contents lists available at ScienceDirect

Fusion Engineering and Design

journal homepage: www.elsevier.com/locate/fusengdes

Study of shielding options for lower ports for mitigation of neutron environment and shutdown dose inside the ITER cryostat

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HIGHLIGHTS

- Mitigation of the radiation environment inside the cryostat needed to reduce ITER coil heating and occupational exposure.
- Cryopump and diagnostics lower ports are significant contributors, shielding options for both are explored.
- Shielding performance studied in terms of neutron transmission and nuclear heating to coils for a range of options.
- Benefits/constraints discussed together with other engineering parameters.

ARTICLE INFO

Article history:
Received 21 August 2015
Accepted 7 December 2015
Available online xxx

Keywords:
Radiation
Shielding
Nuclear analysis
ITER

ABSTRACT

Mitigation of the neutron environment inside the cryostat, and of the subsequent decay gamma dose field from activated materials, is necessary in order to reduce heating of coils and occupational exposure, thereby facilitating smooth operation and maintenance of ITER. Several lines of action are currently being explored to mitigate crucial contributions, such as the leakage through the lower ports. Results are presented here for the two types of lower ports in ITER: cryopump ports and remote-handling ports. Different shielding configurations and material options are investigated and compared in terms of neutron attenuation, coil heating and shutdown dose rate reduction, whilst also considering other engineering constraints such as weight or pumping power. Results enable informed decision-making of best compromise solutions for subsequent design and integration.

1. Introduction

ITER is a nuclear facility under INB-174. Significant mitigation of the neutron environment inside the cryostat, and of the subsequent decay gamma dose field from activated materials, is necessary in order to reduce heating of coils and occupational exposure, thereby facilitating smooth operation and maintenance of ITER. Each port plug owner is responsible of minimizing leakage and activation through these many vessel openings via design optimization and shielding integration. In addition, several lines of action are currently being explored in a collaborative effort between IO and DAs to mitigate other crucial contributions, such as the leakage through the lower ports.

There are two types of lower ports in ITER:

(i) Torus cryopump lower ports (TCP-LP), which are mostly empty and therefore major contributors to neutron leakage ex-vessel.
(ii) Remote-handling lower ports (RH-LP), which are occupied by diagnostics racks during plasma operation and used during maintenance periods for the removal of the divertor cassettes.

Both these ports produce significant radiation cross-talk to the equatorial ports immediately above. Different shielding configurations and material options for these ports are investigated and compared in terms of neutron attenuation and shutdown dose rate

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[1] Passed away before publication.

http://dx.doi.org/10.1016/j.fusengdes.2015.12.010
0920-3796/© 2016 Published by Elsevier B.V.

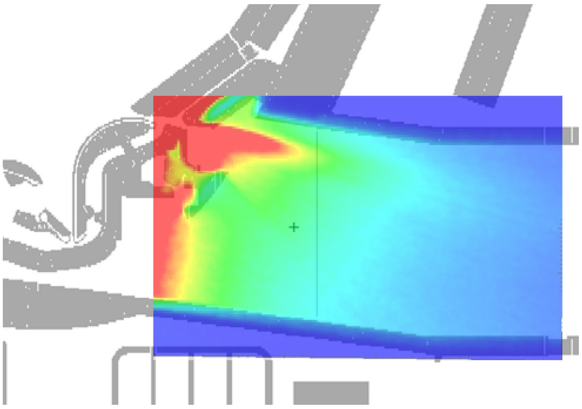

Fig. 1. Neutron flux profile at entrance of TCP-LP with no shielding.

reduction, whilst also considering other engineering constraints such as weight or pumping power.

2. Cryopump lower port

2.1. Shielding options

Earlier studies on this topic focused on gaining an understanding of the physical phenomena of neutron and gamma cross-talk from the TCP-LP to the equatorial ports immediately above, and explored preliminary ideas for neutron shields in the LP and local gamma shields in the EP to mitigate these effects [1,2].

The introduction of shielding material in the LP, in order to reduce the streaming of neutrons along the empty TCP-LPs, interferes with the requirement to maintain pumping capacity by the TCPs. Shielding options for this port are sought that aim at minimizing this interference. Also shielding options closer to the radiation source are preferred, for greater effectiveness. A map of the neutron field at the entrance of the TCP-LP is shown in Fig. 1. Two distinct leakage pathways are identified:

(i) through the gap between the divertor and blanket and between the LP roof and divertor interfaces;
(ii) through the divertor cassette pumping slot.

The current baseline TCP-LP shield for this port is shown in Fig. 2. This steel block, passively cooled in its current configuration, is designed to block neutrons leaking through the first pathway, but coverage is only partial. Shielding options explored as part of this work were based on combinations of three new basic shield concepts, also illustrated in Fig. 2:

(i) *Full front shield*: this is a shield plug fully replicating the vacuum vessel shape at the entrance of the TCP-LP, and provided with a slot in its central lower part to offer pumping capacity to the TCP. Approximate dimensions are 210 cm in height, 120 cm in width, and 50 cm in thickness. The pumping slot is 20 cm in width and 80 cm in height. Reduction in pumping performance of this shield is estimated at >50%.
(ii) *Front shield* (a.k.a. baseline extension): this is a reduced version of the above concept, consisting of the top half of the full front shield, approximately 100 cm in height. This is basically an extended version of the baseline covering entirely the gap between the LP roof and the divertor interfaces. Reduction in TCP pumping performance is estimated at <5%.
(iii) *Lower shield*: this is a block covering the floor of the LP from its entrance for approximately 3 m, provided with a dogleg at its rear end. For engineering feasibility, this shield may be implemented as three independent modules. Reduction in TCP pumping performance of this shield is estimated at ~15%.

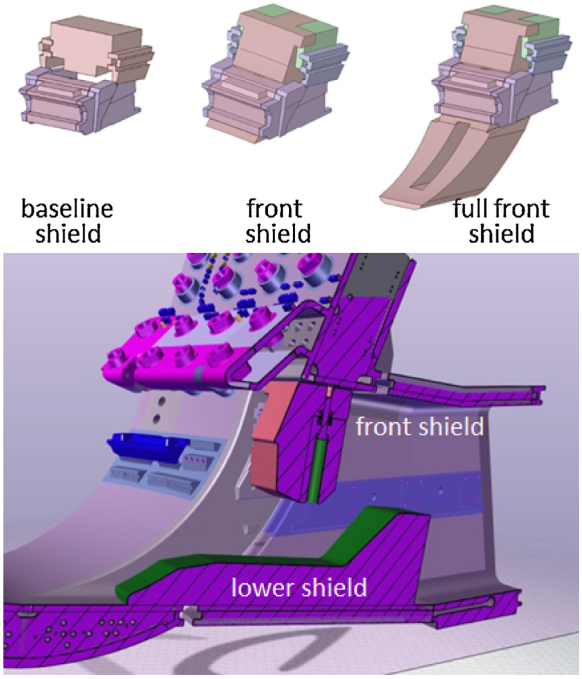

Fig. 2. Illustration of basic shields.

2.2. Shielding analyses and results

MCNP representations of the above shield options were produced either manually or semi-automatically using the MCAM software [3], and integrated into the C-lite reference model. Detailed MCNP representations of the TCP, TCPH (housing), divertor rails and interfaces were included in order to accurately represent the LP environment in the neutronics responses [4].

A series of scoping calculations were performed to investigate the effectiveness of several shielding options [5]. Over 20 different configurations made up of the above three basic shielding options and several material choices were analyzed. Results were obtained and judged in terms of neutron transmission through the lower port, cross-talk to the equatorial port, and flux/heating at neighboring coils. Nuclear heating data for the shields was also produced (Fig. 3).

Neutron transport calculations were performed using MCNP5 v1.60 and FENDL-2.1 nuclear libraries [6,7]. Results of nuclear heating in the shield and reduction of neutron transmission through the LP and heating to the neighboring TFC coils are illustrated in Table 1. Values for cooled (steel and water) and uncooled (steel only) shields are shown.

Water has a beneficial effect in the shielding performance of the front shields thanks to its moderation properties, but this is small in comparison with the large effect of simply blocking the gap through which passage of neutrons occurs. The lower shield provides additional benefits in terms of TFC heating (up to 0.5 kW for the cooled version) and neutron transmission (up to 20%).

3. Remote-handling lower port

3.1. Shielding options

In the RH-LPs there is no interference with pumping requirements. In fact the diagnostics rack, which is already provided

Please cite this article in press as: R. Pampin, et al., Study of shielding options for lower ports for mitigation of neutron environment and shutdown dose inside the ITER cryostat, Fusion Eng. Des. (2015), http://dx.doi.org/10.1016/j.fusengdes.2015.12.010