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Neutronic study of extended DONES irradiation module

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HIGHLIGHTS

- DONES (DEMO Oriented Neutron Source) has been conceived as a simplified of IFMIF.
- Neutron transport calculations were performed to evaluate the irradiation parameters in HFTM zone.
- Neutron fluence rate gradients are lower than 25% in the most volume of HFTM of DONES-IFMIF.
- Enlarge the experimental irradiation volume allows to extend the irradiation experiments to other materials, different of steels.

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ABSTRACT

IFMIF is considered as one of the main pillars in the international fusion program. Its double deuteron beam 125 mA each will produce enough rate of damage behind the lithium target to make available in a few years information on materials damage at DEMO relevant doses. Furthermore the stripping reaction D-Li will produce in Fe-based materials under study a production of He and H similar to those expected in fusion reactor. DONES (DEMO Oriented Neutron Source) has been conceived as a simplified IFMIF-like plant to provide in a reduced time scale and with a reduced budget – both compared to IFMIF- the basic information on materials damage.

In this work, radiation conditions behind the irradiation module, the so-called High Flux Test Module (HFTM), are analyzed with a double objective. First objective is to assess the impact of the second irradiation module on the material irradiation effects in the HFTM due to its potential use as optimization tool for the damage dose and gas production in the specimens. Second objective is to assess on the potential use of that volume for irradiation of additional specimens beyond the HFTM. Then, neutron transport calculations have been performed in order to evaluate the impact on the irradiation effects on the HFTM and to determine the radiation level in the experimental samples of the new module.

1. Introduction

DONES (DEMO Oriented Neutron Source) [1] has been conceived as a simplified IFMIF-like plant [2] to provide in a reduced time scale and with a reduced budget – both compared to IFMIF- the basic information on materials damage. The Conceptual Design of DONES will consist on a number of changes oriented to reduce the time required for construction and the time required to produce the required damage. It will consist of only one accelerator with the same performances as IFMIF (40 MeV and 125 mA). The deuteron beam will impinge on lithium jet with a scale 1:1 of IFMIF in order to produce the neutron source with the appropriate energy spectrum to test materials for DEMO [3]. Out of the planned test modules for IFMIF only the so-called High Flux Test Module (HFTM) would be irradiated containing specimens of those materials with first priority for DEMO design (basically Fe-based material).

The objective of the HFTM of DONES-IFMIF is to test structural materials under similar neutron irradiation nuclear fusion conditions, i.e. trying to reproduce similar damage dose and gas production. For first Wall of DEMO the He and H ratios expected for steels are about 10 He appm/dpa and 40 H appm/dpa [4,5]. Although, these studies have already been done in previous reports [1], the possibility to extend experimental irradiation volume is evaluated in this paper. So do that, a second irradiation modules behind of the HFTM have been placed. This second irradiation module is named in the rest of the paper HFTM2, since, to simplify this study, the design used is a replica of the original HFTM. Therefore, the objective of this paper is, to perform neutron transport calculations in order to evaluate the impact on the irradiation effects on

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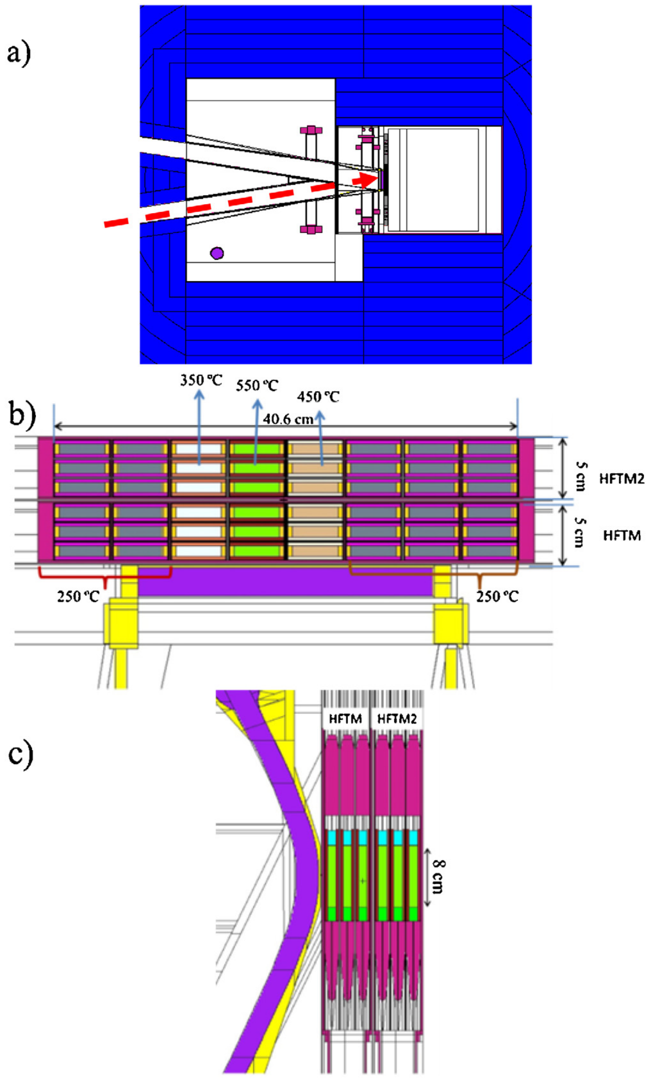

Fig. 1. (a) Horizontal section, in the center of the irradiation area, of DONES Test Cell MCNP geometrical model; (b) horizontal section and (c) vertical section, of both irradiation modules, HFTM and HFTM2.

the HFTM and to determine the radiation level in the new extension of the experimental volume, i.e. in the irradiation module, HFTM2.

2. Methodology

The particle transport code McDeLicious-2011 [6] has been used to perform this study, which was developed by KIT (Germany) enhanced to the MCNP5 code v1.6 [7], in order to simulate the d + ^{6,7}Li IFMIF neutron source [8]. For neutron transport calculations FENDL-3/SLIB release 4 [9] nuclear data libraries was used, though the INPE-FZK [8] nuclear data evaluated libraries have been used for the isotopes ^{6}Li and ^{7}Li [10].

The MCNP geometry model of DONES test cell used was the last version of IFMIF Test Cell model mdl69 [11] but removing all the irradiation modules except the HFTM. Fig. 1a shows the horizontal cross section, in the center of the irradiation area, of DONES Test Cell MCNP geometrical model. The red arrow indicates the direction of the deuteron beam (9°). The blue block surrounding the irradiation area is the concrete shielding of the vessel. In addition, the amplified irradiation area is shown in both figures, Fig. 1b horizontal section and Fig. 1c vertical section, where both the original HFTM and HFTM2 are observed. The lithium jet and the back plate, right behind of the lithium jet are also observed.

Although, the configuration of the specimen containers, named rigs in the IFMIF-literature, could change in DONES respect to the original ones proposed for IFMIF-HFTM [12], in this work, the same type of containers have been used. It provides us a better frame to be able to compare the results obtained with previous calculations. Therefore, each rig contains a Eurofer-97 specimen stack filled with NaK-78 eutectic sodium-potassium alloy, a heater layer with Ni–Cr 80 20 heater wires, MgO insulators, nickel based brazes, an Eurofer capsule, SS316L reflectors and rig hull. Different densities of NaK and different sizes of an insulation gap inside the heater layer according to four designed temperatures were taken into consideration as indicated in Fig. 1 [12]. The considered volume fraction of experimental specimen packaging is 74.19% of EUROFER stainless steel and 25.81% of NaK as it was specified in the HFTM DDD report [13]. The inner volume of each rig is 8 cm × 4 cm × 0.93 cm.

The reference deuteron beam footprint area is 20 cm × 5 cm, however the effect upon the irradiation parameter of several footprint areas has been also considered. The different footprint area considered are 20 cm × 5 cm, 10 cm × 5 cm, 10 cm × 3 cm, and 5 cm × 5 cm.

The mesh-tally used for the neutron transport calculations to determine the radiation effects covers the whole volume of the rigs container of the HFTM. The total dimension of the mesh-tally considered is 40.6 cm × 8 cm × 5 cm, and the minimum cubic bin size is 0.25 cm × 0.25 cm × 0.25 cm. This mesh-tally has been replied for both irradiation modules, HFTM and HFTM2. The response functions considered for this study (damage dose rate, H and He production rate) are obtained by multiplying the neutron flux averaged in each cubic bins by the specific cross section. Once, the response function per emitted particle is obtained, they are integrated for a full-power year. The definition of full-power year (fpy) is a continuous operation for 24 h a day and 365 days with the beam current of 125 mA.

The methodology used to calculate the damage dose rate was the Norget, Robinson Torrens (NRT) model [14], with effective minimum displacement energy E_{Fe} = 40 eV [15], widely used for primary displacement damage dose calculations in steels.

Furthermore, the gradients of the neutron fluence rate have been also evaluated. Low gradients in each individual specimen are important for a correct interpretation of the results. The spatial neutron flux variation should be less than 10% in each individual sample's gage volume [16]. Taking into account that the thickness of the samples is about 2–3 mm, the gradient in the 12 central rigs of the HFTM should be less than 25%/cm. Indeed any value below this reference gradient would be welcome. The gradients are calculated in two different ways: (i) volumetric gradients, in which the gradients around a given point in all the directions are considered, and (ii) perpendicular gradients, in which the gradients in the plane perpendicular to the beam propagation direction are obtained. The first one is relevant to estimate the irradiation conditions between different specimens whereas the second one is relevant to estimate the gradient inside a given specimen (usually they are located in such a way that the volume that will be used for testing is located perpendicular to the beam).

3. Results

First, the neutron fluence rate for the case with a footprint area of 20 cm × 5 cm was evaluated. Neutron fluence rate [n/cm^2 s] mesh-tally horizontal section in the central part of the HFTM is shown in Fig. 2. The geometry of the 24 rigs of each irradiation module is overlapped on the picture. Regarding the first HFTM, in the most area comprised by the 12 central rigs, the neutron fluence rate