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Analysis of activation and damage of ITER material samples expected from DD/DT campaign at JET

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ABSTRACT

Activation inventories, decay heat, contact dose rate and radiation induced damage are important nuclear quantities which need to be assessed on a reliable basis for the safe operation of a fusion nuclear power reactor and its decommissioning. This paper describes the calculations performed in the frame of the EURO*fusion* JET3 programme of the activation and dose rate of materials irradiated in the Inner/Outer Long Term Irradiation Station ((I-O)LTIS) during DD and DTE2 campaigns. In the frame of JET3, samples of real ITER materials used in the manufacturing of several different, mainly in-vessel and vessel, components will be irradiated at JET during DTE2 such as ITER-grade W, Be, CuCrZr, 316L(N), and also functional materials used in diagnostics and heating systems for radiation damage studies. Neutron induced activities and contact dose rates at shutdown are calculated by means of the FISPACT code using the irradiation scenario specified for JET, with the neutron flux densities and spectra provided by the preceding MCNP neutron transport calculation for (I-O)LTIS box.

1. Introduction

The Joint European Torus (JET) is playing an important role in preparing the operations on the future world's largest tokomak, ITER. A new Deuterium-Tritium campaign is proposed at JET in next years (DTE2). The proposed 14 MeV neutron budget for the DTE2 is nearly an order of magnitude higher than any previous DT campaigns (in JET or TFTR) and with this proposed budget, the achievable neutron fluence on the first wall of JET will be up to 10^{20} n/m^2. This fluence is much higher than practically achievable at existing 14 MeV irradiation facility and, also important, it can be obtained in larger volumes thanks to the volume plasma neutron source. The large neutron fluence, as well as the large irradiation surface available at JET will allow to expand the neutron induced activation detection range achievable at existing 14 MeV neutron sources. In order to exploit JET neutrons, samples of real ITER materials used in the manufacturing of the in-vessel and vessel, components will be irradiated at JET during DTE2, as well as functional materials used in diagnostics and heating systems to study the neutron induced activation and the radiation damage respectively.

These materials will be irradiated all along the DT campaign in a Long Term Irradiation Station (LTIS) that will be located inside the JET vessel, at outboard midplane where the maximum neutron fluence will be achieved, and then retrieved after the campaign. In the first case, the Inner Long Term Irradiation Station (I-LTIS), located inside the vessel at the outboard midplane, is already in use for the 2015 DD campaign [1], but it is not favored for DT operations due mainly to tritium contamination of samples, and to the need to use the remote handling for the installation and removal. The I-LTIS consist of a Tungsten Shim, AISI316 Tray Sample Holder and AISI316 Box Sample Holder. Alternatively, as the second case, the Outer Long Term Irradiation Station (O-LTIS) would be located in a closed lower small horizontal port in Octant 7, and the installation/removal of samples does not require the use of in-vessel remote handling system.

The location of O-LTIS in the JET vessel is shown in Fig. 1. The objective of the present work is to calculate the activity, contact

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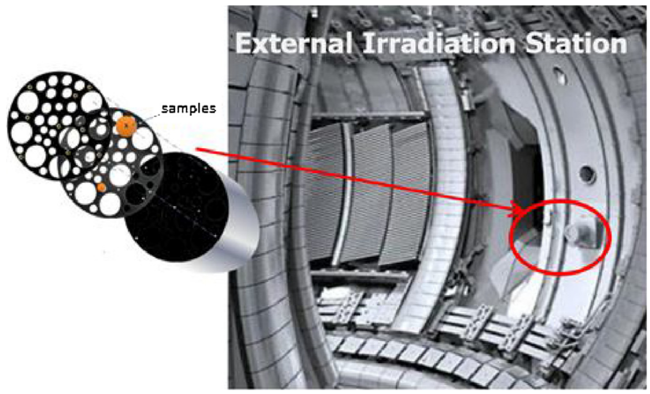

Fig. 1. OLTIS and its position in vacuum vessel.

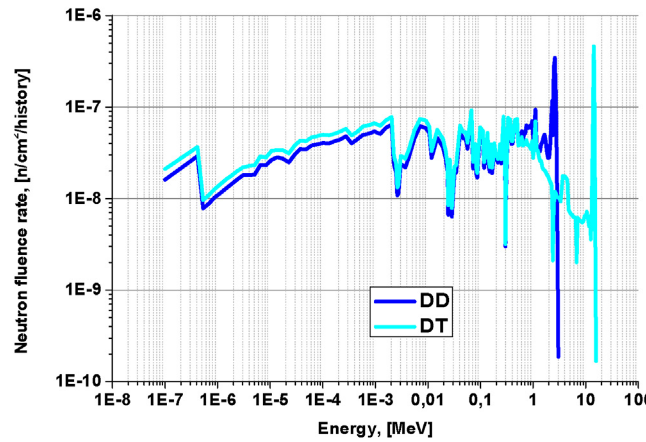

Fig. 2. DD and DT neutron flux at OLTIS box.

Table 1
Selected in-vessel and vessel materials [2].

Component	Material
Vacuum Vessel	SS316L(N)-IG, SS316L
In-wall shield	SS304 (borated), Alloy 660
First Wall	CuCrZr
First Wall	316L(N)-IG
Be armor	Be (S-65C)
Divertor (inner target)	W, OF-Cu, CuCrZr
Divertor (cassette body)	SS316L(N)-IG, XM-19, Al-bronze
Divertor rails	SS316L(N)-IG, Alloy 660
TF coils, PF coils	Nb3Sn, NbTi, 316L, 316L(N),
(I-O)LTS	SS316L, SS316L(N) AISI316(F)
TF coils, PF coils	SS316L(N)
Blanket manifolds	SS316L
Tokamak building	Various concrete formulas
TBM structure	EUROFER

dose rates () and the radiation damage of the samples of ITER structural material and of functional materials at the locations of (I-O)LTIS boxes. We also calculate the activation of station components as resulting from neutron long-term irradiation after a whole DD and DTE2 campaigns.

2. Materials for activation samples

For the calculation of the shim activation, both pure W and W with impurities have been considered (ITER-grade). W has been considered with purity of 99.95%. The typical impurity content assumed for W typical analysis: (ppm) Ca <20, Cu <20, Fe 20, Mg <10, Mo 150, Ni <20, Pb <50, Si <50, Sn <30, Ti <20, C 30, H 6, N 10, O 30.

In the analysis, the list of structural materials given in Table 1 and functional materials in Table 2 has been considered. Material composition is in agreement with the one declared by the supplier, but includes other typical impurities that may be present in W. For the calculation of the activation of the tray and of the box, the same AISI316(F) steel (with main elements: Fe – 65.3%, Ni – 12.0% and Cr – 17.0%) of (I-O)LTIS components used in [2] has been considered, with two different compositions: one derived from literature and the other from [2] with the addition of 0.05% Co and 0.01% Ta (conservative case).

3. Irradiation scenarios

Neutron induced activities and contact dose rates at shutdown are calculated by means of the FISPACT-2010 [3] code with EAF-2010 [4] using the neutron flux densities and spectra provided by the preceding MCNP [5] neutron transport calculation for LTIS box [6]. FISPACT uses approximate estimation of the γ dose rate due to irradiation by neutrons – contact dose from the surface of a semi-infinite slab. These fluxes are shown in Fig. 2 for DD and DT respectively.

This long-term irradiation scenario for DD operation assumes a JET operation over 4 months with a total of $2\,10^{19}$ DD neutrons produced. For the DT operations two scenarios are assumed:

a) one with 6 months of operations with a total of $3 \cdot 10^{20}$ DT neutrons produced (DTa) and
b) one with 6 months of operations with a total of $1.7\,10^{21}$ DT neutrons produced (DTb).

The neutron transport calculation for I-OLTIS was performed with MCNP5 to obtain the neutron fluxes and spectra with the model as illustrated in Fig. 3. The calculated local neutron fluence is $6.3\,10^{-6}$ for DD and $6.23\,10^{-6}$ for DT per source neutron. After the end of irradiation, the activities and dose rates are calculated at the cooling time of 0 and 1 s, 1 h, 1 day, 1 week, 1 month, 1 year.

Table 2
Calculated specific activity and contact dose rates for selected ITER functional materials [see Ref. 10 for details] in case of DTb neutron flux and main contributing nuclide.

Material	Activity		Doserates		main
	1 month	1 year	1 month	1 year	cont.
Sapphire (Al2O3)	<1 Bq/g	<1 Bq/g	–	–	C-14
YAG	~12 kBq/g	~0.5 Bq/g	<0.4 nSv/h	–	Y-90C-14
ZnS	~5 MBq/g	<2 MBq/g	<0.8 Sv/h	~0.3 Sv/h	Zn-65
Spinel	<0.7 Bq/g	<0.7 Bq/g	–	–	C-14
KUI1	~88 kBq/g	~81 kBq/g	~56 µSv/h	<0.5 µSv/h	H-3
KS-4V	~139 kBq/g	~127 kBq/g	~ 46 µSv/h	~0.2 µSv/h	H-3
ALON $Al_{22}O_{30}N_2$	~591 Bq/g	~591 Bq/g	–	–	O–19
ALON-23 $Al_{23}O_{28}N_5$	~1429 Bq/g	~1429 Bq/g	–	–	O–19

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