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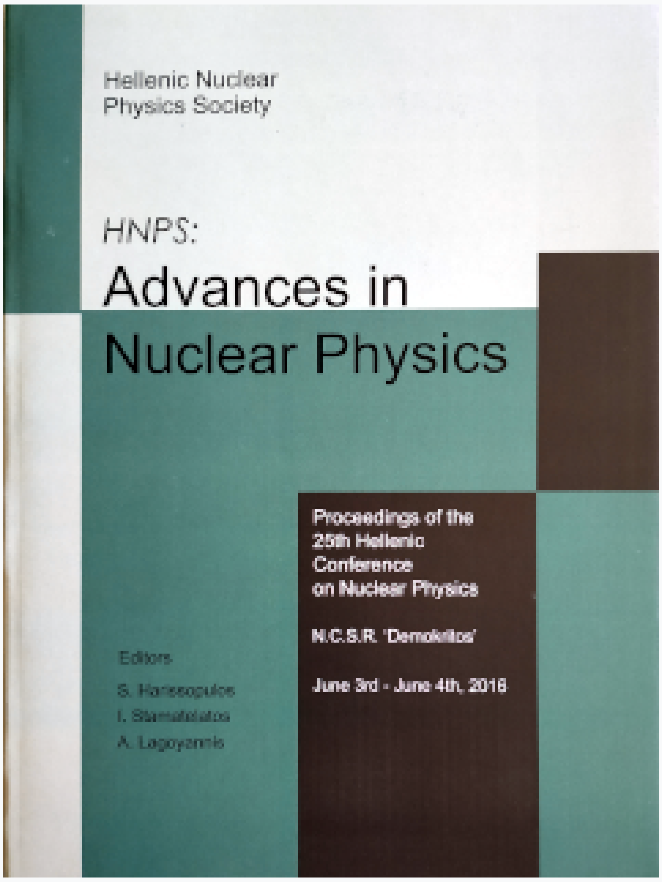

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Preparation of activation experiments for ITER material characterization and data validation in the Deuterium–Tritium JET campaign

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***See the appendix of Romanelli F. et al, 2014, Proc. 25th IAEA Fusion Energy Conference 2014, St. Petersburg, Russia*

Abstract The levels of induced activity in samples of ITER materials and dosimetry foils to be irradiated during the planned JET campaign with deuterium-tritium (D-T) plasma were predicted. Calculations were performed for the neutron energy spectrum of the JET internal Long Term Irradiation Station (LTIS). The European Activation System (EASY-II) and the EAF-2010 nuclear data library were used in order to estimate specific activity and dose rates as a function of time after the end of irradiation. The results of the study provide important data for comparison against activation measurements and support the planning of the irradiation, measurement and radiation protection procedures to be implemented in the planned JET activation experiment.

Keywords fusion, ITER materials, activation analysis, EASY-II

INTRODUCTION

The Joint European Torus (JET) is the largest operating fusion device and its scientific program is devoted to supporting the preparation of ITER operation. Within the framework of the EUROfusion programme, several technology projects are being carried out in conjunction with the planned Deuterium–Tritium (D-T) plasma source experiment on JET. In this context, samples of ITER materials used in the manufacturing of the main in vessel components but also functional materials used in diagnostics and heating systems will be irradiated at JET in order to study, among other parameters, their activation properties. The measured neutron induced activities will be compared against calculation predictions based on state-of-art codes and nuclear data used in ITER nuclear analyses.

Aim of the present work was the analysis of the neutron activation experiments to be performed at the planned JET D-T campaign for characterization of ITER materials, and, in

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particular, the prediction of induced activity and dose rate for sample irradiations at the JET Inner Long Term Irradiation Station (LTIS).

The results of the study provide important data for comparison against activation measurements and support the planning of the irradiation, measurement and radiation protection procedures to be implemented in the experimental campaign.

METHOD

Simulations

The activation calculations were performed using the inventory code FISPACT-II, part of the European Activation System (EASY-II) [1], in conjunction with the EAF-2010 [2] nuclear data library. EASY-II is an international standard code for simulation of activation and transmutation processes caused by nuclear reactions and decays. EASY-II is developed and maintained by the United Kingdom Atomic Energy Authority (UKAEA).

All samples were assumed to be positioned in the LTIS, which is located inside the JET vacuum vessel [3]. The neutron field at the LTIS position has been characterized using a detailed MCNP model of the JET tokamak. The predicted total neutron fluence at the LTIS position during the D-T campaign was 1.06×10^{16} cm^{-2} for a time period of 4 months (120 d). In the present study, the D-T neutron spectrum was used as input in the FISPACT-II calculations assuming a continuous irradiation scheme with a time averaged neutron fluence rate of 1.02×10^{9} $cm^{-2}\cdot s^{-1}$.

Calculations were performed for material sample mass of 1g. The specific activity (Bq/g), dose rate at 1 m distance from 1 g of material (Sv/h) and heating output (kW/g) were calculated for cooling times ranging from 1 d to 600 d.

Materials

The ITER materials considered in this study included both structural and functional components. In particular, 23 materials to be used in the Vacuum Vessel, In-wall shield, First Wall, Divertor and Toroidal Field Coils of ITER were studied. Their composition was taken either from elemental composition certificates provided by the manufacturers or from the available literature for ITER materials [4]. In addition, analysis was performed for a set of dosimetry foils to be irradiated together with the ITER samples for monitoring of the neutron fluence. The foils considered and their characteristics are given in Table 1.

The selection of materials was based on certain requirements. The first one was to obtain fluence measurements over a wide range of neutron energies extending from thermal to fast. The other criteria were their long half-lives since they will be retrieved for measurement several months after the end of irradiation and their properties (i.e. melting point) since they will be exposed to a high neutron fluence under extreme plasma environment conditions within the JET vessel. All foils were assumed to be discs of 18 mm in diameter and 1 mm in thickness.

Foil	Nuclear reaction	Half-life (d)	Target isotopic abund. (%)	Neutron thresh. (MeV)	Photon energy (keV)	Melting point (^oC)	Density (g/cm^3)
Ti	$^{46}Ti(n,p)^{46}Sc$	83.8	8.25	3.8	889	1660	4.5
Mn	$^{55}Mn(n,2n)^{54}Mn$	312.12	100	10.5	834.8	1245	7.2
Co	$^{59}Co(n,2n)^{58}Co$	70.86	100	10.7	810.8	1495	8.9
Ni	$^{60}Ni(n,p)^{60}Co$	1925.28	26.22	5	1332.5	1453	8.9
Y	$^{89}Y(n,2n)^{88}Y$	106.63	100	11.6	898	1523	4.48
Fe	$^{54}Fe(n,p)^{54}Mn$	312.12	5.84	1.8	834.8	1535	7.86
Ni	$^{58}Ni(n,p)^{58}Co$	70.86	68.08	1.5	810.8	1453	8.9
Co	$^{59}Co(n,\gamma)^{60}Co$	1925.28	100	-	1332.5	1495	8.9
Sc	$^{45}Sc(n,\gamma)^{46}Sc$	83.8	100	-	889	1539	2.5
Fe	$^{58}Fe(n,\gamma)^{59}Fe$	44.5	0.28	-	1099.3	1535	7.86
Ta	$^{181}Ta(n,\gamma)^{182}Ta$	115	99.99	-	1121.3	2996	16.6

Table 1. Foils**,** nuclear reactions used for neutron dosimetry and their characteristics

RESULTS AND DISCUSSION

ITER materials

In Fig.1 the specific activity is plotted as a function of time post irradiation for the Vacuum Vessel (VV), In Wall Shield (IWS), Toroidal Field Coils (TFC) and Divertor (D) materials. The dominant radionuclides at each time interval are also shown. As it can be seen (Fig. 1a), a similar activity decay pattern is observed for all VV steels, attributed to their similar elemental composition. It is noted that the dominant nuclide ^{55}Fe is a beta emitter and therefore does not directly contribute to the gamma dose. Moreover, IWS borated steels SS304b4 & SS304b7 present similar activity patterns due to their similar compositions as compared to the composition of S660 steel and in particular its different boron concentration (Fig.1b). On the other hand, significantly different activity decay patterns are observed for the TFC and Divertor materials (Figs. 1c & 1d) due to the differences in their elemental compositions. As it can be seen (Fig. 1c), Nb3Sn material presents the higher specific activity among the TFC materials. The Nb3Sn specific activity is dominated by ^{182}Ta, produced by the $^{181}Ta(n,\gamma)^{182}Ta$ reaction. It is stressed that ^{182}Ta disintegration results in emission of several gamma lines and therefore the gamma dose rate per mass is also significantly higher as compared to the other TFC materials.

Fig. 2 shows the dose rate per g at 1 m distance as a function of time post irradiation for the three materials with the higher dose rates among the materials examined. The higher dose rate calculated for material Nb3Sn, as compared to SS316LN and W, is attributed to its different composition and in particular to the high level of Ta resulting in significant ^{182}Ta production.

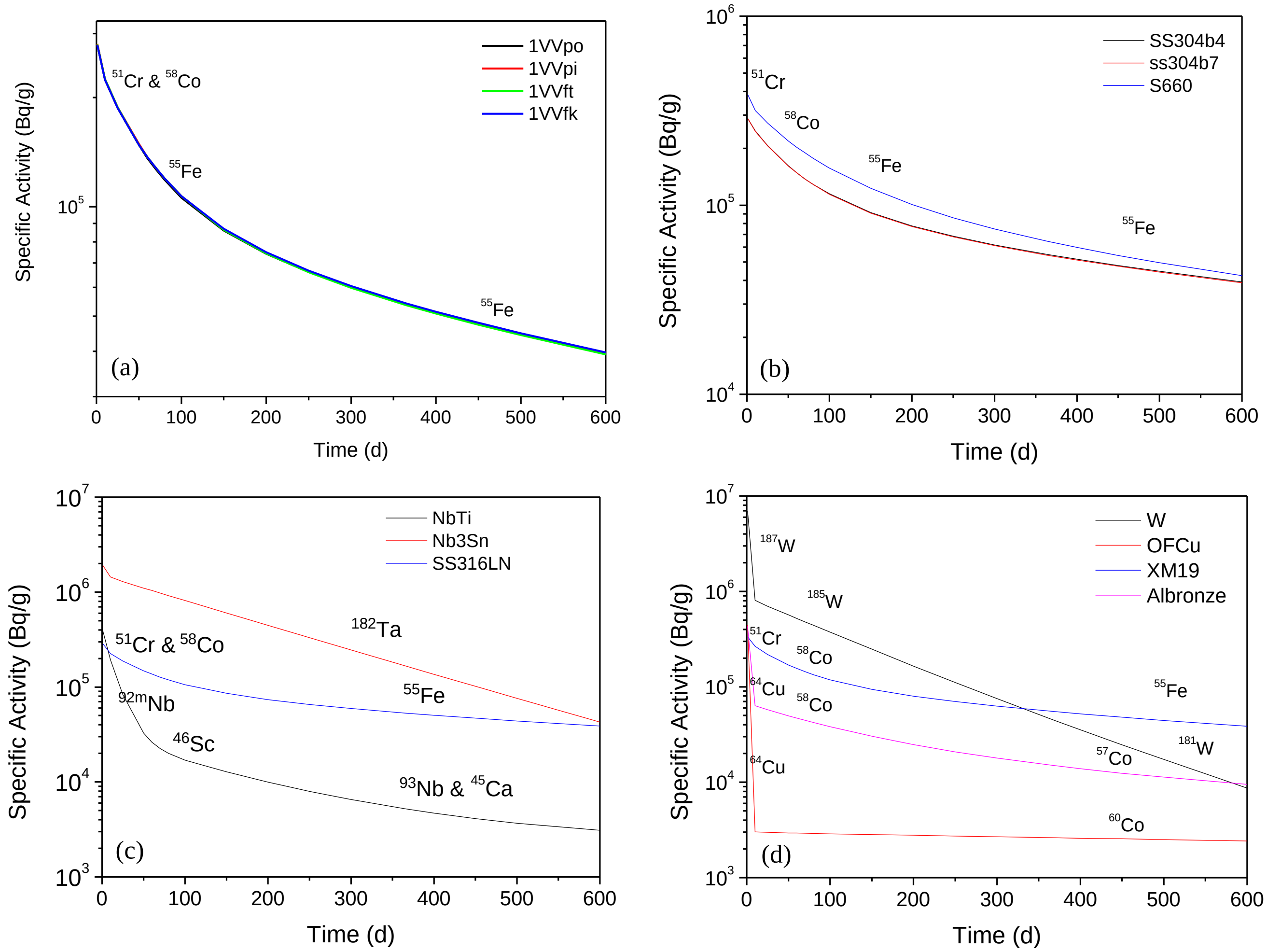

Fig. 1. Specific activity as a function of time after the end of irradiation and major radionuclides for the (a) VV (b) IWS (c) TFC and (d) Divertor materials

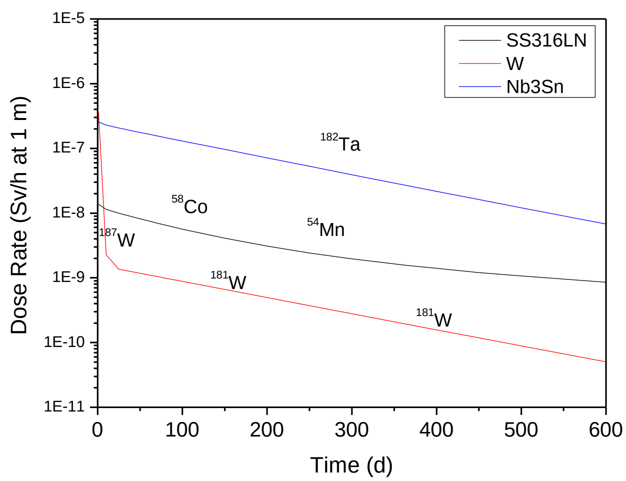

Fig. 2. Dose rate at 1m distance as a function of time post irradiation for three indicative materials

Dosimetry foils

Figs. 3a & 3b show the calculated specific activity (Bq/g) for the radionuclides produced by fast neutron threshold reactions ((n,p) or (n,2n)) and radiative neutron capture reactions (n,γ), respectively, as a function of time after the end of irradiation. As it can be observed, in the case of the neutron threshold reactions, at the end of irradiation the highest activity was obtained in the Co foil by the ^{59}Co(n,2n)^{58}Co reaction. In the case of neutron capture reactions, the highest activity at the end of irradiation was observed in the Ta foil from the ^{181}Ta(n,γ)^{182}Ta reaction, followed by the Sc foil from the ^{45}Sc(n,γ)^{46}Sc reaction.

Fig. 4 shows the calculated dose rate at 1 m distance from the dosimetry foil as a function of time after the end of irradiation. At the end of irradiation the highest dose rate corresponds to the Ta foil. However, 550 days post irradiation the highest dose rate is the one of the Co foil. It is stressed that 150 d and 600 d post-irradiation the dose rate at 1 m from all the foils studied was found to be less than 10 μSv/h and 1 μSv/h, respectively.

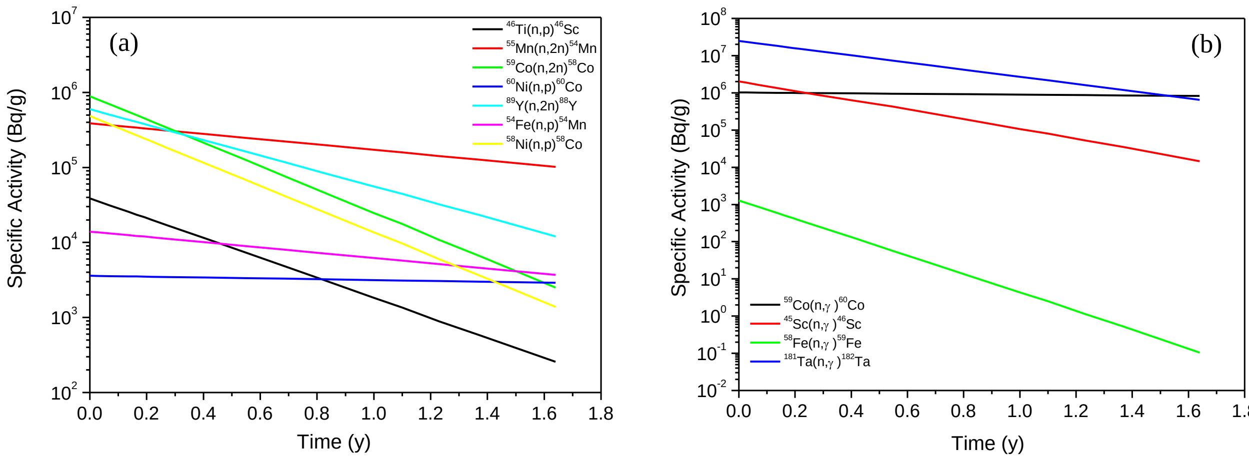

Fig. 3. Specific activity with time after the end of irradiation for the radionuclides produced by (a) threshold and (b) neutron capture reactions in the dosimetry foils

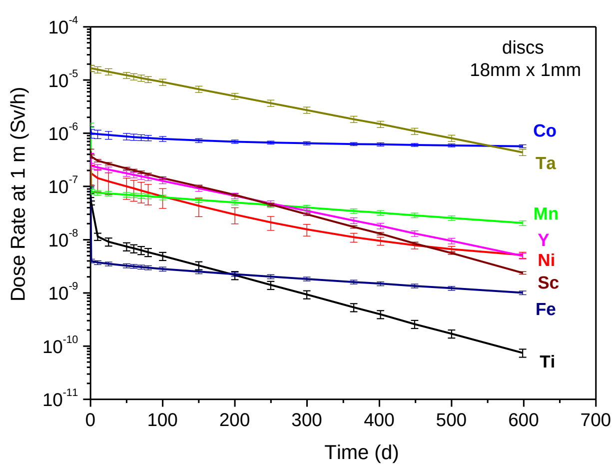

Fig. 4. Dose rate at 1 m distance as a function of time after the end of irradiation for the foils studied

CONCLUSIONS

The structural and functional materials used at ITER need to satisfy a range of requirements. The mechanical properties must be maintained in an environment of a high radiation field, including neutrons with energies up to 14 MeV, mechanical, electro-mechanical and thermal stresses and an intense flux of charged particles, photons and other radiation. Also, neutron activation of the structure can lead to medium-term radiation which could complicate the handling of components in maintenance or decommissioning operations, and to long-term activation which could require special treatment, storage or disposal as waste at end of the plant life [5].

In the present work, the levels of induced activity and gamma dose rates in samples of ITER materials and dosimetry foils to be irradiated during the JET scientific campaign with D-T plasma were evaluated. Regarding the ITER materials, the higher gamma dose rates were observed in the cases of Nb3Sn, SS316LN and W materials. However, the calculated dose rates were low enough to enable post-irradiation handling of the activated samples. Moreover, calculations confirmed the possibility of measuring reactions from trace elements or impurities in some of the materials. Therefore, the detailed knowledge of the composition and in particular of the impurity levels of the ITER materials is of outmost importance for a successful irradiation campaign. The calculations for the dosimetry foils indicated that manageable activities and dose rates are expected to be acquired after irradiation. Nevertheless, further consideration is needed on Ta and Co foils, which present the highest activities and dose rates.

The results of the calculations will be compared against measurements during the D-T campaign, enabling the first ever C/E comparison of real ITER materials irradiated in a realistic neutron spectrum to be performed.

ACKNOWLEDGMENTS

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