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Activation foil measurements at JET in preparation for D-T plasma operation

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Neutronics experiments are carried out at the Joint European Torus (JET) in preparation for the forthcoming high performance Deuterium-Tritium (D-T) campaign. Among others, activation foil measurements are performed in order to evaluate neutron streaming in various positions within the torus hall far from the plasma source. In the present study, the neutron fluence measurements performed using activation foils during the JET Deuterium-Deuterium (D-D) campaign are discussed. The activation foil results are compared against thermoluminescence measurements and Monte Carlo simulations and a satisfactory agreement is observed. Moreover, the pre-analysis of the experiments to be performed in the forthcoming JET Tritium-Tritium (T-T) and Deuterium-Tritium (D-T) campaigns is presented. The results of the study provide important data and support the preparation of the experimental activities in view of the planned JET D-T operation, allowing the exploitation of the unique 14 MeV neutron yields anticipated. Furthermore, they contribute to the validation of the tools employed in nuclear analyses, which are fundamental for the design and safety of ITER and future fusion power plants.

Keywords: Joint European Torus, fusion, neutron fluence measurements, neutron activation

1. Introduction

In the frame of the Joint European Torus (JET) technology program, experiments are planned in order to exploit the high performance JET Deuterium-Tritium (D-T) campaign scheduled for 2020. Aim of the experiments is to validate the neutronics codes and tools used in ITER, therefore reducing the related uncertainties and the associated risks in the machine operation [1].

Accurate measurement of neutron fluence in the device and in the surrounding areas is a crucial aspect with respect to code validation for shielding design, radiation protection and safety assessment. Among other experimental methods, the foil activation technique is used at JET to evaluate neutron streaming in regions far from the plasma source and along large shielding penetrations as well as to provide estimate of the neutron spectra to complement shutdown dose rate measurements [2].

In the present study, the neutron fluence measurements performed using activation foils during the implemented JET Deuterium-Deuterium (D-D) campaign are discussed. The activation foil results are compared against thermoluminescence measurements and Monte Carlo simulations. Furthermore, the pre-analysis of the activation foil experiments to be performed in the forthcoming JET Tritium-Tritium (T-T) and Deuterium-Tritium (D-T) campaigns is presented.

2. Experimental

Measurements were carried out during the JET 2015-2016 D-D campaign, which lasted 82 days. During this period, a total budget of 3.5×10^{18} neutrons was produced at the source. Activation foil measurements were performed using sets of high purity cobalt, silver and tantalum foils, which were placed at the centre of large polyethylene (PE) cylinders (Fig. 1). The PE assemblies were positioned at the South West entrance labyrinth (positions A2 & A4) and at the South East chimney area (positions B2 & B3) of the torus hall (Fig. 2).

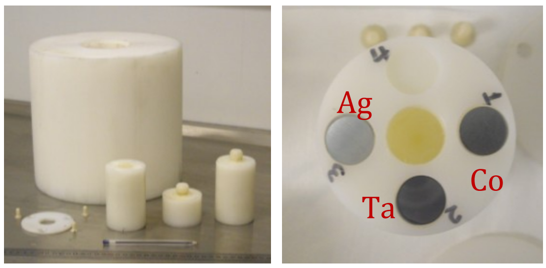

Fig. 1. Polyethylene assembly with activation foils.

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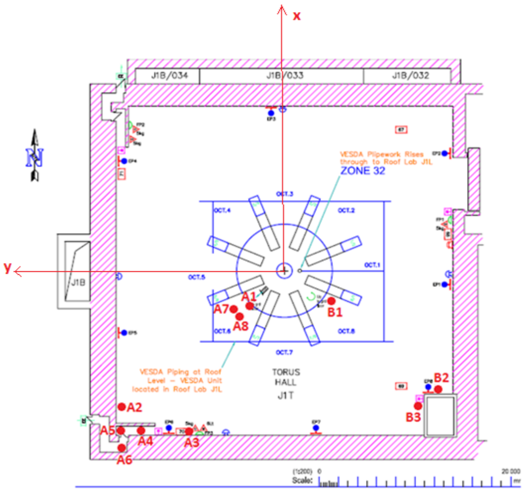

Fig. 2. Experimental positions in the JET Hall.

In addition to the activation foil experiments, thermoluminescence measurements were performed by the Institute of Nuclear Physics of the Polish Academy of Sciences using highly sensitive MCP-N and MCP-7 thermoluminescence detectors (TLDs). TLDs were also placed within PE cylinders which were located close to the ones containing activation foils. More details on the experimental procedure and the analysis of TLDs can be found elsewhere [2, 3].

3. Calculations

Neutron fluence and activity calculations were performed using Monte Carlo code MCNP6 [4] and neutron activation inventory code FISPACT-II [5], respectively. A detailed MCNP model of the studied geometry, including the JET building, penetrations and the PE assemblies, was used for the calculations of neutron transport in the South West labyrinth and South East chimney areas [6]. Neutron fluence was calculated at the centre of each PE moderator using the VITAMIN-J 175 energy group structure. Subsequently, the MCNP output -namely the calculated neutron fluence at the centre of each PE moderator- was fed into FISPACT-II in order to assess the activity induced in each foil.

Calculations were performed for D-D, T-T and D-T plasma sources, assuming a total neutron production of 3.5×10^{18}, 5.0×10^{19} and 1.7×10^{21} neutrons, respectively. These values represent the total neutron yield produced during the 2015-2016 D-D campaign as well as the neutron yields that are expected to be produced during the planned JET T-T and D-T experimental campaigns. The expected duration of the T-T campaign is 90 days while that of the D-T is 120 days. For the purposes of the pre-analysis study, the neutron production at the plasma source was assumed to be constant over each irradiation period, namely a neutron fluence rate of 6.5×10^{12} cm^{-2} s^{-1} and 1.6×10^{14} cm^{-2} s^{-1} was considered for the T-T and D-T source, respectively.

4. Results and Discussion

4.1 Validation of calculations against measurements for the D-D plasma source

Figure 3 shows the experimentally determined neutron fluence as derived from activation foils and TLDs, as well as the MCNP calculated values for the JET positions studied in the case of the D-D plasma source. It is noted that the values presented in Fig. 3 are normalized per source neutron, using the number of neutrons emitted from the source. It is stressed that no meaningful counts were obtained from the silver foils, since the achieved neutron fluence in the D-D campaign was relatively low, thus the respective results were not included in Fig. 3. Moreover, due to a displacement of foils within the PE cylinder located at position B2, no foil results have been produced for this position.

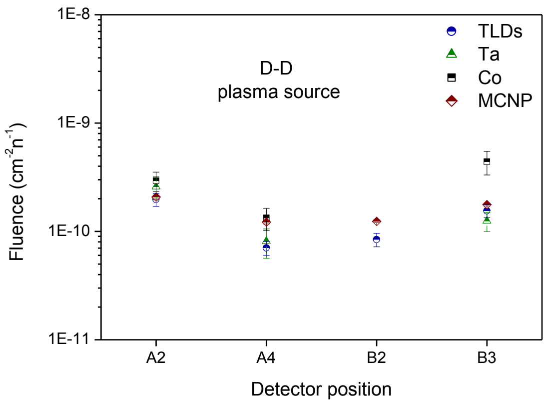

Fig. 3. Experimental and calculated neutron fluence for the detector positions studied for the D-D source (normalization per source neutron).

As it can be seen, the calculated neutron fluence values are in agreement with the experimental results obtained using activation foils and TLDs. The only exception is the cobalt foil in position B3. Nevertheless, the agreement is considered satisfactory, taken into account the overall complexity of the studied geometry and the limitations of the respective MCNP model [7, 8].

4.2 Pre-analysis of the T-T and D-T plasma operations

The MCNP calculated neutron energy spectra at selected JET hall positions are shown in Figs. 4a & 4b, for the T-T and the D-T plasma sources, respectively. As it can be seen, the spectral shapes calculated at the centre of the PE assemblies are similar due to the moderation of neutrons within the PE cylinder.

Furthermore, Table 1 shows the MCNP estimated neutron fluence rates at the centre of the PE cylinders which were subsequently used for the activity predictions. The uncertainties given in parentheses are the percent relative errors of the Monte Carlo computations.

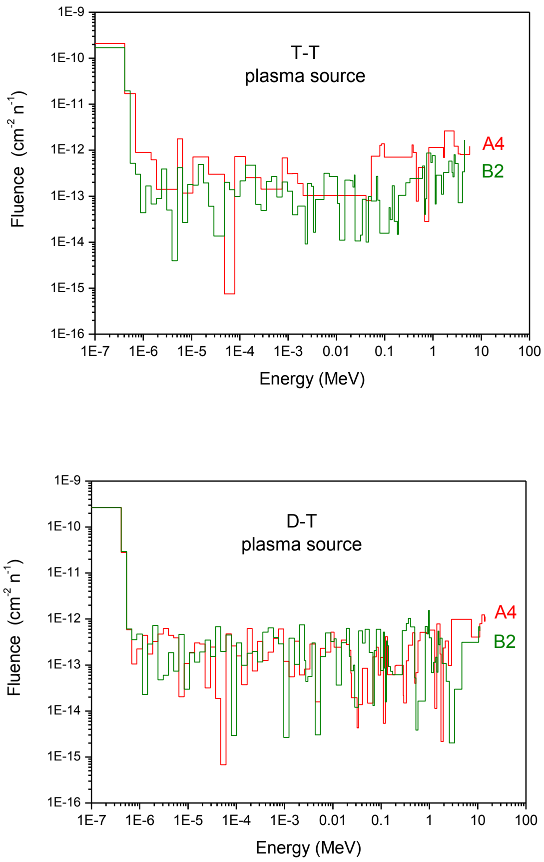

Fig. 4. MCNP predicted neutron fluence for the T-T & D-T plasma sources (normalization per source neutron).

Table 1. MCNP predicted fluence rate for the positions studied

JET hall area	Position	Fluence rate (cm^{-2} n^{-1} s^{-1})	
		T-T	D-T
South West	A2	2.7E+03 (10.7)	9.6E+04 (6.9)
	A4	1.6E+03 (13.3)	5.2E+04 (7.8)
South East	B2	1.3E+03 (7.0)	5.3E+04 (9.9)
	B3	3.7E+02 (12.9)	1.3E+04 (14.1)

The FISPACT predicted specific activities per foil as a function of cooling time for the selected irradiation positions are shown in Figures 5 & 6, for the T-T and the D-T plasma sources, respectively.

It is noted that the uncertainties plotted in these figures are the ones related to the MCNP simulations and the propagation of errors along the subsequent FISPACT calculations.

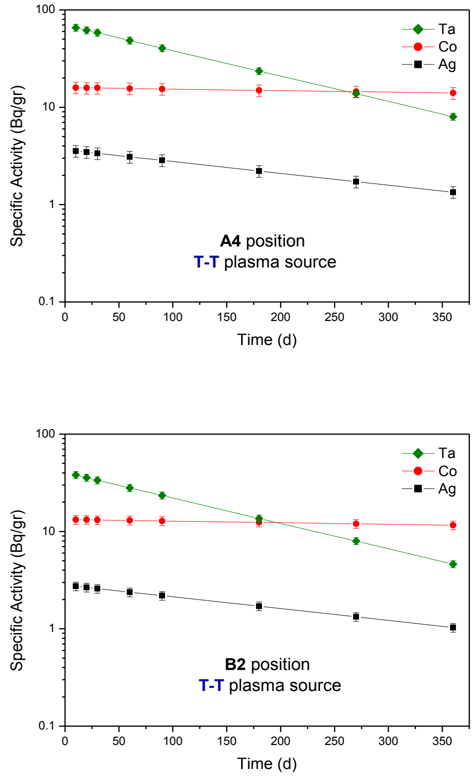

Fig. 5 Predicted specific activity per foil in PE as a function of cooling time for the T-T plasma source.

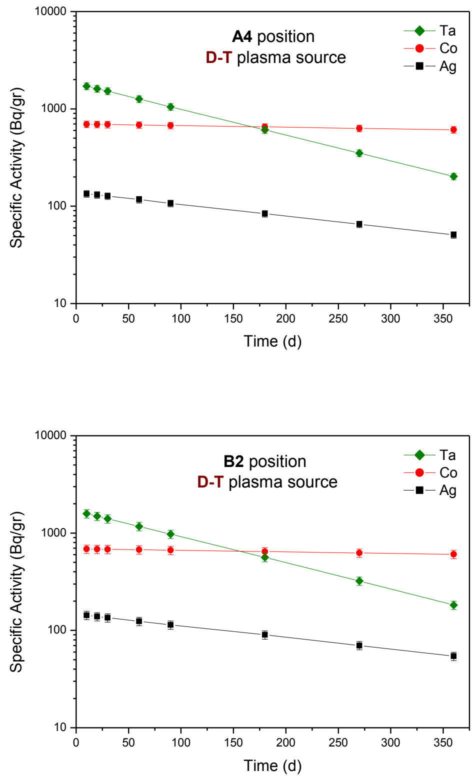

Fig. 6 Predicted specific activity per foil in PE as a function of cooling time for the D-T plasma source.

As observed in Figures 5 & 6, for both T-T and D-T sources and for all examined positions, the higher specific activity was obtained by the tantalum foil. This result can be attributed to the higher thermal neutron cross-section of tantalum as compared to the ones of cobalt and silver, taking into account that neutrons are moderated by elastic interactions with the hydrogen atoms in the PE material. Moreover, in the case of the D-T plasma source the levels of predicted specific activity are much higher than those calculated for the T-T source for all foils studied. This is due to the significantly higher neutron yields expected during the D-T campaign as compared to those of the T-T operation (i.e. higher total neutron production during a longer irradiation period, higher fluence rate at the source and therefore at the irradiation positions).

5. Conclusions

The results of the present work confirm that foil activation is able to provide an unbiased and robust benchmarking tool for evaluation of neutron streaming in JET and other fusion devices.

As shown in the case of the D-D plasma operation, the foil activation technique enables the accurate monitoring of neutron fluence at positions far from the tokamak and along shielding penetrations. The satisfactory agreement observed among experimental and calculated values provides confidence on the computational tools and the respective assumptions employed in fusion studies. Furthermore, the results of the pre-analysis demonstrate the feasibility of performing high quality neutron flux measurements using activation foils during the forthcoming JET T-T and D-T experimental campaigns.

Therefore, activation foils may provide important data for the verification of experimental methodologies and calculations, allowing the exploitation of the unique neutron yields anticipated which is essential for the design of ITER and future fusion power plants.

Acknowledgments

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