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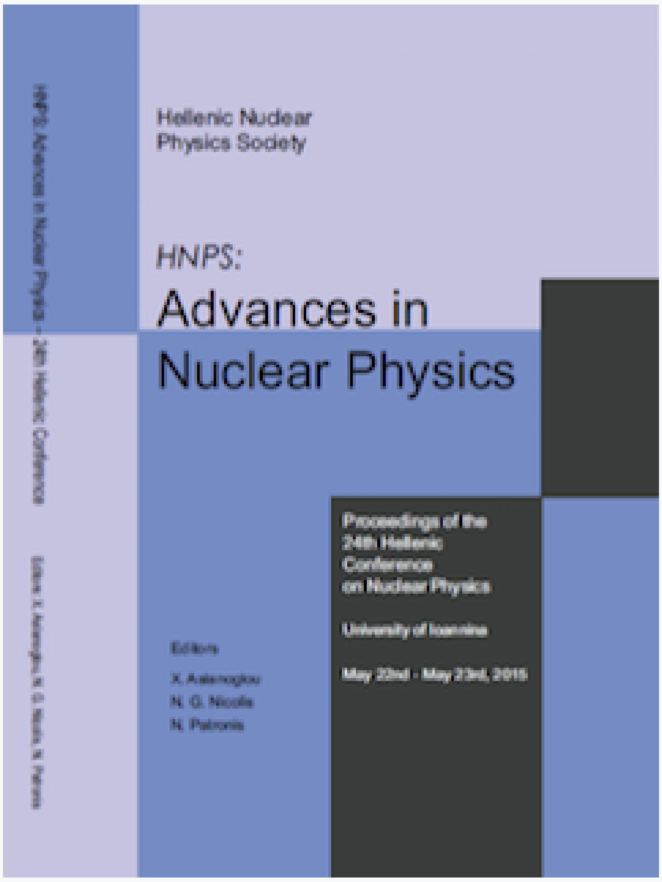

Preanalysis of Neutron Activation Measurements in Shielding Penetrations at JET

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Preanalysis of Neutron Activation Measurements in Shielding Penetrations at JET

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Abstract In the present work, the preanalysis of activation foil experiments to determine neutron fluence rates along JET hall ducts and labyrinths is discussed. Simulations were performed using computational codes MCNPX and FISPACT-II and a detailed model of the JET hall, including the tokamak, biological shield and penetrations. The induced activity and detector count rate were predicted for activation foils placed at selected positions within the JET hall for Deuterium-Deuterium and Deuterium-Tritium JET plasma sources. The results of the calculations showed that satisfactory counting statistics can be obtained with the use of activation detectors and therefore activation analysis offers an unbiased and robust cross-benchmarking tool for comparison against other experimental and computation techniques applied in neutron streaming studies at JET.

Keywords Activation detectors, MCNP, FISPACT, Fusion technology, JET

INTRODUCTION

The Joint European Torus (JET) is currently the largest operating tokamak serving as the main test-bed for fusion plant design and technology development [1]. Among other activities, thermoluminescence measurements and Monte Carlo calculations have been performed in order to evaluate neutron fluence levels in the JET Hall as well as to assess in a real fusion environment the capability of numerical tools to accurately predict neutron transport along long paths and complex shielding geometries [2, 3]. Moreover, neutron activation measurements are planned in the forthcoming JET experimental campaigns. Since the response of activation detectors depends only on nuclear parameters, measurements using activation detectors provide a robust and unbiased technique for neutron fluence determination in a wide range of neutron energies, mixed neutron and gamma ray fields and in complex configurations such as those encountered in a fusion device [4].

In the present work, the computational analysis demonstrating the feasibility of an activation foil experiment for neutron streaming evaluation along labyrinths and ducts in the JET shielding configuration is discussed. Advanced prognosis of the induced activity in selected activation foils was performed for various positions within the JET Hall. The activation foil experiment will provide benchmarking data for comparison against simulations and thermoluminescence measurements. Furthermore, it will contribute towards the verification of the computational codes and data used for the radiation shielding design of the future fusion devices ITER and DEMO.

METHOD

Neutron fluence and activity calculations were performed using computational codes MCNP6 [5] and FISPACT-II [6], respectively. Detectors were positioned at the SW entrance labyrinth (A2, A4) and at the SE chimney area (B2, B3) of the torus hall (Fig. 1). A two-stage simulation approach was employed. In the first stage, a detailed model of the JET torus was used to produce two surface neutron sources. The Surface Source Write (SSW) files registered neutrons on two surfaces: a quarter sphere of 5.0 m in radius centered at the SW hall corner and an orthogonal box surrounding the chimney in the SE hall corner. Subsequently, the SSW files were used as Surface Source Read (SSR) input files for the calculations of neutron transport in the SW labyrinth and SE chimney areas.

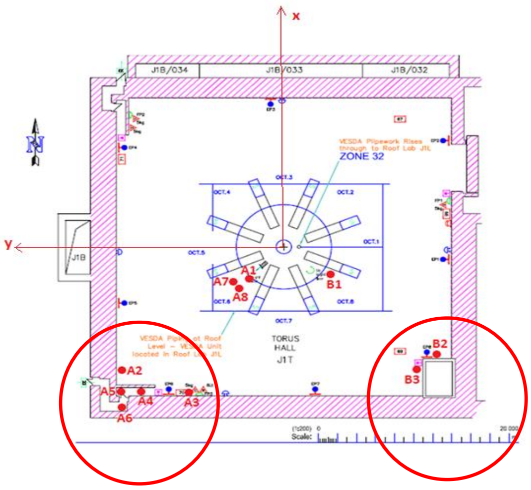

Fig. 1 Experimental positions in the JET Torus Hall area

Sets of activation foils were assumed to be placed within suitable aluminum holders and in polyethylene (PE) moderators. The PE assembly and the aluminum holder are shown in Figs. 2a & 2b, respectively. Neutron fluence was calculated at the detector position within the aluminum holders and at the centre of the PE moderators. Activity calculations were performed using the European Activation File (EAF) library data [7]. Neutron activation inventory code FISPACT-II was used to calculate the activity induced in each foil. Given the fact that the detectors will be accessed and measured several days after the end of the JET irradiation campaign, only isotopes with decay half-times of more than 60 days were considered. Foil materials, nuclear reactions, target isotopic abundances, product nuclide half-lives, gamma ray energies and gamma branching per disintegration are shown in Table 1. All foils were assumed to be discs of 15 mm in diameter and 0.5 mm in thickness.

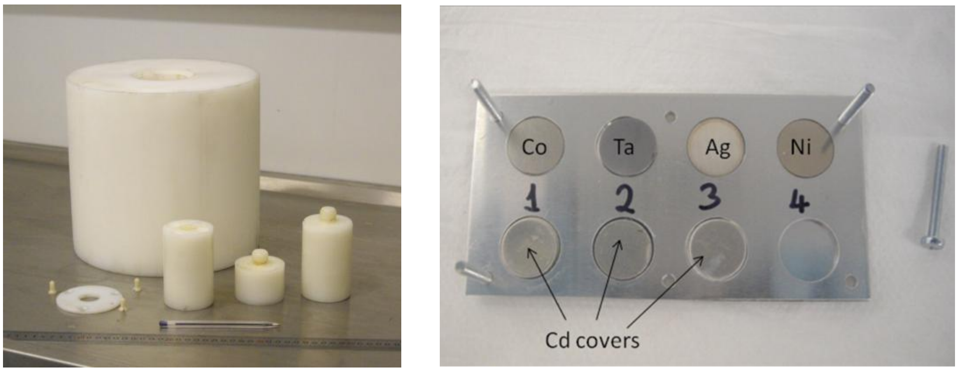

Fig. 2 (a) Polyethylene moderator assembly (b) Aluminum foil holder

Foil	Density ($g \cdot cm^{-3}$)	Reaction	Target Isotopic Abundance (%)	Product Half-life	Gamma Energy (keV)	Gammas per decay (%)	Photo-peak Efficiency
Co	8.9	$^{59}Co(n,\gamma)\,^{60}Co$	100	5.3 y	1332.5	100.0	0.025
Sc	2.9	$^{45}Sc(n,\gamma)\,^{46}Sc$	100	83.8 d	1120.5	95.5	0.030
Ni	8.9	$^{58}Ni(n,p)\,^{58}Co$	68.077	72 d	810.8	99.4	0.045
Ag	10.5	$^{109}Ag(n,\gamma)\,^{110m}Ag$	48.161	249.8 d	657.8	94.7	0.056
Ta	16.6	$^{181}Ta(n,\gamma)\,^{182}Ta$	99.988	115 d	1121.3	35.0	0.030

Table 1 Foil characteristics

Calculations were performed for a total neutron production of 9.9×10^{18} neutrons and 1.7×10^{21} neutrons representing the total neutron yield which is expected to be produced during the planned JET D-D and D-T experimental campaigns, respectively. For the purposes of the present study, the neutron production at the plasma source was assumed to be constant over the irradiation period. Activity rates were calculated using FISPACT-II for decay times of 10, 20, 30, 60, 90, 180, 270 and 360 days.

RESULTS AND DISCUSSION

The FISPACT calculated specific activities per foil as a function of cooling time for the D-D source are shown in Figs 3 & 4, for foils within aluminum holders and in PE, respectively. The FISPACT calculated specific activities per foil as a function of cooling time for the D-T source are shown in Figs 5 & 6, for foils within aluminum holders and in PE, respectively.

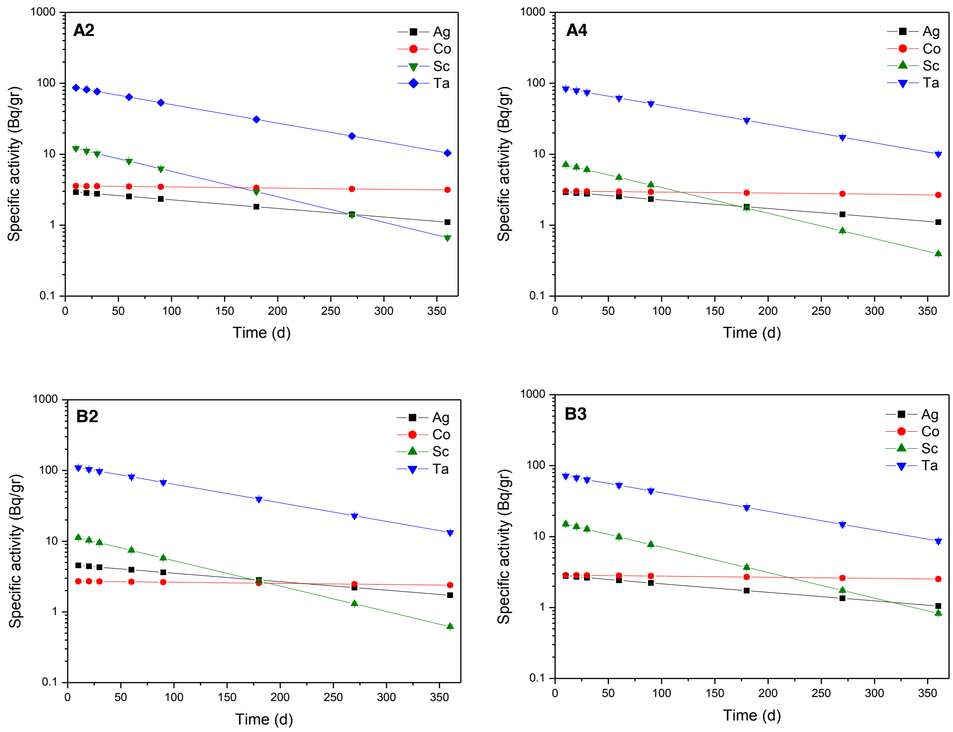

Fig. 3 Predicted specific activity per foil within Al holders as a function of cooling time (D-D source)

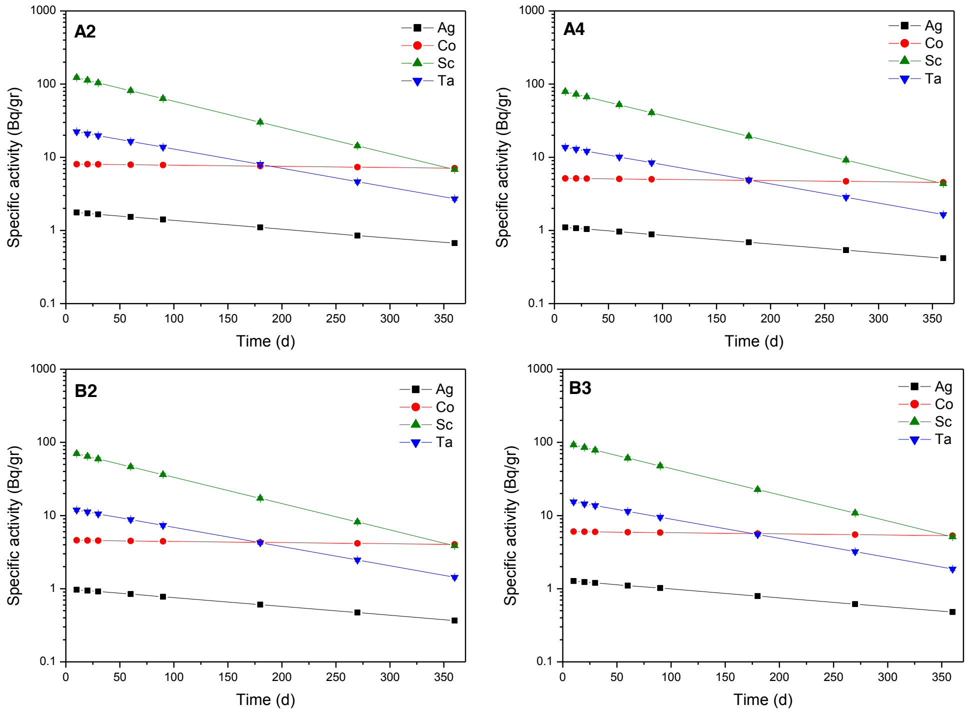

Fig. 4 Predicted specific activity per foil within PE cylinders as a function of cooling time (D-D source)

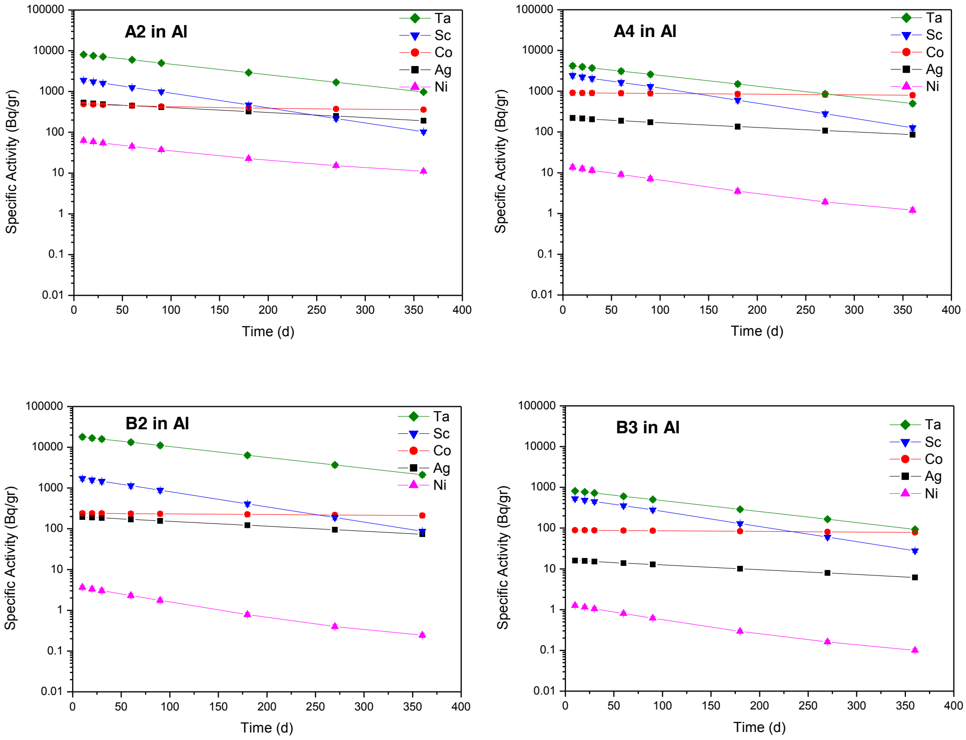

Fig. 5 Predicted specific activity per foil within Al holders as a function of cooling time (D-T source)

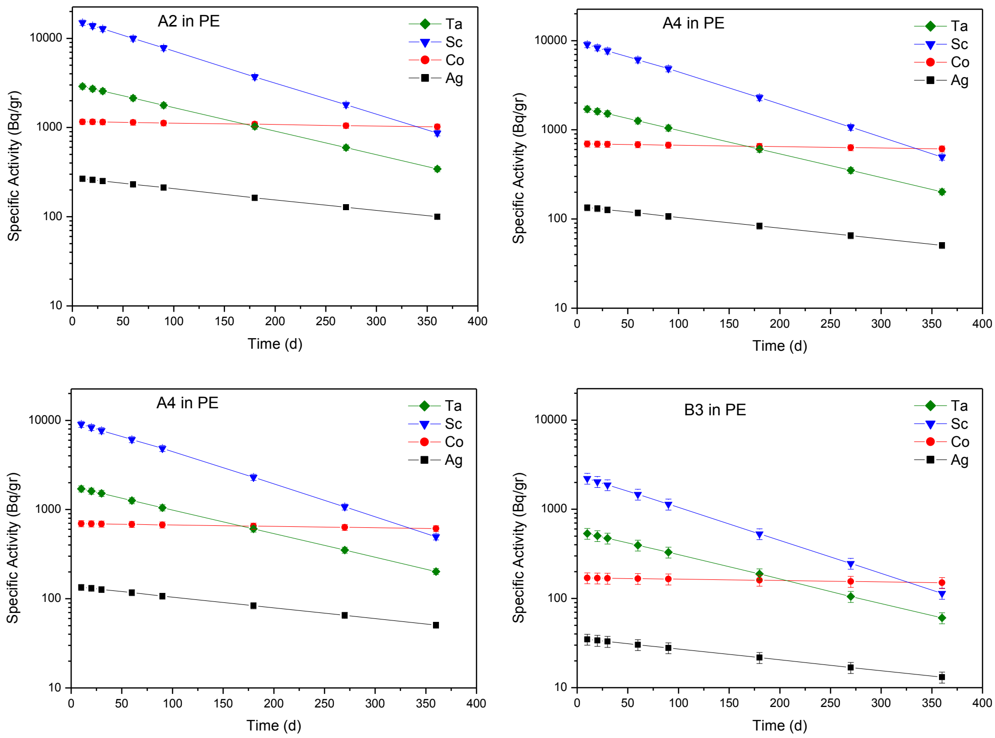

Fig. 6 Predicted specific activity per foil within PE cylinders as a function of cooling time (D-T source)

From Figures 3-6 it can be seen that for the un-moderated detectors (within Al holdres) the higher specific activity was obtained by the tantalum foil for all positions and plasma sources examined. This result is readily explained by the higher neutron capture cross-section of ^{181}Ta in both the slow and resonance regions of the neutron spectrum. On the other hand, among foils positioned within the PE cylinders, scandium presented the higher activity, followed by the tantalum foil. This result can be attributed to the higher thermal neutron cross-sections of scandium and 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. It is noted that at the centre of the PE cylinder the thermal to epithermal neutron ratio was of about 100. The uncertainties plotted in these figures are the ones related to the MCNP simulations and the propagation of errors along the subsequent calculations. Nevertheless, it has to be stressed that, although radionuclide half-life and cross-section uncertainties are considered small for the studied radionuclides, the cross-section errors can be very large for some isotopes and neutron energies, introducing significant errors in the activity calculations.

CONCLUSIONS

The results of this study demonstrated the feasibility of neutron flux measurements using activation foils for the determination of neutron fluence levels in the JET biological shielding penetrations. Activation detectors will be able to provide an unbiased benchmarking tool for the verification of the methodologies used for neutron streaming evaluation in JET and other fusion devices as well.

Acknowledgements

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