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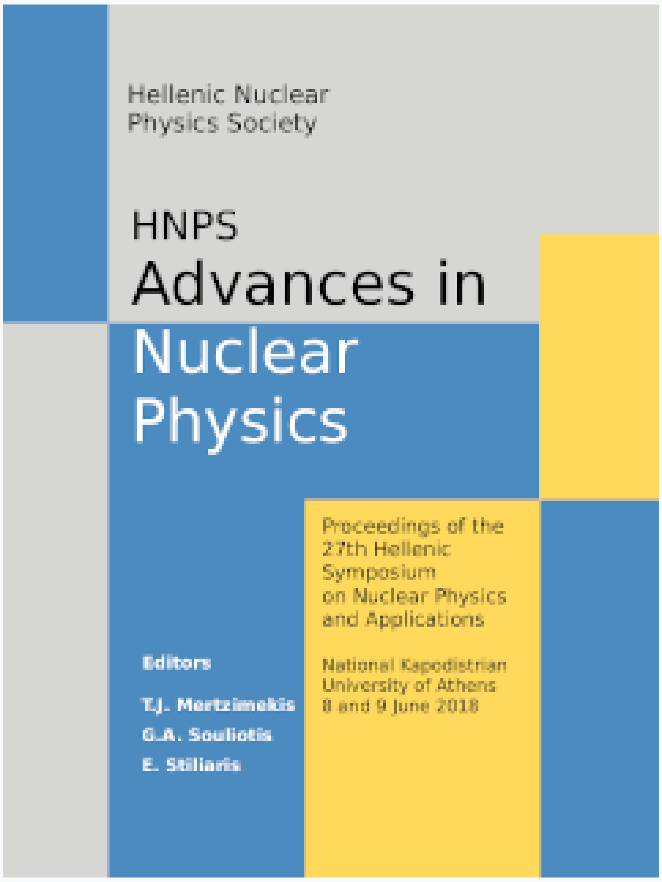

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Overview of NCSRD Activation Experiments at JET

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Abstract The intense collaborative effort for electricity generation through fusion is currently focused on the exploitation of the Joint European Torus (JET) as well as on the preparation of its successors ITER and DEMO. Within this frame, several experiments are carried out at JET aiming to study crucial aspects related to the construction and operation of ITER as well as to the design of future fusion power plants. Most important, a high-performance Deuterium-Tritium campaign is expected to take place at JET in 2020 providing unique neutron yields up to 1.7×10^{21} neutrons. This paper focuses on the participation of NCSRD fusion technology group in JET nuclear analysis and, in particular, on the implementation of activation experiments at JET and discusses the main achievements in the light of their significance for optimizing future fusion activities and studies.

Keywords Fusion, Joint European Torus, neutron activation

INTRODUCTION

The challenge for safe, clean and abundant energy production through fusion and, in particular, the goal of generating fusion electricity by 2050 are tightly connected to the schedule of ITER, the key facility on the path to fusion power, as well as to the exploitation of the Joint European Torus (JET), the largest operating fusion device in the world. Experiments carried out at JET are devoted to the preparation of ITER with the objective of addressing its key nuclear aspects on which there is still limited experience [1]. Moreover, an experiment is planned at JET for 2020 aiming to obtain the first complete and consistent nuclear study for a tokamak using the Deuterium-Tritium fuel cycle [2].

The NCSRD fusion technology group participates in JET nuclear analysis through several experimental studies. Scope of these studies is the accurate measurement of neutron fluence in and around the tokamak as well as along large ducts in the JET biological shielding, the assessment of the radiological properties of ITER materials after long-term irradiation at JET and the development of a novel neutron detector, capable to measure neutron fluence under the harsh conditions encountered in a fusion device. The results of the studies contribute to the validation of other measurement techniques and simulations used in fusion and moreover provide a better understanding of the activation properties of fusion materials.

The present work provides an overview of the collaborative experiments performed at

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JET by the NCSRD fusion technology group.

NEUTRON ACTIVATION TECHNIQUE

Neutron activation is one of the techniques employed to experimentally determine neutron fluence at JET, both close and far from the plasma neutron source [3]. The method is based on neutron irradiation of selected materials –usually in the form of metallic foils- in order to produce radioactive nuclei emitting characteristic gamma rays. After irradiation, the foils are measured in a high purity germanium based gamma-spectrometry system and the induced activity is quantified and interpreted in terms of neutron fluence.

Since the response of the activation foils depends on nuclear parameters only, neutron activation provides a robust and unbiased tool for the determination of neutron fluence in a wide range of neutron energies, fluence rates, mixed neutron and gamma ray fields, without mechanical, electro-magnetic and temperature interferences that are encountered in the complex environment of a fusion device [4]. However, in order to reduce uncertainties and provide reliable data, the activation foils need to be calibrated in known neutron fields that realistically represent the actual conditions of the measurement [5-6].

EXPERIMENTS AT JET

Neutronics experiments

Aim of the neutronics experiments is the validation of the state-of-the-art numerical tools and data used in ITER nuclear analyses in order to predict neutron fluence during plasma operation as well as material activation and gamma dose rates after the shutdown of the tokamak. For this purpose, neutron fluence measurements are performed both close and far from the source, at several locations within JET hall and particularly along streaming paths of the biological shielding (Fig. 1).

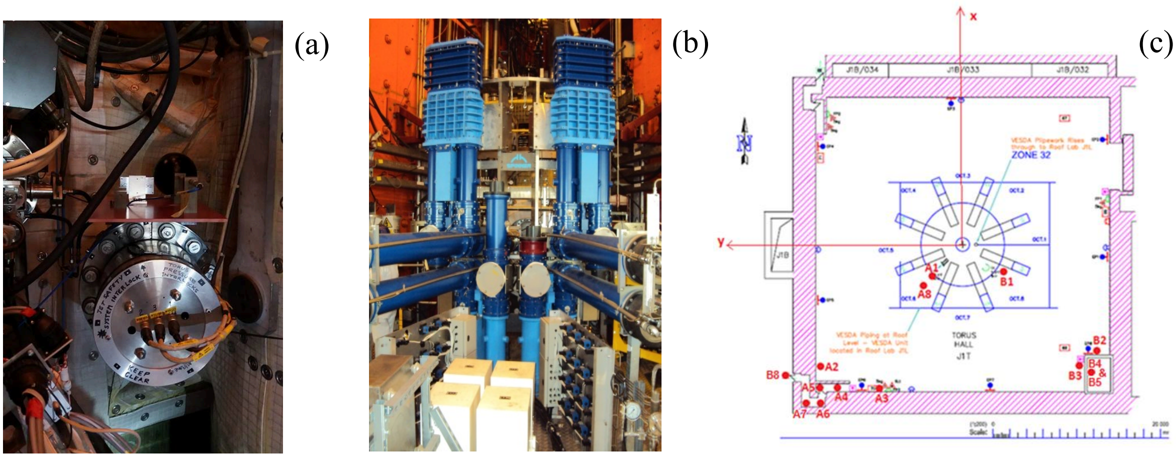

Fig. 1. Measurement positions in JET (a) Octant 1 (b) Octant 2 (c) Torus hall

The sets of activation foils used comprise high-purity cobalt, tantalum and silver discs.

The selection of the specific foil materials is mainly based on the half-lives of the corresponding isotopes, which need to be longer than 60 days, taken into account that the time interval between the end of irradiation and the start of gamma counting is usually in the order of few months. In each assembly both bare and cadmium-covered foils are included, in order to acquire information on the different neutron fluence components (thermal and epithermal). The neutron fluence results derived from activation foils are compared against other experimental techniques (i.e. thermoluminescence measurements, ionization chambers) as well as Monte Carlo calculations based on detailed models of the respective configurations [3, 5, 7].

Figure 2 shows a comparison of calculated and measured neutron fluence values for selected locations far from the tokamak, in particular, positions A2-A4 in the South West entrance labyrinth and positions B2-B3 in the South East chimney area of the torus hall (Fig 1c). Measurements were performed during the first part of the 2015-2016 JET Deuterium-Deuterium campaign, which lasted 82 days, using activation foils and thermoluminescence detectors (TLDs). The neutron fluence values presented in Fig. 2 are normalized per source neutron.

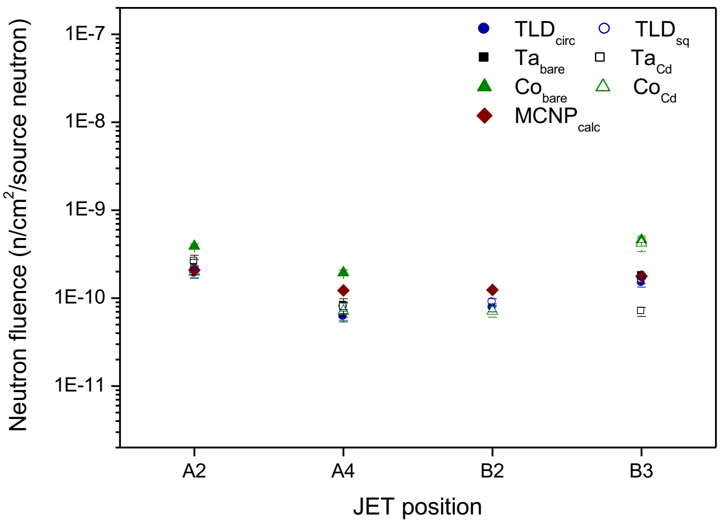

Fig. 2. Comparison of calculated and measured neutron fluence for the detector positions studied (data from ref [6])

Furthermore, Figure 3a shows the neutron fluence values derived from activation foils for two locations close to the machine. The first measurement position was in Octant 1 close to the Radial Neutron Camera (Fig. 1a) and the second one in Octant 2 on the top of ITER like Antenna (Fig. 1b). Measurements were performed during the second part of the 2015-2016 JET Deuterium-Deuterium campaign using sets of bare and cadmium-covered foils. The fluence results obtained by activation foils were compared against Monte Carlo calculations. In Fig. 3b the calculated over experimental (C/E) neutron fluence ratios corresponding to Octant 1 are presented, as an example.

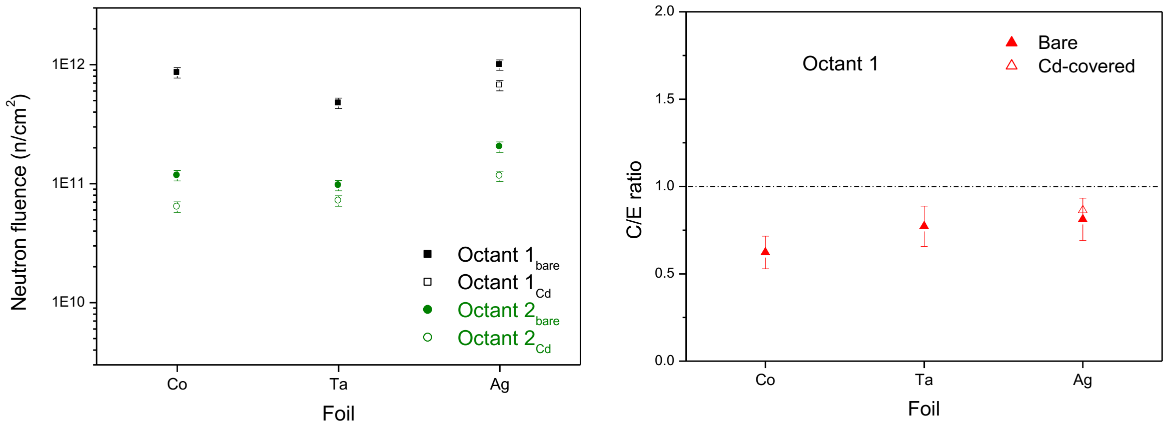

Fig. 3. (a) Activation foil results and (b) Comparison of calculations against measurements (data from ref [3])

As it can be seen from Figures 2 & 3, for positions both close and far from the machine, the calculated neutron fluence values are in satisfactory agreement with the experimental results, taken into account the overall complexity of the studied geometry and the limitations of the respective model [7, 8]. The optimization of the model through a more detailed description of some components of the geometry, which is now in progress, is envisaged to provide a better adjustment of the calculations to the experimental measurements.

Assessment of the radiological properties of ITER materials

Aim of the experiment is the characterization of activation properties of materials that will be used in ITER as structural or functional components [9, 10]. As part of this preparation, a set of dosimetry foils was irradiated with Deuterium-Deuterium plasma in the JET internal Long Term Irradiation Station (LTIS) (Fig. 4). The set of activation foils procured and measured by NCSRD comprised cobalt, tantalum, titanium and nickel discs of 18 mm diameter and 0.5 mm thickness. Their selection was based on the requirements to obtain fluence measurements over a wide range of neutron energies extending from thermal to fast, on their long half-lives since they would be retrieved for measurement several months after the end of irradiation and on their material properties (i.e. melting point) since they would be exposed to a high neutron fluence under the extreme environment of the JET vessel. Irradiation was performed during the JET 2015-2016 scientific campaign, which lasted approximately 15 months. During this period, a total neutron yield of 2.26E+19 neutrons was delivered in 3682 shots.

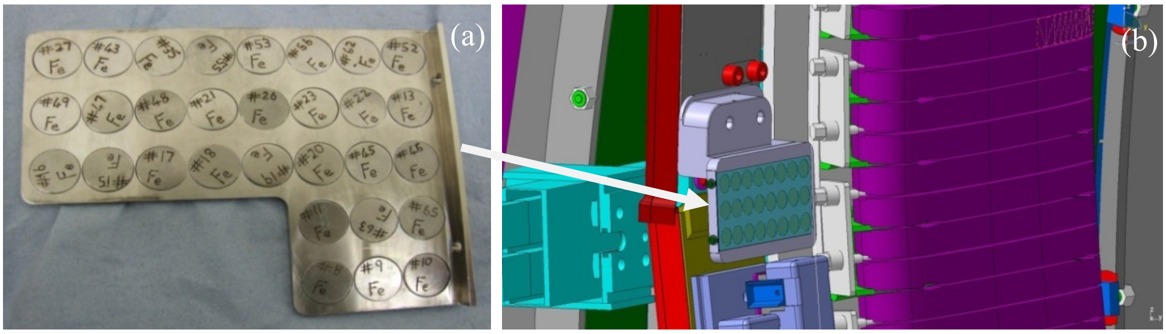

Fig. 4. (a) The activation foil holder and (b) Model of the LTIS including the foil assembly

The experimentally determined specific activities for the foils studied were compared against Monte Carlo and FISPACT calculations [10]. As an example, the calculated over experimental (C/E) specific activity ratios are given in Figure 5 for two reactions resulting in the production of the same isotope (^{58}Co). As it can be observed, the C/E activity ratios corresponding to ^{59}Co(n,2n)^{58}Co reaction are spread around one, while in the case of the ^{58}Ni(n,p)^{58}Co reaction calculations slightly underestimate measurements. The discrepancy is attributed to the assumptions used in the calculations, which have different impact on each of the reactions examined.

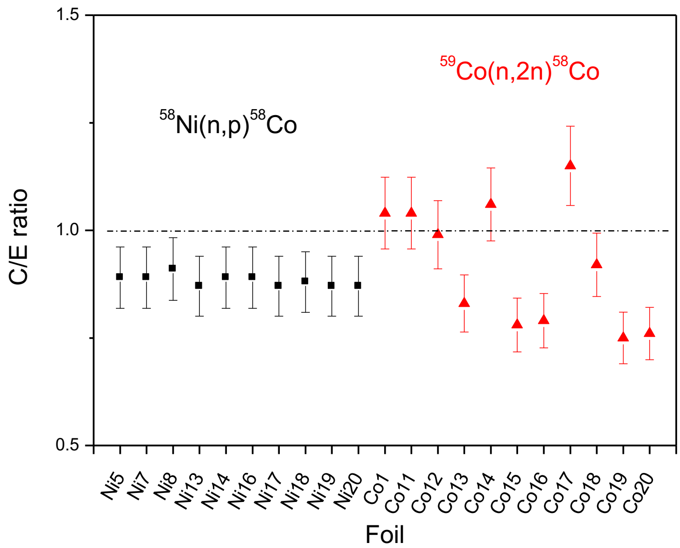

Fig. 5. Activity ratios determined through ^{58}Ni(n,p)^{58}Co and ^{59}Co(n,2n)^{58}Co reactions in nickel and cobalt foils, respectively (data from ref [10])

Development of novel neutron detectors for fusion

A novel neutron activation detector is being developed within the frame of the VERDI project, aiming to provide a robust approach for accurate neutron fluence measurements under the harsh fusion environment [11]. The concept –and at the same time the key novelty- of the proposed detector is the housing of selected metallic foils in a durable low activation matrix capsule which is able to withstand the extreme irradiation conditions of a tokamak (Fig. 6). Combining the established neutron activation method with a computational unfolding procedure, the neutron fluence and energy spectrum can be inferred by the analysis of the gamma lines produced by the activated metallic inclusions [12].

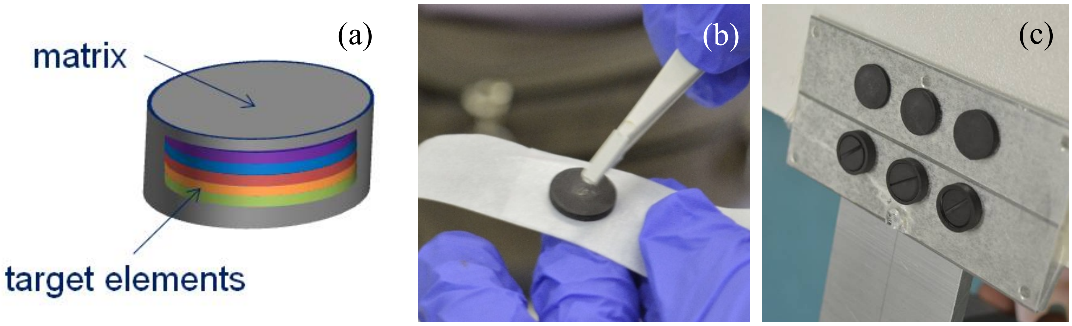

Fig. 6. (a) Conceptual design (b) Prototype (c) Irradiation assembly of VERDI detectors

In order to investigate the aptness and effectiveness of different matrix materials and detector designs, a series of benchmark experiments were performed at ENEA Frascati Neutron Generator providing fusion relevant neutron spectra [13]. The unfolding code MAXED was then used to reconstruct neutron spectra. Finally, the unfolded spectra were compared against predictions based on Monte Carlo calculations. In Figure 7 the MCNP predicted and the MAXED unfolded spectra corresponding to a set of VERDI detectors irradiated under 14 MeV neutrons are plotted as a function of energy. As it can be seen, a quite satisfactory agreement is observed, confirming the feasibility to reproduce the neutron spectrum using the VERDI detectors.

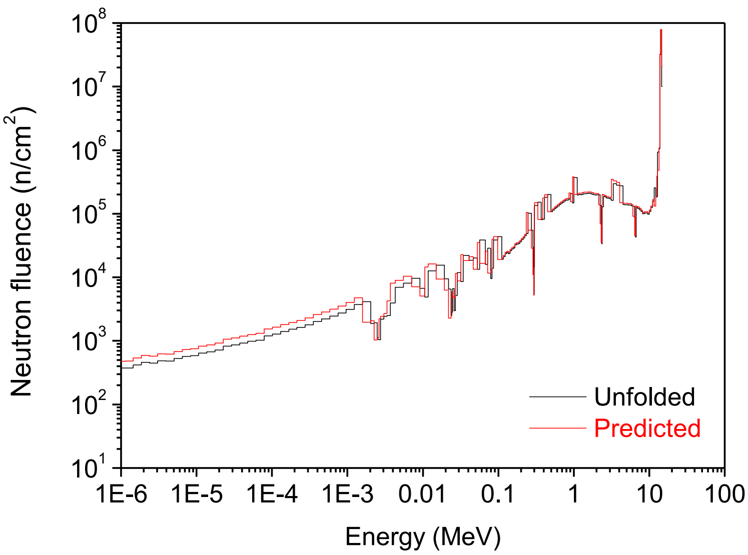

Fig. 7. Comparison of predicted and unfolded neutron spectrum as inferred by VERDI detectors (data from ref [13])

CONCLUDING REMARKS

In the present paper the collaborative experiments performed at JET by the NCSRD fusion technology group were described. It was demonstrated that neutron activation technique is a robust technique which is able to provide accurate neutron fluence results in the demanding environment of a fusion reactor. The results of the implemented activation experiments enable the benchmarking of other experimental techniques and computational methods used at JET and, moreover, contribute to the validation of the numerical tools employed for the design and safety of ITER and future fusion power plants. The significant experience gained through these experiments will allow the full exploitation of the unique neutron yields anticipated in the forthcoming JET Tritium-Tritium and Deuterium-Tritium campaigns and provide important information to be applied on ITER nuclear analysis.

References

[1] X. Litaudon et al., Nucl. Fusion 57, 102001 (2017)
[2] P. Batistoni et al., Fus. Eng. Des. 109-111, 278 (2016)
[3] R. Villari et al., Fus. Eng. Des. 123, 171 (2017)
[4] P. Batistoni, Fus. Eng. Des. 105, 58 (2016)
[5] P. Batistoni et al., Radiat. Prot. Dosimetry 180, 102 (2018)
[6] T. Vasilopoulou et al., Improved neutron activation dosimetry for fusion, submitted to Fus. Eng. Des. (2018)
[7] P. Batistoni et al., Nucl. Fusion 55, 053028 (2015)
[8] B. Obryk et al., Fus. Eng. Des. 89, 2235 (2014)
[9] L.W. Packer et al., Fus. Eng. Des. 124, 1150 (2017)
[10] L.W. Packer et al., Nucl. Fusion 58, 096013 (2018)
[11] M.I. Savva et al., Proc. of 26th HNPS conference, Adv. in Nucl. Physics p.115 (2018)
[12] C.R. Nobs et al., Neutron spectrum unfolding for the development of a novel neutron detector for fusion, submitted to Fus. Eng. Des. (2018)
[13] M.I. Savva et al., VERDI detector benchmark experiment at the ENEA 14 MeV Frascati Neutron Generator, submitted to Fus. Eng. Des. (2018)