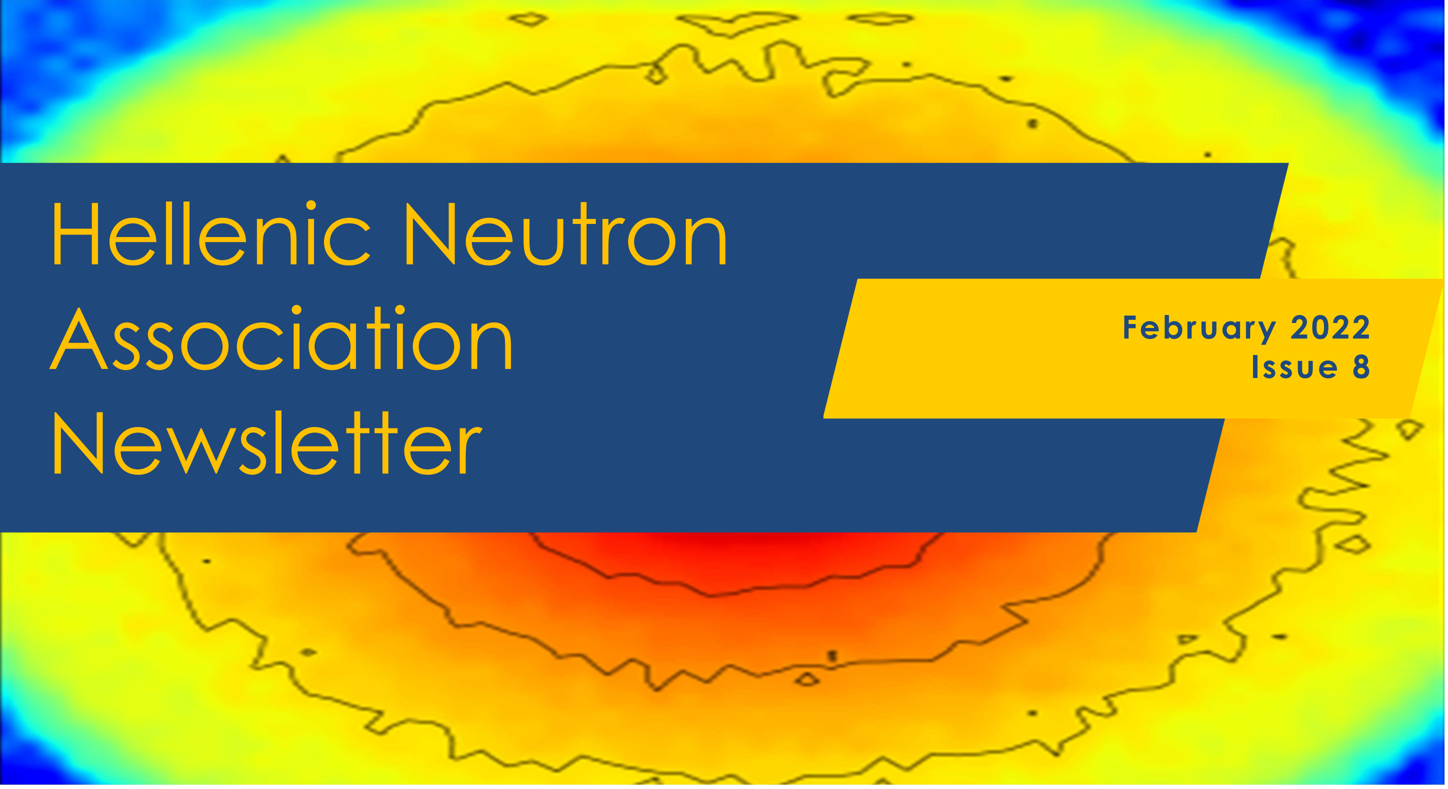

Hellenic Neutron Association Newsletter

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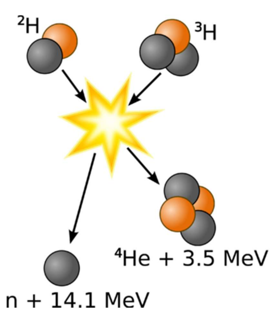
Deuterium - tritium fusion reaction



Editorial

By Konstantina Mergia (NCSR "Demokritos", Athens, Greece)

Clean, abundant and affordable energy is the prerequisite for human prosperity. This dream can become reality when the physical process by which the sun produces its energy is mastered by the scientists and engineers. This physical process is called **Fusion** and for many decades a large number of European Research Centers and Universities are working towards the goal of utilizing Fusion for electricity production within the framework of EUROfusion project.

In the current issue Dr Marilia Savva, post-doctoral researcher of the Fusion Technology Group, at NCSR "Demokritos", in Athens, Greece, describes the use of VERDI neutron detectors for neutron spectrum and fluence measurements in fusion devices.

We hope you enjoy reading this newsletter!

VERDI detectors for neutron spectrum determination in fusion devices using the multi-foil activation technique

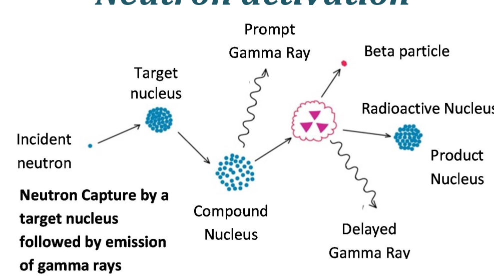
By Dr. Marilia I. Savva (Fusion Technology Group, National Centre for Scientific Research "Demokritos", Athens, Greece)

For fusion devices, such as ITER under construction in France or the future demonstrator power plant DEMO, there is a large need for detectors which are capable to accurately monitor neutron energies and intensities under the harsh conditions imposed by the fusion environment. Neutron diagnostics in large tokamaks are the essential and primary means in estimating fusion power. The power output of fusion reactor-like devices and fusion experiments in general is measured in terms of neutron emission rates which are directly related to the fusion yield rate. Different approaches have been developed in order to measure neutrons in fusion. Most fusion experiments employ both active detectors located around the machine such as fission chambers, proportional counters, scintillation detectors, enabling to monitor the time evolution of the neutron emission rate, as well as complementary systems which allow determining local neutron fluence levels off-line [1].

> ***"…there is a large need for detectors which are capable to accurately monitor neutron energies and intensities under the harsh conditions imposed by the fusion environment."***

Neutron activation methods are well suited to perform accurate measurements of the neutron fluence in environments with a high background of gamma-rays or other forms of radiation and magnetic fields, such as the fusion environment. Neutron Activation Analysis (NAA) is a nuclear analytical technique enabling non-destructive multi-elemental analysis in a variety of sample matrices with excellent sensitivity, accuracy and precision [2]. The technique is based on the irradiation of the sample under a neutron field and detection of the characteristic gamma rays that are emitted as a result of neutron induced nuclear reactions in the sample matrix.

"Neutron activation"



For the realization of the technique, the knowledge of the incident neutron energy and fluence, the occurring nuclear reactions and their cross sections is required. The analysis of the complex gamma ray spectra encountered after the irradiation is performed using gamma ray detectors, with high purity germanium (HPGe) semiconductor detectors being the most common selection due to their high energy resolution.

Neutron detectors based on activation methods are being used to measure neutron fluence since their response is linear over a wide range of fluence rates. Moreover, since activation detectors are passive detectors, they address the problem of measuring neutrons in the presence of electromagnetic fields, high temperature and high radiation loads, i.e. in environments where active detectors may lose their reliability. At the Joint European Torus (JET), for example, neutron activation systems are used to measure neutron yield and provide complementary information to highly sophisticated instruments such as advanced neutron spectroscopy systems and neutron cameras [3]. They have been shown capable to provide neutron measurements with accuracy better than 10% [4], as required for example for ITER, where precise neutron yield measurement is important for tritium accountancy.

A novel neutron activation detector has been proposed under the project “No*ve*l Neut*r*on Detector for Fus*i*on (VERDI)”, implemented under EUROFusion programme, providing a robust approach for accurate neutron fluence measurements under the harsh environment conditions encountered in a fusion plant. The detector comprises of a composite low activation matrix compound capsule containing a defined concentration of added metallic elements, in the form of disc-shaped foils (Figure 1). The neutron fluence and energy spectrum can be inferred by the analysis of the gamma lines produced by the activation reactions in the metallic elements employing a computational unfolding procedure.

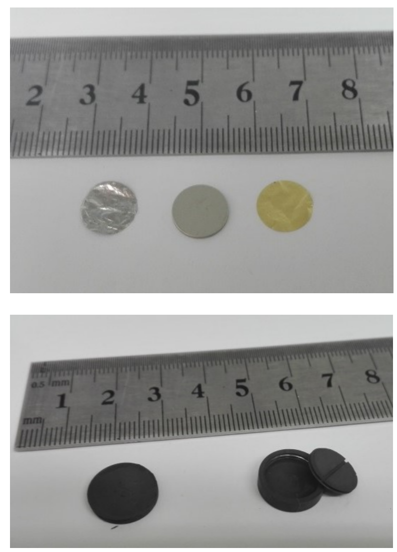


Figure 1: Target element foils (top) and capsules (bottom) of the VERDI detectors.

Figure 2 presents an example of a typical spectrum from the analysis of a VERDI detector after irradiation. The spectrum is collected using a HPGe detector (Figure 3) and the product isotopes of the activation reactions have been marked.

The composite capsule and the selection of the foils which undergo capture and threshold reactions, make the VERDI detector unique from other foil based detection systems. The detector should be capable in a single measurement to perform characterization of the neutron energy spectrum from the thermal up to the fast neutron region, therefore allowing discrimination of the detected neutrons as primary from the source (D-D and/or D-T) and scattered from walls and other structural materials and components.

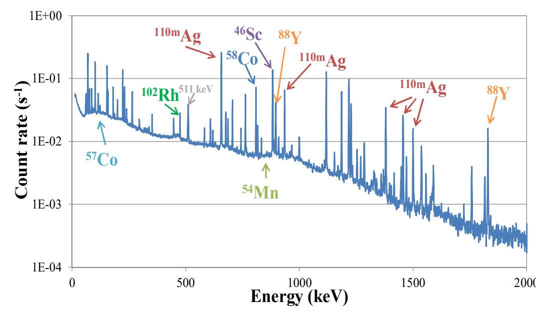


Figure 2: Typical γ-spectrum of an activated VERDI detector.

Neutron spectrum unfolding is a promising method for extracting the neutron fluence indirectly by processing the convolution of gamma-ray measurement and activation foil response function to infer the neutron energy spectrum. An a priori spectral information, providing the neutron energy region of interest, can be combined with response functions, based on cross section data, and measured reaction rates to give the reconstructed neutron spectrum and fluence. The a priori spectral information provides a guessed spectrum defining the neutron energy of interest, thermal, epithermal and/or fast, for the deconvolution. The response functions are based on the cross section data of each realized reaction, capture or threshold, taking into account also the atomic number density and the volume of each activation foil. Example of the response functions used for the VERDI detectors is given in Figure for all occurring reactions of interest.

Figure 3: The HPGe detector used for the analysis of the irradiated VERDI detectors.

For the spectrum reconstruction, a computational code is used, which for the case of the VERDI detectors is applying the maximum entropy method. The solution to the unfolding problem is obtained by maximizing the relative entropy subject to constraints imposed by the measurements.

This approach permits the inclusion of prior information in a well-defined and mathematically consistent way, and it leads to a solution spectrum that is a non-negative function which can be written in closed form [5].

Example of the inferred spectrum as determined using the VERDI detectors data from the 2019 JET campaign [6] is presented in Figure , together with the respective aggregated spectrum calculated using the Monte Carlo code MCNP [7]. The spectra are presented in lethargy units, calculated by dividing the flux values with the natural logarithm of the energy bin width in order to take into account any unequal energy bin widths.

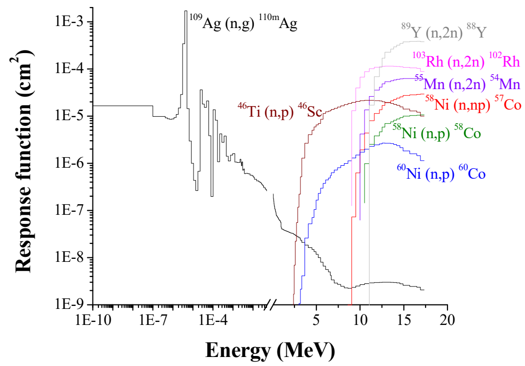


Figure 4: Response functions for each detected reaction plotted as a function of energy (note the split logarithmic-linear x-axis)

Concluding Remarks

The feasibility of the VERDI detectors to measure the neutron spectrum and fluence has been demonstrated in both fusion relevant experimental apparatus using a fast neutron generator and at JET, revealing the great potential of employing VERDI detectors for neutron measurements in real fusion environment. Interferences from the capsule material were found minimal and it was shown that the complexity of the gamma spectra from the activation products is disentangled by the careful selection of active elements in order to have minimum overlapping of the emitted photons. In addition, VERDI detectors can be tailored, in terms of added metallic elements and composition, to fit different applications, such as to measure neutron fluence in fission reactors.

Neutron monitoring is of crucial importance for fusion devices such as ITER and DEMO. Activation methods are one of the few available options for measuring fusion power and quantifying the neutron energy spectrum at the measurement location. In the Novel Neutron Detector for Fusion (VERDI) project, the neutron activation technique is advanced by providing a composite activation target and implementing the activation analysis method based on high sensitivity gamma-ray detection.

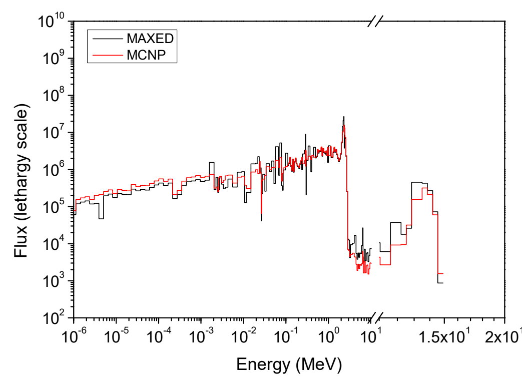


Figure 5: Comparison of JET neutron spectra using the MAXED unfolding code and the Monte Carlo code MCNP (note the split logarithmic-linear x-axis)

This approach delivers a robust technique for determining neutron fluence in the demanding fusion environment and could replace or complement existing neutron monitoring methods. In particular, it would provide an absolute calibrated basis for comparison of time-integrated neutron yield measurements from other types of detectors, and also of other neutron spectrometry diagnostics. It will therefore allow monitoring the neutron fluence on components and materials, tritium breeding rates, nuclear heating, and a variety of other parameters in fusion devices as well as future fusion power plants.

"It will therefore allow monitoring the neutron fluence on components and materials, tritium breeding rates, nuclear heating, and a variety of other parameters in fusion devices as well as future fusion power plants."

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Neutron News

Find out about the League of advanced European Neutron Sources (LENS) League and read the associated news, neutron related webinars and scientific highlights in the link https://www.lens-initiative.org/

Read about the recent advances of the BrightnESS2 project in the link https://brightness.esss.se/news-and-events

Neutron Conferences

*International Conference on Neutron Scattering (ICNS 2022) 21-25 August Buenos Aires, Argentina (https://icns2022.org)
*MLZ Conference 2022: Neutrons for mobility, 31 May 2022 - 03 Jun 2022, Lenggries, Germany, https://indico.frm2.tum.de/event/306/

Neutron Schools

* EMBO Practical Course: "Small angle neutron and x-ray scattering from biomacromolecules in solution" 20-24 June 2022, Grenoble, France, https://meetings.embo.org/event/22-biomacromolecules

*Bombannes Summer School 2022 — 15th European Summer School on "Scattering Methods Applied to Soft Condensed Matter", 20 - 28 June 2022, Carcan-Maubuisson (Gironde), France, https://workshops.ill.fr/event/219/

* 24th JCNS Laboratory Course – Neutron Scattering 2022: 05-16 September 2022, Jülich/Garching, Germany, www.neutronlab.de