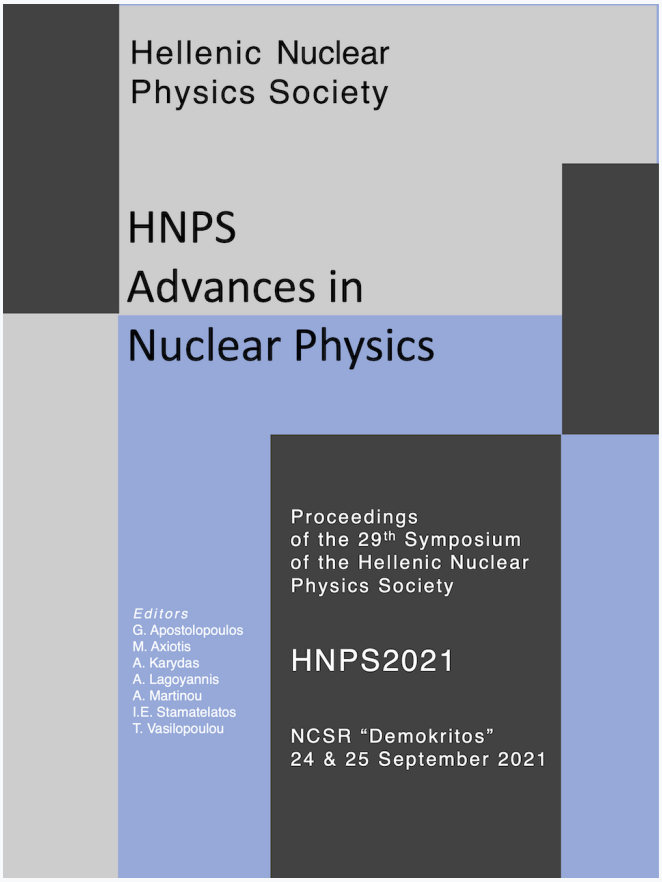
Annual Symposium of the Hellenic Nuclear Physics Society

Τόμ. 28 (2021)

HNPS2021



Compton Suppressed Gamma Spectrometry for activation analysis of materials irradiated at JET

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doi: 10.12681/hnps.3599

Βιβλιογραφική αναφορά:

Savva, M. I., Vasilopoulou, T., Nobs, C. R., Packer, L. W., & Stamatelatos, I. E. (2022). Compton Suppressed Gamma Spectrometry for activation analysis of materials irradiated at JET. *Annual Symposium of the Hellenic Nuclear Physics Society*, *28*, 211–214. https://doi.org/10.12681/hnps.3599

Compton Suppressed Gamma Spectrometry for activation analysis of materials irradiated at JET

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Abstract Compton Suppressed Spectrometry (CSS) provides a method to improve the peak-to-background ratio, and consequently counting statistics and the limit of detection. The NCSRD Fusion Technology Group CSS system consists of a NaI detector coupled to a 40% HPGe. The NaI detector consists of an annulus, surrounding the HPGe, and a plug, which can be removed for sample positioning, offering a 4π detection geometry. The signal processing chain of the configuration allows for the simultaneous collection of both the suppressed and the unsuppressed spectra. The simultaneous collection of suppressed and unsuppressed spectra allows the analyst to use the optimum spectrum, depending on the radionuclide to be determined. In this work, the performance of the CSS system in the analysis of dosimetry foils of different material samples irradiated at the Joint European Torus (JET) during the 2019 DD campaign is presented. The Compton continuum was significantly reduced providing better peak identification for peaks of non-cascade nuclides. The developed methodology will be applied to study the activation characteristics of materials to be used in ITER components manufacturing, after irradiation at the significant 14 MeV neutron yield during the JET DT campaign.

Keywords fusion, JET, Compton Suppression, activation foils, gamma spectrometry

INTRODUCTION

Improving the sensitivity and detection limits of neutron activation analysis depends, among others, on the reduction of the continuous background of the gamma spectrometric apparatus. Reduction of the Compton continuum can be achieved by surrounding the HPGe detector with shield detectors that can detect the scattered radiation that escapes the HPGe detector. Events collected in both detectors are Compton or escape events, while those detected only by the HPGe are photopeaks considered useful for analysis.

The technology program WPJET3 aims to deliver the maximum scientific and technological output from JET operation, via exploitation of the high neutron fluxes predicted in and around JET [1]. In particular, within the sub-project "ACT" we aim to irradiate a range of real ITER materials in JET and obtain valuable nuclear response benchmark data from those materials. Therefore, accurate determination of the neutron fluence via neutron activation dosimeters is of outmost importance.

In this work the performance of Compton suppressed gamma spectrometry for the analysis of activation dosimetry foils irradiated under real fusion conditions at JET is presented.

MATERIALS AND METHOD

Dosimetry foils irradiation at JET

Co and Ni disc-shaped with a diameter of 17.5 mm and a thickness of 0.5 mm were studied. The foils were irradiated in the Long-Term Irradiation Station (LTIS) of JET, a location very close to the JET vacuum vessel, outside of the vacuum boundary. Fig. 1 shows a drawing of the part of the

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tokamak where the holder assembly was installed, the holder tube at the edge of which the samples were installed and the arrangement of the holders. The irradiation was part of the JET C38A DD campaign and lasted for a total of 147 days. The plasma source neutron emission for the irradiation period was determined experimentally using the JET fission chamber diagnostic system, also referred to as KN1 [2]–[4], to be 3.1505E+19 neutrons ± 10% [5]. The total number of neutrons reaching the samples varied, depending on their exact position, from 1.8332E+14 to 1.9214E+14 n/cm^2.

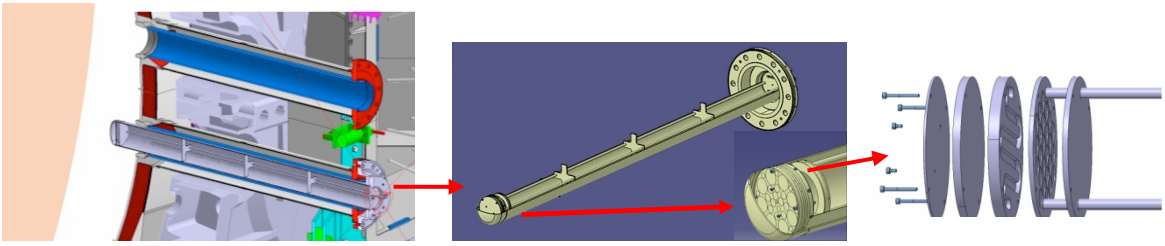

Fig. 1. *The LTIS assembly holder where the samples were irradiated (from the left: holder tube in the tokamak, holders in the tube, arrangement of holders)*

The samples were retrieved approximately 13 days after the end of irradiation and distributed for gamma spectrometry measurements. The measurements took place approximately three months after the end of irradiation following a standard methodology for analysis which determined the induced activity at the end of JET irradiation period. More details about the induced activity measurements can be found in [1].

The NCSRD Compton Suppression Spectrometer

The dosimetry foils were measured by means of Compton Suppressed gamma spectrometry. The FTG Compton Suppression Spectrometer consists of a 40% HPGe coupled to a NaI detector, which is made to completely surround the primary HPGe detector. The HPGe has an Al endcap and a resolution of 0.93 keV @ 122 keV and of 1.90 keV @ 1332 keV. The secondary NaI detector consists of two parts: an annulus and a plug (Fig. 2). The plug can be removed for the positioning of the sample. The whole system is housed in a home-made lead shielding made with lead bricks.

The output signals of both the HPGe and the NaI detectors are fed into digital signal analyzers (DSA). A gating signal is transferred from the NaI DSA to the HPGe DSA in order to perform the coincidence check between the two detectors and provide rejection signals for the HPGe detector data, producing the suppressed spectrum. According to the manufacturer instructions [6], the coincidence time is set to 1 μs.

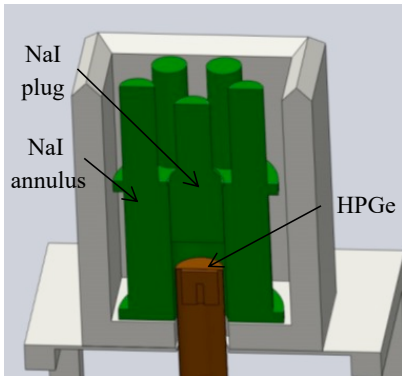

Fig. 2. *The FTG Compton Suppression System.*

RESULTS AND DISCUSSION

Typical spectra collected in this study are presented in Fig. 3, one for each studied element. For the Co foils, in the unsuppressed spectra, peaks corresponding to ^{58}Co and ^{60}Co were detected as product of the reactions ^{59}Co (n,2n) ^{58}Co and ^{59}Co (n,γ) ^{60}Co, respectively. For the Ni foils, the peaks of ^{57}Co and ^{58}Co were detected in the unsuppressed spectra, produced through the reactions ^{58}Ni (n,np)/(n,d) ^{57}Co and ^{58}Ni (n,p) ^{58}Co, respectively.

It is evident that the continuous background is significantly reduced in the suppressed spectrum. For the evaluation of this reduction, the count rate in specific energy regions without any characteristic peak was compared in the two spectra. For the Co foils, the energy region 530 – 800 keV was selected, while for the Ni foils the energy region 210 – 410 keV. The ratio of the count rate in the unsuppressed spectrum over the count rate in the suppressed spectrum for all studied foils is presented in Fig. 3. It was concluded that the continuous background in the case of Co foils is suppressed using the CSS by ~11 times, while for the Ni foils this suppression is ~4 times.

As shown Fig. 3, the continuous background of a typical Co foil is around 0.5 cps, while for a typical Ni foil it is much lower, just above 0.05 cps. Thus, the effect of the guard detector, which is the suppression of the continuous background, is more intense in the suppressed spectra of the Co foils and this is due to the higher energy of the ^{60}Co peaks at 1332 and 1173 keV as compared to 810 keV of ^{58}Co.

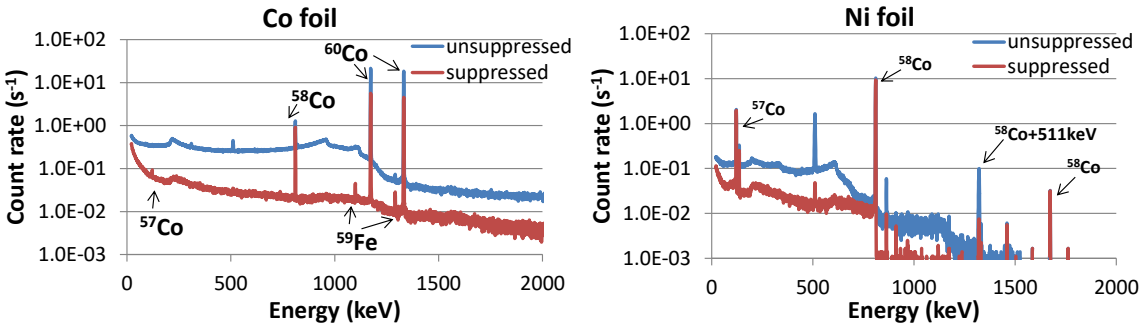

Fig. 3. *Typical Co (left) and Ni (right) foil samples spectra in contact with the HPGe.*

The most important effect of the CSS use for the analysis of the activation foils is the detection of additional peaks of ^{59}Fe and ^{57}Co, which are all hidden in the unsuppressed spectrum continuous background. The two peaks of ^{59}Fe are not in cascade, thus their detection is enhanced in the suppressed spectrum. The isotope is produced through the reaction ^{59}Co(n,p)^{59}Fe and could not be detected in the unsuppressed spectra due to its low concentration in the sample. The ^{57}Co peak at 122 keV is attributed to the small Ni impurity contained in the Co foils, around 800 ppm, and is produced through the reaction ^{58}Ni (n,np)/(n,d) ^{57}Co.

An investigation of the Minimum Detectable Activity (MDA) improvement was also performed, and it was found that for the Co foils the MDA for ^{58}Co was reduced by ~3.5 times, while for the Ni foils an improvement of ~1.8 times was found for all detected isotopes.

CONCLUSIONS

A Compton Suppression System performance was evaluated for the analysis of activation foils after irradiation under real fusion conditions at JET. It was found that Compton suppressed spectrometry significantly reduced the continuous background and provided better peak identification,

thus enhancing detection capabilities. The Compton continuum was reduced in the suppressed spectrum ~11 times in the Co foils and ~4 times in the Ni foils. The most important observation was the reveal of ^{59}Fe and ^{57}Co peaks in the suppressed spectrum, which could not be detected otherwise. Finally, the MDAs were reduced by around 2–3.5 times, which can be also considered as an improvement of the minimum detectable neutron fluence.

Acknowledgments

This work has been carried out within the framework of the EUROfusion Consortium and has received funding from the Euratom research and training programme 2014-2018 and 2019-2020 under grant agreement No 633053. The views and opinions expressed herein do not necessarily reflect those of the European Commission. The funding from the Greek National Programme for the Controlled Thermonuclear Fusion is acknowledged.

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