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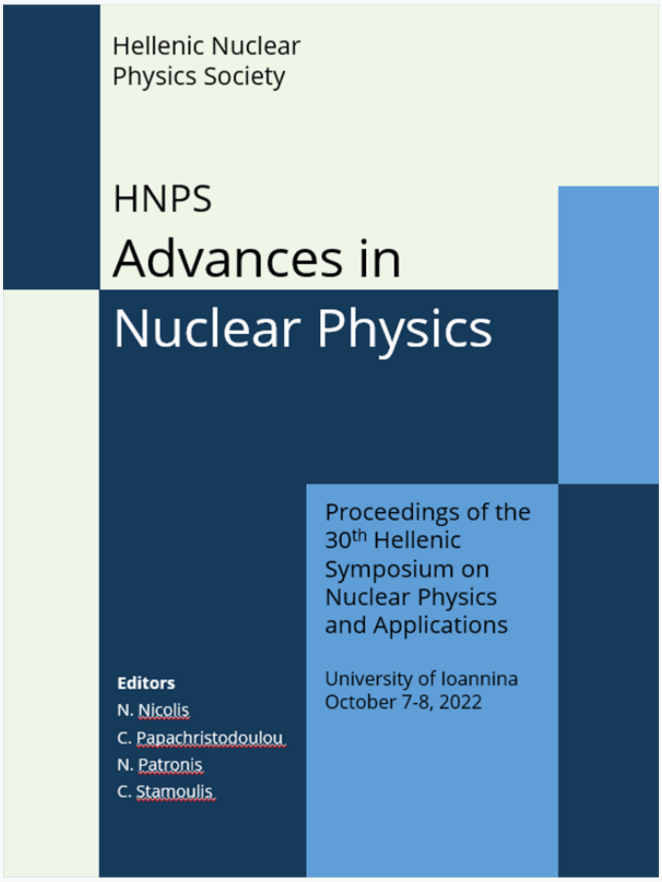

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Compton Suppression System performance evaluation for measurement of VERDI activation detectors

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Abstract The VERDI detector was developed for accurate neutron measurements in the plasma-facing modules of a tokamak. It comprises a low activation capsule, capable to withstand the harsh conditions of the fusion environment, containing a defined mass of metallic foils. The neutron fluence and energy spectrum are derived by analysis of the gamma lines produced by neutron activation of the metallic elements. In this work, the use of a Compton Suppression System (CSS) is investigated aiming to enhance the sensitivity of VERDI detector analysis. The CSS consists of a 40% HPGe primary detector coupled to a set of NaI secondary detectors. The apparatus was set to discard signals simultaneously recorded on both primary and secondary detectors, thus lowering the Compton continuum. The VERDI detectors were irradiated at the Joint European Torus (JET) during the 2019 Deuterium-Deuterium (DD) campaign. The CSS performance was studied by calculating peak and continuum suppression factors. The advantage introduced by Compton suppressed gamma spectrometry for each nuclide of interest is explored and the suitability of this system for VERDI detector measurements is discussed.

Keywords neutron dosimetry, gamma spectrometry, Compton Suppression System, VERDI detector, fusion

INTRODUCTION

The neutron activation analysis of the noVel nEutRon Detector for fusIon (VERDI) yields promising results for tokamak neutron diagnostics. VERDI detectors have been tested in benchmark experiments [1] and in the tokamak conditions [2].

An approach to enhance the capabilities of the VERDI detector is the use of a Compton Suppression System (CSS) during gamma measurements of the detectors. In CSS the main HPGe detector is surrounded by an active shielding of NaI detectors. The electronic set-up is such that any events captured by both detectors are discarded as Compton scattering events, while events recorded only on the main detector are deemed useful, as they carry the information of the incident photon energy. Therefore, the CSS can lower the Compton continuum and offer improved detection limits in gamma spectroscopy.

In this study, the use of a CSS is investigated aiming to enhance the sensitivity of VERDI detector analysis. The VERDI detectors were irradiated at the Joint European Torus (JET) during the 2019 Deuterium-Deuterium (DD) campaign. The advantage introduced by Compton suppressed gamma spectrometry for each nuclide of interest is explored and the suitability of CSS for VERDI detector measurements is discussed.

MATERIALS AND METHOD

VERDI detector description

The VERDI detector is a multi-foil metallic element configuration housed in a low activation, mechanically robust capsule that allows for the accurate determination of the neutron fluence and

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energy spectrum in the high temperatures, strong E/M fields and high neutron and gamma radiation fluxes encountered in a fusion reactor. Each VERDI detector features a cylindrical capsule made of either graphite or Ceramic Matrix Composite (CMC) material sealed with high temperature graphite adhesive. The selected target elements placed in the capsule are disc-shaped foils of Au, Mn, Nb, Ni, Rh, Ti and Y of known mass. The neutron flux and energy spectrum are calculated based on the spectroscopic analysis of the gamma-lines produced from these activated metallic inclusions [1].

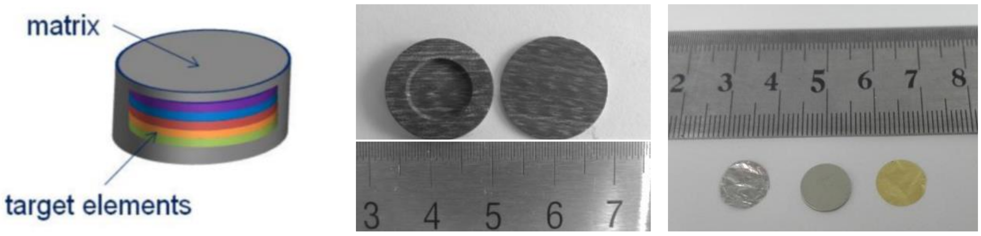

Figure 1. *Conceptual design of VERDI (left), capsule matrix (center), disc-shaped metallic foils (right)*

Sample irradiation at JET

A set of eight VERDI detectors was analysed, two of which were blank to study the activation of the capsule materials. The samples were irradiated in the Long-Term Irradiation Station (LTIS) of JET, a location in close proximity to the vacuum vessel. The irradiation was part of the JET C38A DD campaign and the integrated number of neutrons reaching the samples was estimated at 1.9×10^{14} n/cm^2 over 147 days [3]. The measurements presented in this work took place approximately two years after the end of irradiation.

The NCSRD Compton Suppression System

The Compton Suppression System, used in the study, consists of a 40% HPGe coupled to a NaI detector, which surrounds the primary HPGe detector, and the entire system is housed in 5 cm thick lead shielding. The HPGe has an Al endcap and a resolution of 0.93 keV at 122 keV and of 1.90 keV at 1332 keV. The secondary NaI detector consists of two parts: an annulus and a removable plug for the positioning of the sample either in contact with the Al endcap of the HPGe or in various distances up to 7.5 cm from the primary detector (Fig. 2 left). The secondary detector also features an Al endcap, which cuts off low energy gamma rays.

Two digital signal analyzers (DSA) receive the output signals of the HPGe and the NaI detectors respectively. A gating signal is transferred from the NaI DSA to the HPGe DSA in order to perform the coincidence check between the two detectors (Fig. 2 right). The suppressed spectrum is produced by

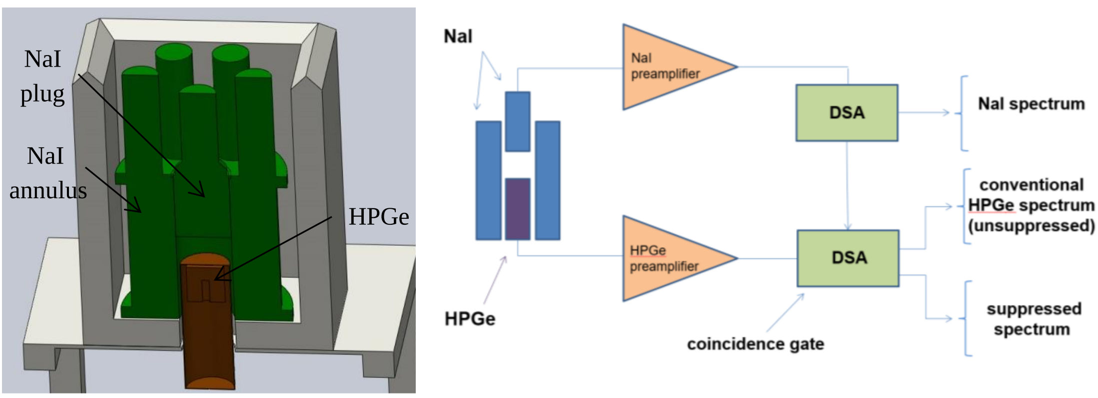

Figure 2. *The schematic of the Compton Suppression System (left) and the electronics set-up (right)*

rejecting signals for the HPGe detector data upon detection of a signal in the secondary detector within a coincidence time window set to 1 μs [4]. The unsuppressed – or conventional – signal is also recorded and used for sample analysis.

CSS Evaluation method

The performance of the Compton Suppression System was evaluated using as criteria the reduction factor (RF) and the peak reduction factor (R_p). The former offers a way to quantify the Compton continuum reduction that is implemented by the CSS (Fig. 3 – left), while the latter measures the collateral decrease in the photopeak area in the suppressed spectra (Fig. 3 – right).

For the reduction factor, continuum areas in each spectrum are selected and the RF is calculated as the mean count rate in the unsuppressed spectrum over the same quantity in the suppressed spectrum. The peak reduction factor is calculated as the ratio of the net peak area in the suppressed and unsuppressed spectrum for a specific photopeak.

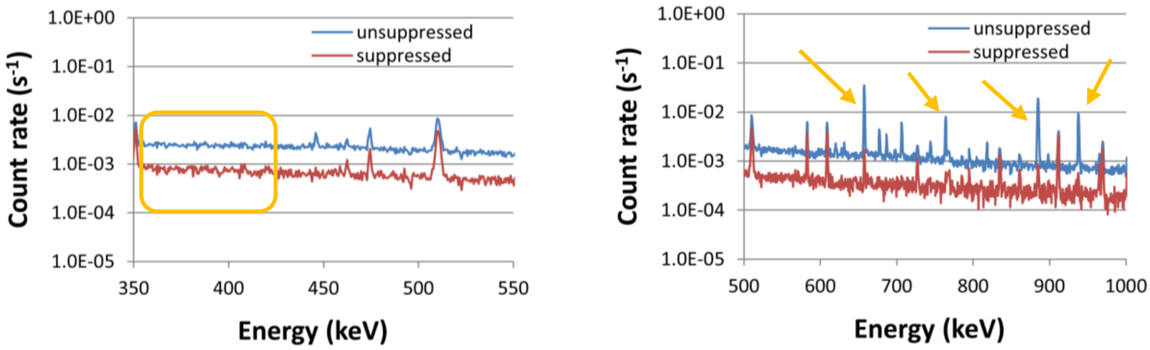

Figure 3. *Selected areas of the same VERDI spectrum for the calculation of RF (left) and R_p (right)*

RESULTS AND DISCUSSION

In the scope of the present study, the analysis of the reduction factor yields unvarying results for all VERDI detectors containing foils, which are presented in Table 1 for two selected detectors.

Table 1. *Reduction Factor for two VERDI detectors in continuum regions of the spectra*

VERDI name	Reduction Factor (RF)			
	355–400 (keV)	1010–1115 (keV)	1245–1330 (keV)	1600–1725 (keV)
ACT15	3.19	3.57	3.07	2.44
RADA13	3.20	3.50	3.11	2.37

The continuous background is lowered by a factor of 2.3 to 3.6 enabling the enhancement of detection limits for weak photopeaks situated in areas of a higher background, such as the 122 keV photopeak of ^{57}Co.

As far as the peak reduction factor is concerned, Table 2 contains the calculated R_p values for the most prominently detected photopeaks of each isotope in two of the VERDI samples along with their uncertainty in 1σ.

R_p is ≈1 for ^{57}Co and ^{54}Mn, which are detected by the CSS as non-cascade isotopes, since both the HPGe and NaI aluminum endcap cut off the 14 keV photon of ^{57}Co. Low R_p values are observed for cascade emitters ^{102m}Rh, ^{110m}Ag and ^{182}Ta, where events are rejected due to the detection of more than one photon in the main and secondary detectors simultaneously. It is noted that Ta is a trace element impurity in the material of the Y foil.

Table 2. *Peak Reduction Factor for the detected photopeaks of interest in two VERDI detectors*

Foil	Nuclear reaction	Isotope	Energy (keV)	Peak Reduction Factor (R_p)	
				ACT15	RADA13
Ni	^{58}Ni (n, np) ^{57}Co (67.8%) ^{58}Ni (n, d) ^{57}Co (32.2%)	^{57}Co	122.06	1.02 ± 15.21%	1.01 ± 13.01%
Rh	^{103}Rh (n, 2n) ^{102}Rh	^{102m}Rh	475.06	0.36 ± 10.65%	0.46 ± 11.06%
Mn	^{55}Mn (n, 2n) ^{54}Mn	^{54}Mn	834.85	1.08 ± 10.91%	1.00 ± 9.50%
Ag	^{109}Ag (n, γ) ^{110m}Ag	^{110m}Ag	657.69	0.04 ± 7.33%	0.04 ± 7.58%
Y	^{181}Ta (n, γ) ^{182}Ta	^{182}Ta	1222.09	0.51 ± 9.34%	0.62 ± 9.11%

CONCLUSIONS

The performance of a Compton Suppression System was investigated for the analysis of multi-foil VERDI detectors irradiated with a DD plasma source at JET. It was found that the CSS led to an overall reduction factor of ~2.9 in the continuum in all samples containing foils. From the analysis of the individually detected photopeaks, it is concluded that this device enhances detection capabilities for non-cascade isotopes, while it has adverse effects in the study of cascade emitters, so for these radionuclides the unsuppressed spectra should be employed for the analysis instead.

Acknowledgments

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