

## High-energy neutron characterization of scintillator and solid-state detectors for lost fast ions measurements in JT-60SA and ITER

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### 1 Introduction

In JT-60SA [2] a high neutron flux on the first wall and on the FILD of up to  $10^{12} \text{ s}^{-1} \text{ cm}^{-2}$  coming from D–D fusion reaction is foreseen. Therefore, assessing the neutron response of the active component employed in the detector is vital for FILD operation on JT-60SA as well as in other future fusion devices. In order to assess the neutron sensitivity of the scintillator employed in the FILD, called TG–Green [3], to 2.5 MeV and 14.1 MeV a specimen of said scintillator has been tested at the *Frascati Neutron Generator* (FNG) [4].<sup>1</sup>

Two solid state detectors, a Single-crystal Diamond Detector (SDD) and a Silicon Carbide Detector (Sic), were also analyzed and identified as suitable alternatives for FILD operation.

### 2 TG–Green neutron sensitivity

A 10  $\mu\text{m}$  specimen of TG–Green scintillator ( $\text{SrGa}_2\text{S}_4:\text{Eu}^{2+}$  with density  $3.65 \text{ g cm}^{-3}$ ) [3] deposited on a 0.5 mm stainless steel (SAE 304) has been irradiated with 2.5 MeV and 14.1 MeV

<sup>1</sup>FNG can provide a flux of up to  $10^{11} \text{ ns}^{-1}$  at 14.1 MeV and  $10^9 \text{ ns}^{-1}$  at 2.5 MeV when operated in D–T and D–D mode, respectively, and with high precision control of the neutron flux, thank to a series of absolutely calibrated reference detectors [5]. For this reason, measurements at FNG have a very high quantitative accuracy.

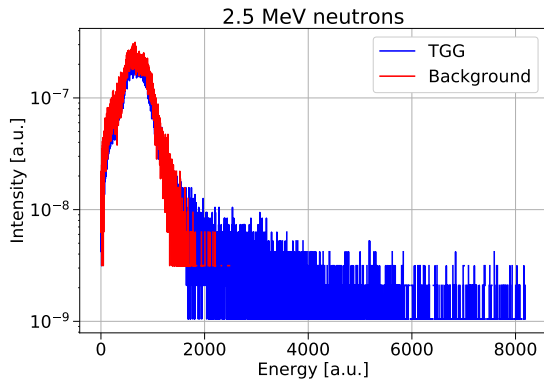


Figure 1: Recorded TG-Green spectrum (blue) and background (red) using the pure graphite case.

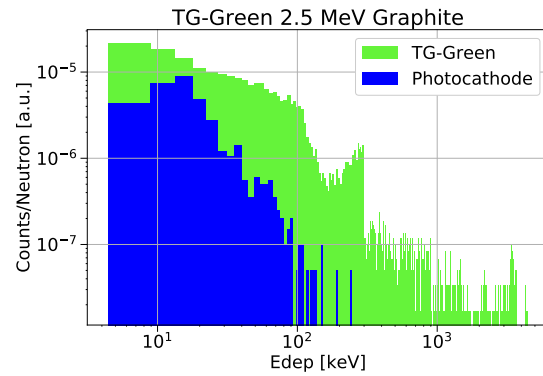


Figure 2: Simulated deposited energy in TG-Green (green) and PMT window (blue)

neutrons at the FNG. The scintillator was coupled to a photomultiplier tube (PMT) and housed in a case in order to seal out ambient light and hold the setup into place.

Figure 1 shows an example of the measured spectra. The red line is the background spectrum measured by exposing to the neutron flux the setup with the TG-Green scintillator removed. The blue line is the spectrum measured by exposing the whole setup, including the scintillator, to the neutron flux. For sake of simplicity, here we just show the data obtained with 2.5 MeV with the most promising setup, i.e. the one made of pure graphite; similar comparisons have been made also for the other cases, i.e. 14.1 MeV and aluminum support/shielding. The difference in the two spectra is ascribable only to the TG-Green scintillator, and is thus a measure of the TG-Green neutron sensitivity.

A series of GEANT4 [6] simulations have been performed as a support for the interpretation of the collected data (see figure 2). Comparing the data and simulations, we concluded that:

- the majority of the collected counts are due to secondary charged particles originated into the whole setup (not directly into the TG-Green) via neutron-induced nuclear reactions;
- the scintillator itself and its support plate are origin of only a small components of counts;
- because a major source of counts is due to protons from the  $^{27}\text{Al}(n, p)^{27}\text{Mg}$  reaction, the induced background is strongly reduced with the use of a pure graphite support/shielding.

The latter consideration is of special importance for the envisaged application. In fact, the design of the FILD detector for JT-60SA includes a detector housing and shielding made in graphite, in order to minimize the possible background sources. Moreover, we have to underline that the setup used in the present measurements is less favorable in terms of neutron-induced

background compared with the envisaged FILD setup. This is due to the fact that in the setup used in FNG the PMT is closer (about 500 mm) to the source, while in the FILD the PMT will be located away from the plasma and the light from the scintillator will be collected via a suitable optics. As a consequence, the estimated number of background counts normalized to the total neutron fluence, constitutes an absolute maximum for the expectable neutron-induced background of the FILD. Such background resulted, in the case of 2.5 MeV neutrons, to be of about  $2 \times 10^{-4}$  counts/neutron for the full system (scintillator, support/shielding and PMT); only about  $10^{-5}$  counts/neutron can be ascribed to the TG-Green itself.

### 3 SDD and Sic neutron efficiency

Solid state detectors represent a valuable alternative to scintillators for the detection of charged particles in a FILD system. The most promising are SDD and Sic detectors, that have proven useful solid-state detectors in harsh environments like burning plasma devices [7, 8, 9]. Both SDD and Sic can be realized with lateral dimensions of about 5 mm, i.e. compatible with the expected space resolution of the FILD for JT-60SA. The optimal crystal thickness for FILD use is 10  $\mu\text{m}$  to 20  $\mu\text{m}$  in order to minimize the neutron sensitivity while maintaining an ion sensitivity in the order of 100 %. It has been found difficult to obtain high-quality SDD crystals of said thickness due to manufacturing issues.

A 500  $\mu\text{m}$  SDD and 100  $\mu\text{m}$  Sic have been tested. The efficiency of the two detectors to be 2.5 MeV neutron resulted to be around  $1.8 \times 10^{-3}$  MeV for the SDD and of about  $3.5 \times 10^{-4}$  MeV for the Sic detector.

Those values are compatible with the theoretical results based on cross-section calculations and they show that the efficiency to neutrons just scales with volume, as expected. This result implies that the extrapolated neutron-induced background for 10  $\mu\text{m}$  to 20  $\mu\text{m}$  thickness detectors would be of about  $7 \times 10^{-5}$  for both crystals, a very similar value to the one expected for TG-Green based detector systems.

### 4 Conclusions

A specimen of TG-Green scintillator has been exposed to 2.5 MeV and 14.1 MeV neutrons in order to assess its sensitivity to neutrons.

It has been found that the neutron sensitivity is  $10^{-5}$  for 2.5 MeV neutrons. Therefore, it is possible to forecast that  $10^7 \text{ s}^{-1} \text{ cm}^{-2}$  events will be ascribable to the neutron background JT-60SA FILD. As a reference in AUG FILD,  $10^{14} \text{ s}^{-1} \text{ cm}^{-2}$  counts are produced by fast ions.

Furthermore alternatives to the scintillator to be used in the FILD have been investigated. Two solid state detectors, the SDD and the Sic detector, have been characterized with 2.5 MeV neutrons. The neutron sensitivity of both solid state detectors scales with thickness as expected suggesting that a semiconductor crystal could be tailored to optimize the  $S/B$  for FILD applications.

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