International Conference on Diagnostics For Fusion Reactors: the Burning Plasma Era (ICFRD2025)

Contribution ID: **36**

Type: **Short Contributed Oral**

MCNP-based characterization of the High-Energy Background in gamma ray spectrometers for fusion power measurements in DT plasmas

Wednesday 3 September 2025 12:15 (15 minutes)

Accurate measurement of fusion power in tokamaks is vital for operational control, licensing, and scientific research. Conventionally, this is achieved by detecting neutrons produced in the T(D,n)^{4}He reaction. A novel alternative, gamma-ray spectroscopy of the T(D,γ)^{5}He reaction, has recently been demonstrated at JET [1,2]. Unlike neutron diagnostics, which require detailed knowledge of plasma distribution and the computation of adjoint flux via an MCNP reactor model, gamma-ray diagnostics demand only knowledge of the plasma volume along the detector's line of sight, thereby simplifying and accelerating the calibration procedure.
Despite its advantages, this gamma-ray technique introduces several complexities, such as the need to design an effective neutron attenuator, necessitated by the T(D,γ)^{5}He reaction's low branching ratio of $2.4\cdot10^{-5}$ relative to T(D,n)^{4}He, and the challenge of understanding the origin of high-energy gamma background.
To investigate the source of background in the 15–20 MeV energy range, beam-on-target experiments were performed at FNG, supplemented by MCNP simulations. Results identified steel and copper near the target as the dominant contributors to high-energy background, consistent with findings reported in literature [3].
Further analyses were carried out in the context of the JET tokamak, by developing an MCNP model aimed at the characterization of the high energy gamma background of the 3×6 $LaBr_3$ gamma-ray detector used during JET campaigns.
Due to the low probability of gamma reactions in the high energy region, variance reduction techniques, such as Weight Windows, DXtran, and F5 tallies, were employed to improve simulation efficiency. Analyses of these methods, as well as a comparison between nuclear libraries, will be presented. Final validation of simulation outcomes will be performed against experimental results, and the role of gamma-ray diagnostics in future fusion devices, including ITER, DEMO, BEST, and SPARC, will be evaluated.

[1] Rebai M et al. "First direct measurement of the spectrum emitted by the H3(H2,γ)He5 reaction and assessment of the relative yield γ1 to γ0."Phys Rev C. 30 July 2024;110(1):014625.
[2] Dal Molin A et al. "Measurement of the Gamma-Ray-to-Neutron Branching Ratio for the Deuterium-Tritium Reaction in Magnetic Confinement Fusion Plasmas."Phys Rev Lett. 30 July 2024;133(5):055102.
[3] Parker, C. E. (2016). "The ^{3}H(d,γ) Reaction and the ^{3}H(d,γ)/ ^{3}H(d,n) Branching Ratio for Ec.m. ≤ 300 keV" [Doctoral dissertation, Ohio University]

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Track Classification: Fusion Technologies