In-situ neutron calibration technology on future D-T fusion devices

Changlin Lan[1], Bo Xie[1], Haiqing Liu[2], Ruijie Zhou[2], Xiaodong Pan[1]
[1] School of Nuclear Science and Technology, Lanzhou University,
[2] Institute of Plasma Physics, Chinese Academy of Sciences
e-mail (speaker): lanchl@lzu.edu.cn

The pursuit of controlled nuclear fusion – envisioned as a clean, efficient, and virtually limitless ultimate energy source – confronts a pervasive and critical challenge: core reactions, particularly the deuterium-tritium (D-T) reaction central to future energy prospects, release immense amounts of energy accompanied by abundant high-energy neutrons. These neutrons are not merely direct products of the fusion reaction; they constitute crucial carriers of the reactor's energy output, accounting for approximately 80% of the total energy released in a D-T reaction. Consequently, the precise and reliable measurement of neutrons produced within fusion devices, known as neutron diagnostics, represents a fundamental task within the entire field of fusion research. It is essential for determining the neutron emission rate, a key parameter of the device, which in turn dictates the accurate assessment of fusion power – a key metric of device performance.

However, when operated continuously within the harsh, complex environment of fusion devices, neutron diagnostic systems are inevitably subject to drift or degradation in key performance parameters – such as detection efficiency and energy response. This uncertainty propagates directly to the measurements, introducing systematic biases in the assessment of neutron yield and fusion power. To ensure the long-term accuracy, reliability, and comparability of fusion parameter diagnostics, the development of in-situ neutron calibration techniques specifically designed for reactor environments, and the establishment of corresponding calibration systems, becomes indispensable.

This paper presents a systematic review of in-situ neutron calibration, a critical enabling technology for fusion research, covering its development internationally and implementation in China. First, the article introduces globally representative magnetic confinement fusion devices and traces the origin, evolution, and application of international in-situ neutron calibration techniques. By synthesizing decades of research, it highlights significant progress achieved in the field.

Furthermore, the article systematically summarizes and analyzes the current application of in-situ neutron calibration techniques on representative fusion devices. It places particular emphasis on the TFTR (Tokamak Fusion Test Reactor) and JET (Joint European Torus), as the only two devices to have conducted D-T fusion reactions. The analysis encompasses: detailed methodologies employed (e.g., mobile ^{252}Cf sources, compact D-D/D–T neutron generators, or plasma self-generated neutrons serving as internal standards); deployed system architectures; achieved technical specifications; and practical operational procedures. Concurrently, it critically examines the strengths and limitations demonstrated by existing techniques across diverse device environments, highlighting advantages, shortcomings, and common challenges.

Finally, the article addresses magnetic confinement fusion research in China. It details the specific work and phased experience gained in researching and applying in-situ neutron calibration techniques on major domestic devices like the Experimental Advanced Superconducting Tokamak (EAST) and HL-2A/M.

At the end, this work delineates the core challenges and critical scientific/technological bottlenecks for developing in-situ neutron calibration for future Chinese D-T devices.

References

[1] Bertalot, L., et al. "Present status of ITER neutron diagnostics development." Journal of Fusion Energy 38 (2019): 283-290.
[2] Hendel, H W, et al. "In situ calibration of TFTR neutron detectors." Review of Scientific Instruments; (USA), vol. 61:7, Jul. 1990.
[3] Strachan, J. D., et al. "Neutron calibration techniques for comparison of tokamak results." Review of scientific instruments 61.10 (1990): 3232-3232.
[4]Hoenen, F., et al. "In situ calibration of neutron detectors on TEXTOR." Review of scientific instruments 63.3 (1992): 1945-1952.
[5]N. Pu, et al. "In situ calibration of neutron activation system on the large helical device." Rev. Sci. Instrum. 1 November 2017; 88 (11): 113302.
[6]Batistoni, Paola, et al. "14 MeV calibration of JET neutron detectors—phase 2: in-vessel calibration." Nuclear Fusion 58.10 (2018): 106016.