IN-SITU CALIBRATION OF NEUTRON FLUX MONITOR FOR HL-3 TOKAMAK

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Neutron flux monitors, as fusion power measurement systems are important for ITER and future fusion reactors because the ultimate goal of fusion research is to output fusion power. The neutron flux monitor then needs to be calibrated in-situ in order to obtain the fusion power from the measurements. Calibrated neutron sources are of limited strength and have different energy properties and spatial distributions than plasma sources. Therefore, in-situ calibration is a very complex task. Lots of effort and time went into the in-situ calibration at many devices [1-2]. Machine time for future fusion devices is very valuable. It is very attractive to reduce the use of machine hours and to perform in-situ calibrations efficiently. In January 2025, HL-3 occupied the tokamak for a total of 14 hours for in-situ calibrations.
The Neutron Flux Diagnostics consists of five B-l0 counters for low neutron flux measurements, and five U-235 fission chamber detectors, arranged as shown in Fig. 1. The B-10 counter has a sensitivity of about 3 cps/nv, was placed in 5 cm polyethylene moderator. Additionally, a 2 cm lead barrier is positioned between the detector and the polyethylene to further attenuate gamma rays' interference [3]. Two high sensitivity fission chambers (No. 1 and 2) are about 1-2 g U-235, three other low sensitivity fission chambers (No. 3, 4 and 5) are about 0.1 g U-235. All fission chambers were placed in a 3 to 5 cm polyethylene moderator.

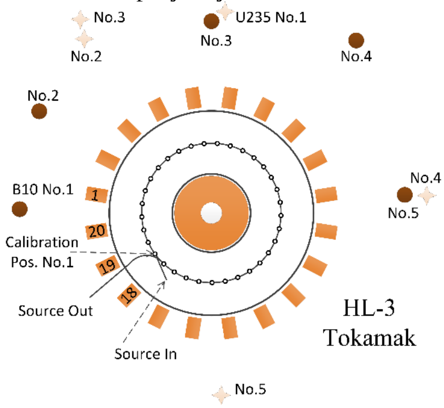

Fig. 1 Detector arrangement of the HL-3 neutron flux monitor, and schematic diagram of the calibration structure and distribution of calibration points

The neutron source used for the calibration was the Cf-252 neutron source with an intensity of about 6.71×10^6 n/s. The position control structure of the neutron source consists of an aluminum-plastic tube and a rope inside it. The tube is approximately 15 meters long, with an outside diameter of 32 mm and an inside diameter of 26 mm. During installation, the engineers pulled the tube into the vacuum chamber through the window between the toroidal field coils #18 and #19. During the pull-in process, the engineers manually bent the tube gradually to bring it closer to the magnetic axis position. The tube was then secured to bolts inside the vacuum chamber by means of ropes. Based on the measurement results, the engineers adjusted the tension of the rope to ensure the precise position of the tube. The shape of the completed tube, as well as the inlet and outlet of the neutron source, are shown in Figure 1. The whole installation process took about 2.5 hours. Dismantling after calibration took 1 hour. Since the pipes in the inlet and outlet sections were off the magnetic axis, the first and last points of the calibration were determined near the end of the inlet section and the beginning of the outlet section, respectively. The other points were then reasonably evenly divided, and a total of 33 calibration points were identified, which are marked in Fig. 1. The calibration was conducted during the night and lasted 10.5 hours.
After subtracting the detector background measured before calibration, the efficiencies at different locations considering statistical errors are shown in Fig. 2. The errors in most of the results are not significant, except for a few points in the low-sensitivity fission chamber. The detection efficiencies of the detectors were obtained by averaging, with the B-10 counting tubes and the high-sensitivity fission chambers having a detection efficiency

error of less than 1%, and the rest of the detectors at about 3%. At low neutron fluxes, the highest sensitivity count rate was set to greater than 4.5 kHz, taking into account the 1-ms time resolution and 20% total uncertainty. Then the calibration results show that the most sensitive neutron detector can cover measurements up to 1×10^{10} n/s, and the least sensitive neutron detector can cover measurements up to 1.7×10^{17}n/s if the maximum count rate reaches 1×10^{9} Hz, as shown in Fig. 3.

Using a neutron source with an intensity of 6.71×10^{6} n/s, we completed the calibration of the HL-3 tokamak neutron flux measurement system with a measurement range of 1×10^{10} n/s to 1.7×10^{17} n/s in less than 1 day. For the ITER neutron measurement system with a range of 1×10^{14} n/s to 2×10^{20} n/s, the maximum measurement range is three orders of magnitude higher than that of the HL-3 system. If a neutron source with an intensity of 6.71×10^{9} n/s is used, small neutron generators of this intensity exist, the two are closer in terms of calibration difficulty and complexity, and the calibration time required is similar. Based on the above comparative analysis, this similarity suggests that our low-range calibration experience is still of some reference value despite the higher measurement range and system complexity of ITER. By learning from our calibration strategy, time planning, and resource allocation methods, the calibration process of the ITER neutron measurement system is expected to be optimized to improve efficiency and reduce potential uncertainties.

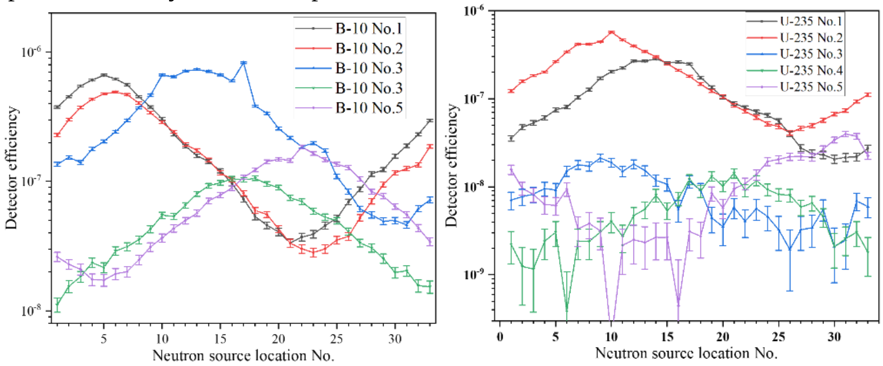

Fig. 1 In-situ calibration results for detector efficiency

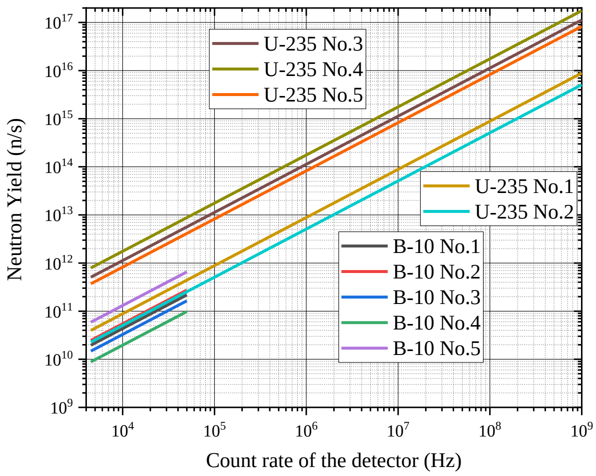

Fig. 3 Measuring range of the detector.

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