PRELIMINARY DESIGN AND DEVELOPMENT OF NEUTRON ACTIVATION SYSTEM ON CN HCCB TBS

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Abstract：

This paper presents a comprehensive system design of the Helium-Cooled Ceramic Breeder Neutron Activation System (HCCB NAS), a critical subsystem within the CN HCCB Test Blanket System (TBS) for the ITER project. As an auxiliary system, the NAS measures neutron flux and fluence within the HCCB Test Blanket Module (TBM) to validate its design. The system comprises irradiation ends, sample capsules, a pneumatic transfer system, and a counting station. During operation, encapsulated samples are activated by fusion neutrons and transported via helium gas through dedicated tubing to a counting station. The main capsule transfer process is illustrated in Figure 1. The pneumatic transfer system includes gas supply mechanisms, transfer stations, connecting lines, disposal bins, and a Programmable Logic Controller (PLC)-based control subsystem, enabling precise monitoring of temperature, pressure, flow rate, and capsule positioning. Key components, such as the transfer station and capsule loader, have been successfully manufactured, and a test circuit for the NAS is under construction to evaluate the pneumatic system's performance.

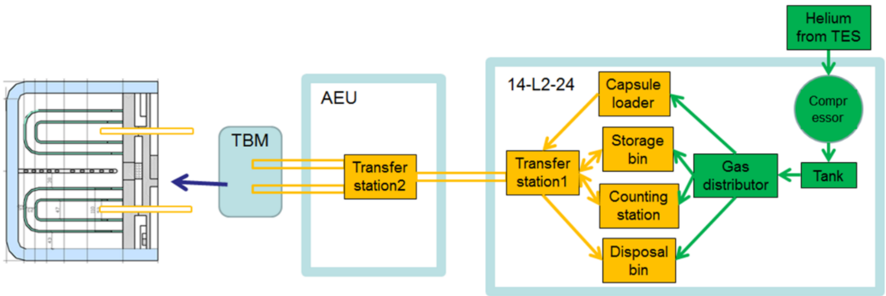

Figure 1 Main transfer process of HCCB TBS NAS

The NAS is composed of several key parts, namely the irradiation end, pneumatic transport system, transfer station, capsule loader, and counting station. Its main components are located in designated areas such as 14 - L2 - 24 and 11 - L1 - C18. The current layout of the NAS in 14-L2-24 is shown in Figure 2. Austenitic steel (AISI 316L) is selected as the primary material for piping and components because of its outstanding corrosion resistance and weldability. S304 steel is used for the supporting structure, offering a balance of performance and cost - effectiveness. Grade 660, with its high strength, is chosen for bolts and washers. The design operation parameters of the NAS, including those of the cooling loop, measurement loop, and irradiation ends, are precisely defined. In the cooling loop, for example, the pressure is set at 1.2 MPa, the mass flow - rate at 0.003 kg/s, and the temperature at 100 °C.

The NAS operates in 12 well-defined states (see Figure 3), closely synchronized with the HCCB TBS and ITER operational phases. Each state has specific parameters and permitted transitions. Design limits for equipment are explicitly defined; for instance, the capsule loader has a maximum allowable pressure of 1 MPa and temperature of 100 °C.

During operation, the NAS adheres strictly to the ITER Operation Handbook, with maintenance minimized to reduce costs and radiation exposure. Maintenance strategies vary by location:

a) In the restricted Port Cell (11-L1-C18), long-term maintenance (LTM) is performed in the Hot Cell, while other states involve only online inspections or data backups.
b) In the Vault Annex (14-L2-24), short-term maintenance (STM) includes valve testing and instrumentation calibration, whereas LTM permits comprehensive activities.

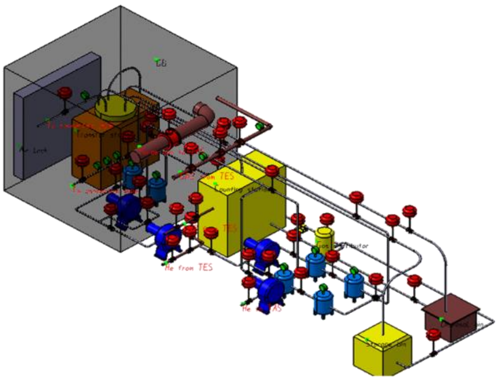

Figure 2 NAS layout in 14-L2-24

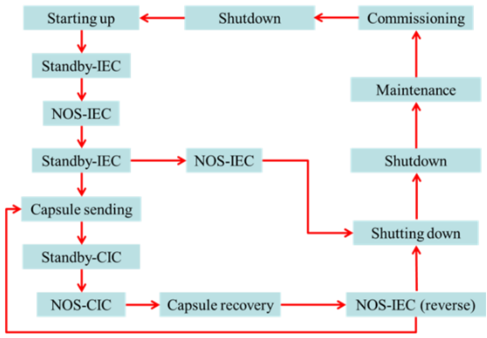

Figure 3 Defined 12 operational states for NAS

Safety is of utmost importance for the NAS. It adheres strictly to ITER's safety guidelines to protect workers, the public, and the environment. The safety objectives include effectively confining and controlling radioactive and energy sources, preventing accidents, and minimizing radioactive waste. Key safety principles such as ALARA (As Low As Reasonably Achievable), Defence-in-Depth, and Passive Safety are implemented. Components are classified based on safety importance, seismic requirements, quality, and pressure equipment regulations. Most components are classified as SIC - 1 or SIC - 2 in terms of safety importance and are designed to meet the ITER SC - 1 earthquake category requirements for seismic classification.

In terms of constructability, most components are sourced from the market, and pipes are manufactured internally. Welding is the main construction method, especially in areas like the Ancillary Equipment Unit (AEU), to minimize leakage. The initial assembly follows a meticulous process, including thorough cleaning of components, precise fixing in position, and secure connection. After the system is assembled or any maintenance activity that breaks the pressure confinement is carried out, commissioning is conducted to verify the system's reliability. Once the NAS reaches the end of its life cycle, all components will be decommissioned and transported back to China.

Verification and validation analyses have been carried out to ensure the integrity of the design. These analyses cover stress analyses of pipes, metallic structural supports, and closure systems, guaranteeing that the design meets all relevant code criteria. The validation also includes demonstrating compliance with Essential Safety Requirements (ESRs) of ESP/ESPN regulations, issuing a preliminary hazard and risks analysis, and validating that the loads transmitted to embedded plates are within the allowable limits. Overall, the HCCB NAS is designed to meet the complex requirements of the ITER project, ensuring reliable operation and safety.

The NAS design represents a robust and safety-focused approach to neutron flux monitoring within the HCCB TBS. By adhering to ITER's stringent safety and operational requirements, the NAS ensures reliable performance, minimal maintenance, and effective containment of radioactive materials. The detailed design, comprehensive I&C system, and thorough maintenance planning position the NAS as a critical subsystem for the successful operation of the ITER project. Future work will focus on refining the design based on ongoing analyses and preparing for system assembly and commissioning.