Definition of the Q-PETE Experiment for Investigation of Hydrogen Isotopes Permeation through the Metal Structures of a DEMO HCPB Breeder

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Objectives and rationale of the Q-PETE experiment

In the HCPB, bred tritium is purged by a flow to the tritium extraction system. Tritium permeates into/through structures (cooling plates, pipes).

The Q-PETE (Hydrogen Permeation and Transport Experiment) was designed as a “purged permeation setup” with morphology, materials, temperatures and hydrogen partial pressures relevant for the HCPB:

1. To produce relevant benchmark data for codes to predict the tritium losses in purged scenarios (application for safety and tritium budget).
2. To directly derive material properties (Diffusivity, Sieverts constant).

Experimental setup and procedure

The Q-PETE/D2 experiment setup is composed of:

1. A temperature controlled permeator setup enclosed in a vacuum vessel:
   a. The “retentate chamber” (formed by a stainless steel flange) is flooded and continuously supplied with hydrogen containing feed gas (Argon + Deuterium).
   b. The “membrane” (1.2 mm Eurofer disk), through which the hydrogen permeates (time dependent flux $J_{\text{D2}}(t)$).
   c. The “permeate chamber” receives the permeated hydrogen from the membrane.

2. A pure argon sweep flow collects the permeated hydrogen from the permeate chamber and transports it to a quadrupole mass spectrometer for time resolved quantitative detection.

3. The setup is completed with a vacuum system, controlled purge gas supply and a temperature control system (200-600°C).

Characterization of mass spectroscopy method

Low noise and low background level of the mass spectrometer are key properties for successful experiments, because this allows sufficiently high purge gas flow rates to minimize residence time induced signal distortions.

- The noise level was characterized dependent on the deuterium concentration, spectrometer dwell time and secondary electron multiplier (SEM) voltage (selected value 1400 V). We envisage signal levels of 0.5 – 20 ppm and sampling times 0.1 – 2 s.

- The background level at m/z=4 ($D_2$, H2) was systematically optimized:
  1. A needle valve was installed at the spectrometer outlet to keep the system pressure near 0.4 bar (g) over atmospheric pressure (to antagonize possible (helium) leaks in the valves of the inlet system).
  2. The unused part of the spectrometer inlet system are continuously evacuated by a membrane pump or turbomolecular pump to avoid any leakage into the measurement.

- The background is well suppressed and significantly lower than the corresponding limit of detection LOD 43 ppm of the GAM300.

(Summary diagrams)

Summary and Conclusions

- Q-PETE/D2 was designed and optimized for HCPB-relevant $D_2$ permeation through metal membranes at 200 - 600 °C for code validation.

- Time resolved measurements will be performed with mass spectroscopy. The method was optimized to suppress the background to ~ 5 – 20 ppb (below limit of quantification).

- The limit of detection is 43 ppb and limit of quantification 141 ppb are well suited for measuring the expected signals with levels of 0.5 - 20 ppm ($D_2$).

- The Q-PETE experiment is assessed to be fit for its purpose and is currently under construction.