Tritium Permeation Rate Estimation of HCCR-TBS NAS

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1. Introduction

The Helium Cooled Ceramic Reflector (HCCR) Test Blanket System (TBS) Neutron Activation System (NAS) comprises two irradiation ends and its ancillary systems such as transfer system, counting system and connection pipes between them. The HCCR-TBS NAS (Figure 1) measures the neutron fluxes and spectra, providing incident neutron information to HCCR-TBM and verifying neutronics calculation related.

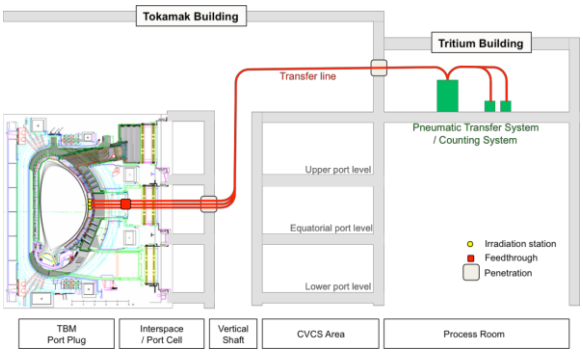

Figure. 1 Schematics of CCWS-1

2. Description of model

NAS has two irradiation ends and no direct connection with TES (Tritium Extraction System) nor HCS (Helium Cooling System), therefore, tritium inventory of NAS is mainly caused by permeation through structural material and vacuum. Figure 2 is a CAD drawing which shows allocation of each NAS pipe. According to current design of NAS, there are two tritium migration paths.

Path1 (irradiation end A): This end is allocated inside of TBM sub-module. Tritium permeation takes place from the empty space between breeding zone box and external box structure to NAS tubes. Tritium migration from irradiation end to neighbouring volumes happens along the transfer lines during NAS operation.

Path2 (irradiation end B): This end is allocated back side of TBM back manifold. It is assumed that tritium permeation in this volume is negligible. Because there is no meaningful tritium source near this end.

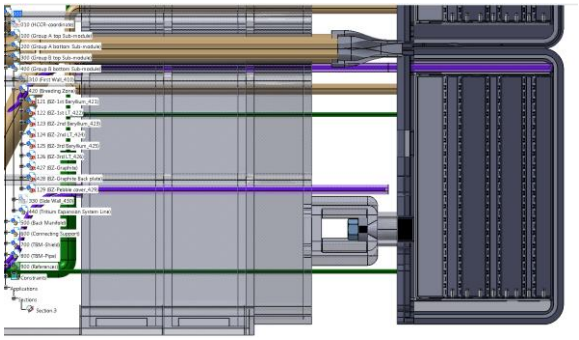
Figure. 2 Schematics of NAS Location

One transfer line consists of two SS316L tubes, whose outer diameter and thickness are 12 mm and 1.5 mm, respectively. Total length of in-vessel and in-port transfer line is about 60 m. For irradiation ends A and B in-vessel parts mostly, whose outer diameter and thickness are 30 mm and 2 mm, respectively.

It is assumed that the temperature of the irradiation end in TBM sub-module is 450°C, which is corresponding to TES outlet temperature. Transfer lines in port interspace are assigned to be 200°C, which is very conservative, based on the calculation result [1] and NAS tubes in port cell, gallery and tritium building are considered as room temperature (25°C) due to natural convective cooling of spaces (Table 2).

3. Assumptions

To estimate the release of tritium in a NAS, followings were assumed.

- Tritium production is given by neutronics calculation. (no extra tritium flux from plasma)
- Continuous back to back plasma pulse with duty factor 0.25.
- Steady state condition (instantaneous tritium diffusion to the purge gas isotropically)
- Averaged tritium generation rate (constant over the time and uniform in the TBM volume)
- Transport mechanism through structural materials is bulk diffusion.
- Tritium in NAS tube is accumulated over time. (no service vacuum system)
- Tritium concentration in space is constantly zero to estimate conservative release rate.
- Averaged temperature and pressure for each region

4. Modeling

To estimate the release of tritium through NAS, Fick's laws of diffusion was used and general expression of the law is,

$$J(t) = \frac{K}{PRF}(\sqrt{P_1} - \sqrt{P_2})$$

$$K = \mathrm{D_S} \cdot S = F \cdot \exp\left(-\frac{E}{RT}\right)$$

$$Q = \frac{A}{l}\int J(t)\,dt$$

where,
J(t):Permeation flux [molm^{-1}s^{-1}]

K : Permeability [molm^{-1}s^{-1} Pa$^{-0.5}$]
S : Solubility [molm^{-3}Pa$^{-0.5}$]
D_s : Diffusivity of tritium in a solid metal [m^{2}s^{-1}]
F: Pre-exponential factor of tritium permeability [molm^{-1}s^{-1}Pa$^{-0.5}$]
P_1,P_2 : Tritium partial pressure [Pa]
A : Surface area [m^2]
L: Thickness of material [m]
Q : Amount of permeated tritium [mol]
PRF : permeation reduction factor [-]

5. Material properties

Structural material for HCCR-TBM NAS tubing is considered to be SS316L. Capsules (Carbon Fiber reinforced Carbon) were not taken into account for tritium permeation. Material properties were given by benchmark guideline [2], therefore, AISI-316L were chosen for estimation of diffusivity, solubility and permeability of hydrogen isotopes in the pipes.

Parameter	Value/correlation	Unit
Sieverts' constant AISI-316L	1.47·exp(-20600/RT)	mol· m^{-3}· Pa$^{-0.5}$
Diffusivity AISI-316L	7.66·10^{-8}·exp(-42500/RT)	m^2· s^{-1}

Table. 1 Tritium transport parameters

6. Calculation results

Based on the given tritium permeation model and boundary conditions, tritium release rate from NAS of HCCR TBS is presented in table 2, which is estimated values after 500 cycles of operations. Due to negligible permeation of irradiation end B, this release is contribution of irradiation end A only.

Continuous operation 500 cycles postulate equivalent load over ten days of 3-shift back to back operation, which is nearly one campaign (11 days operation + 3 short term maintenance). Tritium concentration at the end of 500 cycles is 2.48E-01 Pa, however, it is drastically decreased in real situation. Because service vacuum system of ITER is continuously venting the used driving gas in NAS tubes.

Location	Tritium release rate(mg/day)	NAS Pipe Temperature (℃)
Port Interspace	1.49E-03	200
Port Cell	8.30E-08	25
Gallery	2.94E-07	25
Tritium Building	3.12E-07	25

Table.2 Tritium release rate at each location

7. Future Works

HCCR-TBS NAS design is evolving recently. When detail operation scenario and design are finalized, this draft tritium release estimation should be revised. But it is expected that the release could be negligible as oxide layer of pipe surface and service vacuum system exist.

8. Acknowledgement

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8. References

[1] Hyung Gon Jin, "HCCR-TBS Accident Analysis Report" ,QQL5TP V1.0 (2015)
[2] I. Ricapito, TBM Project team, F4E "Guideline for the Benchmark Exercise on Tritium Modelling of TBSs", TM9J3Q (2016)