

Role of Outgassing of ITER Vacuum Vessel In-Wall Shielding Materials in Leak Detection of ITER Vacuum Vessel

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Abstract. ITER Vacuum Vessel is a torus-shaped, double wall structure. The space between the double walls of the VV is filled with In-Wall Shielding Blocks (IWS) and Water. The main purpose of IWS is to provide neutron shielding during ITER plasma operation and to reduce ripple of Toroidal Magnetic Field (TF). Although In-Wall Shield Blocks (IWS) will be submerged in water in between the walls of the ITER Vacuum Vessel (VV), Outgassing Rate (OGR) of IWS materials plays a significant role in leak detection of Vacuum Vessel of ITER. Thermal Outgassing Rate of a material critically depends on the Surface Roughness of material. During leak detection process using RGA equipped Leak detector and tracer gas Helium, there will be a spill over of mass 3 and mass 2 to mass 4 which creates a background reading. Helium background will have contribution of Hydrogen too. So it is necessary to ensure the low OGR of Hydrogen. To achieve an effective leak test it is required to obtain a background below 1×10^{-8} mbar l s⁻¹ and hence the maximum Outgassing rate of IWS Materials should comply with the maximum Outgassing rate required for hydrogen i.e. 1×10^{-10} mbar l s⁻¹ cm⁻² at room temperature. As IWS Materials are special materials developed for ITER project, it is necessary to ensure the compliance of Outgassing rate with the requirement. There is a possibility of diffusing the gasses in material at the time of production. So, to validate the production process of materials as well as manufacturing of final product from this material, three coupons of each IWS material have been manufactured with the same technique which is being used in manufacturing of IWS blocks. Manufacturing records of these coupons have been approved by ITER-IO (International Organization). Outgassing rates of these coupons have been measured at room temperature and found in acceptable limit to obtain the required Helium Background. On the basis of these measurements, test reports have been generated and got approved by IO. This paper will describe the preparation, characteristics and cleaning procedure of samples, description of the system, Outgassing rate Measurement of these samples to ensure the accurate leak detection.

1. Introduction

ITER Vacuum Vessel ITER Vacuum Vessel is a torus shaped double wall structure. The space between double walls will be filled with In-Wall Shielding (IWS) Blocks and water. IWS Blocks will fill up about 60 % of volume between two shells. Schematic Diagram of In-Wall Shielding Block between the double walls of vessel is shown in figure-1. Main aims of these blocks are to provide neutron shielding during ITER Plasma Operation and to reduce the toroidal field ripple. There are certain requirements of high quality vacuum for the plasma which vacuum vessel along with IWS



blocks must satisfy. If vacuum Vessel does not meet the requirement, vacuum quality will be investigated by Helium Leak Testing. IWS blocks are made of (a) Borated Steel SS 304 B4 (1-1.25 % Boron), SS 304 B7 (1.75-2.25 % Boron), Ferrite Steel SS 430 and Support Structures are made of SS 316 L (N)-IG. Selection of these materials is based on comprehensive assessment of the functional, operational, technological and radioprotection requirements.

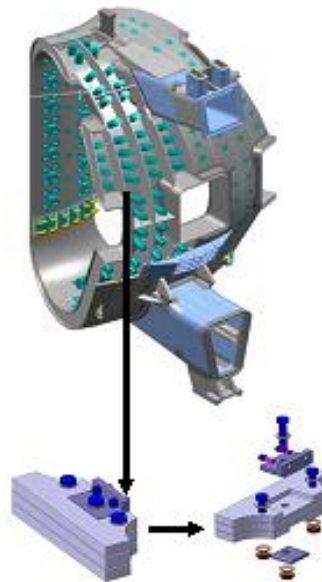


Figure 1. Schematic diagram of IWS Block.

2. Outgassing of IWS Blocks

Although IWS Blocks will remain in between the walls of vessel along with the water, yet play an import role in leak detection of ITER Vacuum Vessel. To provide high quality of vacuum and avoid any leak, Vacuum Vessel will be baked up to 200 °C after installing the In Wall Shielding Blocks in between the walls. It is not possible to eliminate or remove all the gas sources but it is very important to have a low Outgassing rate of IWS Materials and subsequently low Gas Load in Vessel [3]. The Outgassing of Hydrogen from Stainless Steel is the main gas load in Ultra High vacuum System [6] particularly in large systems. During manufacturing of IWS Materials it may possible that during rolling of material hydrogen gas can diffuse into the bulk of material which will result in the high outgassing of hydrogen in vacuum. Thus the hydrogen Outgassing is most significant limiting factor in reaching low Outgassing Rate in Stainless Steel vacuum Systems. By reducing the hydrogen content in bulk, hydrogen outgassing can be reduced. Water Vapor can be removed by baking the system. Outgassing results mainly from release gas molecules/atoms adsorbed on the surface and diffusive release of impurities present in the sub surface. IWS Materials undergo many operations like water jet cutting and CNC machining which may change the surface property of material and consequently the Outgassing rate. Thus the measurement of Outgassing Rate of IWS samples validates the manufacturing process of material as well as the component. Acceptable limit for Outgassing Rate of IWS Materials is $\leq 1 \times 10^{-10}$ mbar l s⁻¹ cm⁻² [1,2]

3. Samples for Outgassing rate Measurement

Measurement of Outgassing rate of IWS plates is not feasible so this measurement has been carried out on samples of IWS materials. These samples have been manufactured using the same techniques which are going to be used for production of actual IWS components. Three (03) samples of IWS Materials SS 304 B4, SS 304 B7, SS 316 L (N)-IG and SS 430 have been manufactured for the

measurement. IWS blocks are not accessible for maintenance and repair after fabrication of vacuum vessel. Hence, manufacturing and assembly procedures must be validated for IWS operational conditions. Surface area of each sample was $\sim 200 \text{ cm}^2$. Surface Roughness plays a crucial role in determination of Outgassing rate of material. IWS components will have machined and un-machined surface both. Ratio (f) of surface area of as received surface (roughness about $12.5 \mu \text{ Ra}$ maximum) and area of machined surface (roughness about $8.3 \mu \text{ Ra}$ maximum) is on an average 1.25 and same has been applied to Outgassing Samples. For plain stainless steel plates, Outgassing rate after baking for 48 hours at 200°C will not significantly vary for surface having roughness $12.5 \mu \text{ Ra}$ and $8.3 \mu \text{ Ra}$. Hence, IN-DA and IO agreed to carry out Out-gassing measurements for IWS material coupons having different values of (f). [4]

4. System Design

A system with known conductance has been designed to measure the Outgassing rate of IWS Materials which is shown in figure 2. This system can measure total gas load due to thermal outgassing and composition of various gases evolving from the material sample when exposed to different baking temperatures as a function of exposure time in vacuum. Material of system is SS 304L. Complete system is baked up to 200°C . The acceptance limit Outgassing rate of IWS materials as per In Wall Shielding Procurement Arrangement is $< 1 \times 10^{-10} \text{ mbar l s}^{-1} \text{ cm}^{-2}$ [1]. Before starting the measurement, system has been calibrated. This includes Gauge Calibration and Conductance Calibration. A schematic diagram of the system to measure the Thermal Outgassing rate of ITER VV-IWS Materials is shown in figure 2.

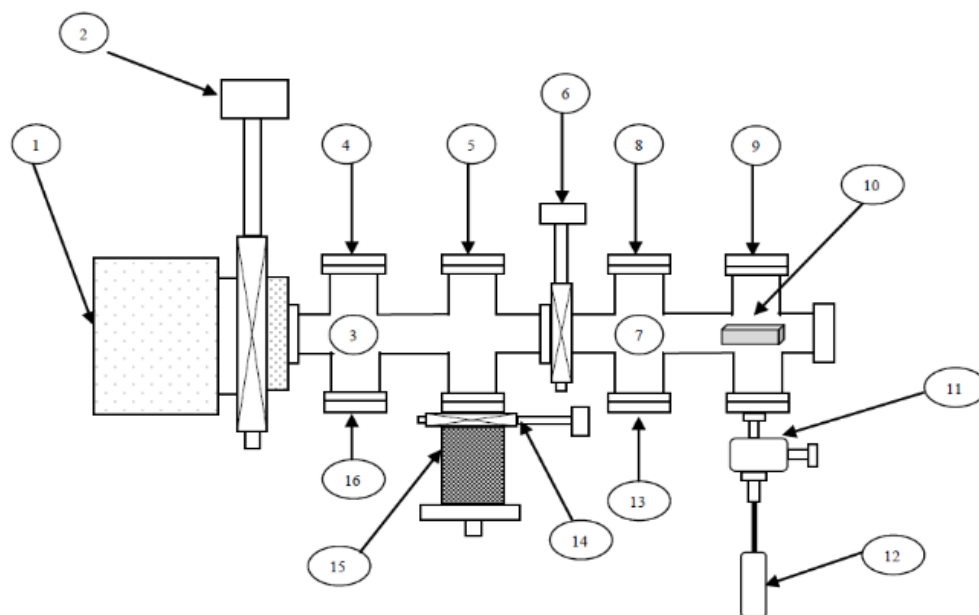


Figure 2. Design of Outgassing System.

1. Ion pump, 2. UHV Gate Valve, 3. Pumping chamber, 4. Pressure Gauge (Range: 1000 mbar to 1×10^{-9} mbar), 5. Residual Gas Analyzer (Range: 1 – 200 amu), 6. UHV Gate Valve, 7. Sample chamber, 8. Pressure Gauge (Range: 1000 mbar to 1×10^{-9} mbar), 9. Feed through for Temperature Measurement, 10. Sample coupon, 11. Variable leak valve, 12. Pressure gauge (Range: 2 bar to 1×10^{-2} mbar), 13. Extra port for venting valve, 14. UHV Gate Valve, 15. Turbo molecular pump, 16. Extra port.

4. Method of Measurement of Outgassing rate

The basic parameter measured in the system is gas load. The gas load is measured by measuring the pressure difference across a known conductance. The system measures the flow of the gas evolving from the sample material due to Thermal Out-gassing and the specific Thermal Out-gassing rate Q_{th} is given by

$$Q_{th} = C \Delta P/A \quad (1)$$

where, C = Known conductance (l/s)

ΔP = Pressure difference across the conductance (mbar)

A = Area of the desorbing surface- measurable physical area of the sample (cm²).

The measured Outgassing rate is the net rate of the difference between the intrinsic Outgassing Rate of the surface and the re-adsorption rate [5].

Outgassing rates of different samples of IWS Materials measured at Room Temperature is listed in table 1, table 2, table 3 and table 4 which satisfies the acceptable criterion.

Table 1. Outgassing Rate of SS 304 B7

Samples	Values (mbar l s ⁻¹ cm ⁻²)
Sample-1	2.30×10^{-11}
Sample-2	3.48×10^{-11}
Sample-3	1.65×10^{-11}

Table 2. Outgassing Rate of SS 304 B4

Samples	Values (mbar l s ⁻¹ cm ⁻²)
Sample-1	1.01×10^{-11}
Sample-2	3.48×10^{-11}
Sample-3	4.27×10^{-11}

Table 3. Outgassing Rate of SS 316 L (N)-IG

Samples	Values (mbar l s ⁻¹ cm ⁻²)
Sample-1	6.22×10^{-11}
Sample-2	3.78×10^{-11}
Sample-3	2.88×10^{-11}

Table 4. Outgassing Rate of SS 430

Samples	Values (mbar l s ⁻¹ cm ⁻²)
Sample-1	3.04×10^{-11}
Sample-2	3.75×10^{-11}
Sample-3	3.90×10^{-11}

Gas Load in Vacuum vessel comes from all the sources which can be found in system. Those sources need to be considered separately. Hence, total Surface area of Shield Blocks and Interspace of vessel for one sector is calculated which comes out approximately 2000 m². Total Gas load can be

determined by multiplying the Outgassing rate of Materials with surface area covered. As determined from experiments, order of Outgassing Rate of IWS materials is same so to estimate the Gas load, Outgassing rate is averaged out and multiplied by surface area and hence the Gas Load for One Vessel Sector comes out as 9.3×10^{-6} mbar l s⁻¹.

5. Conclusion

Outgassing rate of IWS Materials in vacuum under ITER operating conditions gives an insight how IWS blocks will perform in leak detection of ITER Vacuum Vessel. Diffusion of hydrogen in bulk of material and the surface roughness during the production of actual component from these materials impact the Outgassing rate. Measurement of Outgassing rate and its compliance with the acceptable limit validates the both the production processes and materials as well as components from vacuum vessel point of view.

References

- [1] Ioki K, Choi C H, Daly E, Dani S, Davis J, Giraud B, Hamlyn-Harris C, Jun C, R Le Barbier, J-M Martinez, Preble J, Terasawa A, Utin Yu, Wang X ITER Vacuum vessel and Vacuum requirements in *IVS 2012*.
- [2] *ITER Vacuum handbook* Appendix-12
- [3] Sefer A, Bojan E 2012 *Materials and Technology* **46**
- [4] Mathewson A G *Vacuum* **24** 505
- [5] IN DA Procedure for outgassing system for IWS (IDM no 4LQJP5)
- [6] Redhead P A, *Extreme high vacuum, Proceedings of the CERN Acceleration School*, Snekersten, Denmark, CERN