BORATED WATER CHEMISTRY CONTROL FOR DTT VACUUM VESSEL

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Introduction

The tokamak element named "Vacuum Vessel" (VV) of fusion nuclear reactor has the functions of neutron shielding superconducting magnets, provides a high-vacuum environment for the plasma, allows the plasma stability and act as primary confinement barrier for radioactivity. In the Divertor Tokamak Test (DTT) [1] facility the neutron shielding of the superconducting coils is obtained with the use of borated water circulating through the vessel's double steel walls ensuring neutrons heating below 1 mW/cm3. For this purpose 8000 ppm in B enriched to 95% in ^{10}B (4.58 wt% H_3BO_3) is needed in DTT VV but the high boron concentration will produce stainless steel corrosion and Stress Corrosion Cracking effects.

DTT will exploit the alternation of ultrapure water and borated water in the Vacuum Vessel (VV) to guarantee sufficient protection of the superconducting coils by neutrons generated through the deuterium-deuterium reactions in high performance operations.

Borated water corrosion mitigation strategies

Borated water is enriched in 95% ^{10}B added in the form of H_3BO_3 and is maintained at 60 °C. The boric acid needed in the DTT VV is well above the operational experience of any operating pressurized water reactor (PWR). Corrosion mitigation strategies were assessed on the basis of the Light Water Reactors experiences by water chemistry control and testing. Similarities between nuclear fusion VV cooling circuits and the Pressurized Water Reactors (PWRs) fleet reside on the fact that both operate with a controlled water chemistry regime that mainly uses boric acid with the addition of a base (either LiOH or KOH) to increase a maintain an optimum pH [2]. PWRs lessons learnt in the past decades indicate that reducing conditions and a very pure water (free from contaminants) are beneficial to counteract corrosion problems such as pitting, crevice corrosion and SCC. Hydrogen usually is inserted in the coolant to suppress the formation of oxidising species induced by water radiolysis, in PWRs, 15-50 cm3 (STP) H2/kg H2O are usually inserted [3].

DTT water chemistry guidelines, like the injection of hydrogen or the addition of a base to counteract the effect of boric acid are not yet defined. Even though stainless steels are generally resistant to corrosion, they are not immune to general corrosion [4] and stress corrosion cracking (SCC) [5] especially at low pH [6]. The water pH chosen for DTT VV is challenging compared to the one used in the current power plant fission fleet. To test the effect of boric acid on steel surfaces of DTT cooling circuit, general corrosion tests were performed using trace metal analysis technique.

Release rates were measured experimentally during 12 weeks tests on 316L, 316LN-IG, and welds, tungsten inert gas (TIG) method and shielded metal arc welding (SMAW) method. These welds were manufactured for ITER VV and kindly provided by Westinghouse - Mangiarotti S.p.A. Monfalcone (GO). 316L, welds and SMAW welds exposed to UPW and 8000 ppm B water for 12 weeks at 80 °C [7] in stagnant conditions (given the low velocity of water inside VV cooling circuits).

Trace metal analyses were performed, Fe releases were measured to be 100 times larger from steels exposed to 8000 ppm B water than UPW (Gasparrini et al., under review) highlighting the increase of releases induced by low pH water.

Analysis of VV Steels Stress Corrosion Cracking due to borated water

The effect of high B concentration in water solution is to reduce pH at the range of 3-4, creating a potential de-passivation of the stainless steels, which can generate pitting and/or crevice corrosion. Cracking initiation can be generated from the pits when the component is under loading condition or for residual stress due to cold working effect [8, 9, 10].

Studies of such cracking phenomena can be done utilizing specific laboratory testing where is possible to associate stress conditions with corrosive environments. One of the most common approaches is to perform Slow Strain Rate Testing, to assess the degradation of mechanical performance of the metal alloy when exposed to the corrosive environment under tensile stress. Uder approach is the utilization of Compact Tension (CT) testing, where the fracture mechanics test can give a complete scenario of the susceptibility of the metal alloys to the cracking damages [11, 12]. An example of experimental apparatus for conducing SCC testing, is shown in the figure below. This apparatus, located in Rome at CSM-Rina Consulting (CSM) laboratories, consisted in a autoclave equipped by a HPHT loop, in which the solution is moved by a pump, Figure 1.

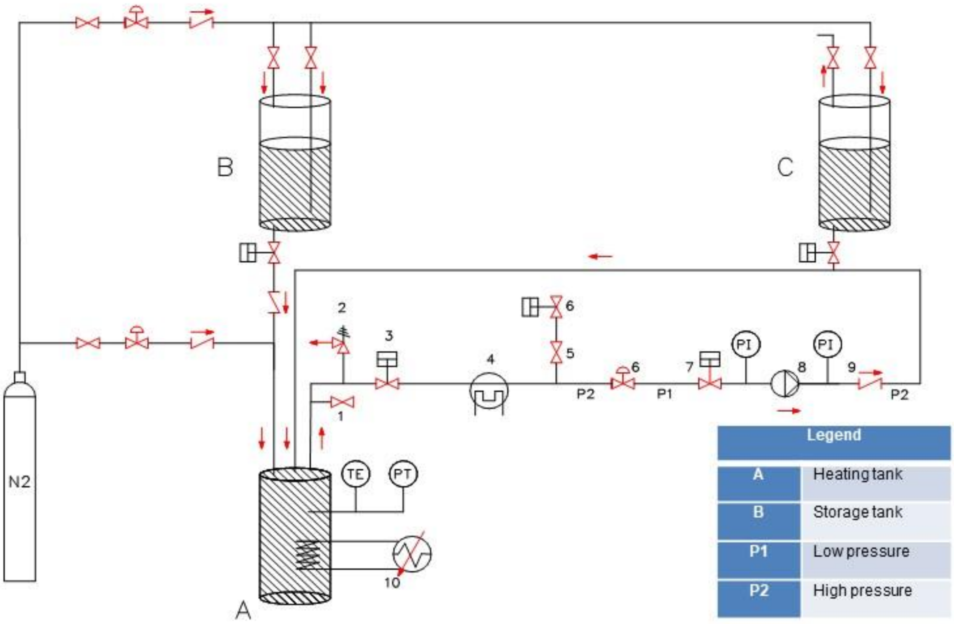

Figure 1 Schematic draw of a HPHT corrosion loop, located at CSM laboratories

Stress corrosion cracking (SCC) initiation tests were also performed on 316L (Gasparrini et al., under review) showing that steels passivated in 8000 ppm B were more prone to SCC initiation than the ones passivated in UPW over 12 weeks.

To compensate the addition of boric acid, a coordinated water chemistry was also chosen. Trace metal analyses measured indicated that releases were larger on samples exposed to 8000 ppm B and 5.7 ppm Li compared to 8000 ppm B and 57 ppm Li showing the importance of the choice of a correct water chemistry. Irradiation also has a big impact on corrosion and SCC (IASCC), to assess the influence of irradiation on general corrosion of 316L exposed to 8000 ppm B, 3 dpa Ni ion irradiated samples were exposed to the same conditions tested in Gasparrini et al.[7]. Results showed that Fe and Ni releases were higher from the ion irradiated samples compare to the unirradiated one after 1 week of exposure [13]**Error! Reference source not found.**.

Furter tests are ongoing to reveal the effect of ion irradiation on the phenomenon of SCC initiation.

Numerical Analysis of Activated Corrosion Products in DTT-VV

Activated Corrosion Products (ACPs) inside the Water Cooling System (WCS) of the Vacuum Vessel (VV) have been estimated to understand if they might be relevant hazardous source terms in DTT. Corrosion products, in fact, are activated by the neutron flux in the VV and contaminate the out-flux regions of the WCS. The VV-WCS has been modelled considering the detailed geometrical data already available for those components located in the Tokamak Hall. Approximations based on engineering judgement were instead adopted for the balance-of-plant components located in building 174, due to their still preliminary design.

The model represents a closed water cooling loop embedding regions both under neutron flux and outside the Tokamak Hall. The analyses have been performed using OSCAR-Fusion V1.4a [14], delivering results in term of masses and activity inventories for different gamma emitting radionuclides such as Co-60 or Mn-54.

The operative conditions of the DTT-VV-WCS fall outside the validation domain of OSCAR-Fusion, which relies on a solid and extensive experimental database derived from French PWRs [15]. To mitigate this issue, the corrosion laws employed in the simulation have been interpolated using the last experimental data provided in [16] even if the experimental result doesn’t cover the operative conditions of DTT.

Figure 2 shows the surface activity per component of the loop in Mbq/m^2. The IF components, hosted in the Tokamak Hall, shows the largest activity, as expected. These preliminary results seem to indicate that the deposits in the out-of-flux regions might not problematic for the occupational radiation exposure of the working personnel called to perform maintenance operation on the balance-of-plant components. On the other hand, in-flux regions present non-negligible inventories even with the current very preliminary irradiation and operational data implemented in the model. This could affect accidental scenario evolution, waste management, and machine availability, maintainability and inspectability.

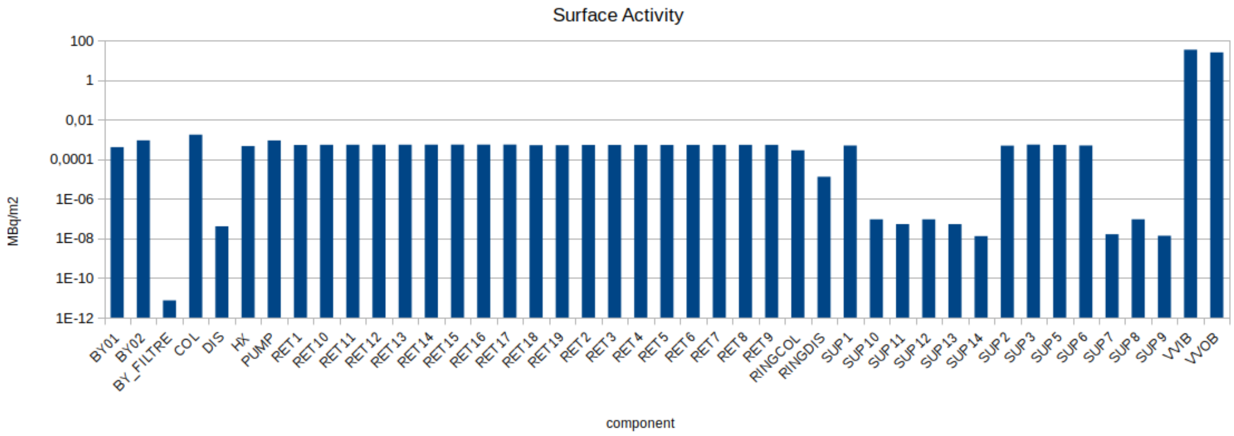

Figure 2. Surface activity in MBq/m^2 per component.

In addition two different water qualities have to be considered inside the VV and VV loop depending on the three modes of operations foreseen:

- Low Performance Phase: Demi water (conductivity <0.1 µS/cm)
- High Performance Phase: Bored Water
- Baking: every three / six months using Nitrogen

The effect on SCC and corrosion product production due to the borated water and the alternation between borated water and hot nitrogen should be investigated in order to identify if mitigation strategies are required.

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