BORON CARBIDE CERAMICS AS NEUTRON SHIELDING FOR ITER PORT-PLUGS

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1. INTRODUCTION

One of the main tasks of the diagnostic ports of the ITER is to ensure neutronic protection of both the diagnostic and plasma control systems and personnel. At the same time, the ports have a strict restriction on the total mass, so it is not possible to apply the standard approach (thick iron-water protection). In 2013, the BINP, together with RFDA and ITER Organization (IO), started the integration of the diagnostic ports (EP11, UP02, UP08 [1]) and quickly came to the conclusion that without additional neutron shielding, the radiation protection requirements could not be met. It was proposed to use boron carbide for neutron shielding. This material has a low density and high neutron interaction cross-section. Since the conceptual design stage of ITER diagnostic ports was not supposed to use ceramics, and in the port design it is planned to use a large number of ceramics, it requires careful confirmation of the possibility of using a large number of ceramics in a ITER vacuum vessel. I.e., the ceramic should not contain dangerous contaminants, and shall meet the requirements of the ITER Vacuum Handbook (IVH). Tray-mounted ceramic blocks will fill all available space inside the ports (Fig.1). In Equatorial Port 11 alone, 40 thousand ceramic blocks with a total surface area of 407 m^2 will be installed [1]. After discussion with the ITER vacuum group, it was decided to significantly limit the outgassing of ceramics in the approved specifications (ITER_D_457TBH). There are very strict requirements for ceramics: the outgassing rate is limited to $1{\cdot}10^{-8}$ $Pa{\cdot}m^3{\cdot}s^{-1}{\cdot}m^{-2}$ for hydrogen at 100 °C and below$1{\cdot}10^{-10}$ $Pa{\cdot}m^3{\cdot}s^{-1}{\cdot}m^{-2}$ for impurities. These limits are 10 times lower than the requirements for any other material in the ITER vacuum chamber.

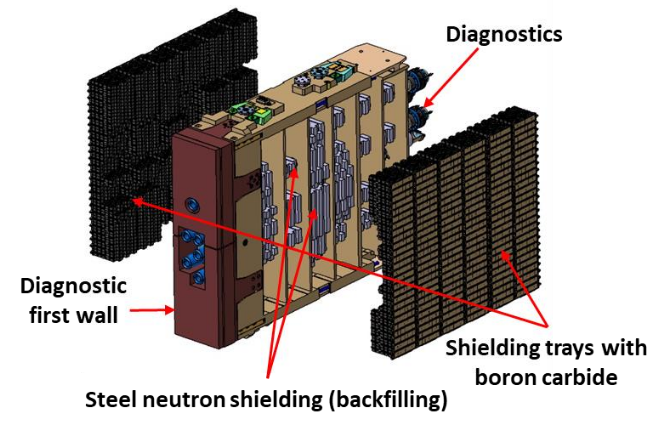

Figure 1. Radiation protection scheme of the Diagnostic Shield Module (DSM) #2 at ITER Equatorial Port No. 11 (left) and BINP made full scale mockup of shielding tray with B_4C hot-pressed blocks (right).

2. STUDIES OF CHEMICAL COMPOSITION, NEUTRON ACTIVATION, THERMAL AND VACUUM PROPERTIES OF VARIOUS BORON CARBIDE CERAMICS

Numerous studies have been carried out to select a suitable boron carbide ceramic and demonstrate that it meets the stringent requirements of IO [1-5]. The chemical composition of sintered (density ~2.33 g/cm^3), hot-pressed (2.53 g/cm^3) and reaction-bonded ceramics (~2.64 g/cm^3) from different manufacturers was investigated. The amount of impurities in sintered and hot-pressed ceramics of boron carbide did not exceed 1%, which meets the requirements of ITER [3,5]. Hot-pressed ceramics have less porosity, but they are much more expensive and the speed of production is limited. Sintered ceramics made by Virial Ltd. were chosen for the ports developed by the

BINP. In order to obtain reliable data, additional vacuum tests were carried out with a large number of sintered ceramics. We used 638 samples of 55×55×5 mm in size, with a total area of 4.56 m^2 [1-4]. The tests demonstrated that after 24 hours of heating in vacuum, the ceramics met the IVH and manufacturing specifications for ceramics. And after 30 months in a vacuum, the outgassing decreases to $2.1\cdot10^{-9}$ $Pa\cdot m^3\cdot s^{-1}\cdot m^{-2}$ [1]. The thermal properties of sintered boron carbide ceramics at various temperatures were measured and found to meet the specification ITER_D_457TBH. At 100 °C, the mean linear thermal expansion coefficient was $3{,}12\cdot10^{-6}$ K^{-1}, specific heat 1308 $J\cdot kg^{-1}\cdot K^{-1}$, and thermal conductivity 30,81 $W\cdot m^{-1}\cdot K^{-1}$.

At the BINP for the development of boron neutron capture therapy of malignant tumors, an accelerator source of epithermal neutrons was proposed and created [6]. Experiments on irradiation of ceramics with fast [2] and slow neutrons [3] were carried out at this neutron source. Slow neutron experiments allowed to measure the manganese content in the samples (0.0001% in sintered Virial ceramics) [3]. The first fast neutron experiments (average energy 5.68 MeV, fluence $3.6\cdot10^{12}$ neutrons/cm^2) were performed to evaluate the activation of ceramics [2]. The activity of the ceramic samples was 50 μSv/h after the end of irradiation and 0.14 μSv/h (natural background level) after 3 days. Then, a long-term fast neutron test with a fluence of 10^{14} n/cm^2 (corresponding to 2-200 ITER shots for EP11 DSM) was performed to evaluate the degradation of the ceramic properties. Not one sample cracked. Mechanical strength decreased by 15%.

3. SERIAL PRODUCTION OF B_4C CERAMICS ACCORDING TO THE REQUIREMENTS OF ITER ORGANIZATION

Virial Ltd. has started serial deliveries of sintered ceramics for installation in ITER ports. The manufacturer prepared all necessary documents, which were approved by the IO. Vacuum tests of the first delivery batch were carried out by the BINP (Fig.2). Outgassing rate was $8.25\cdot10^{-9}$ $Pa\cdot m^3\cdot s^{-1}\cdot m^{-2}$, ceramics meet all ITER requirements. The IO approved the End of manufacturing report of the delivery batch (ITER_D_DAGDG6).

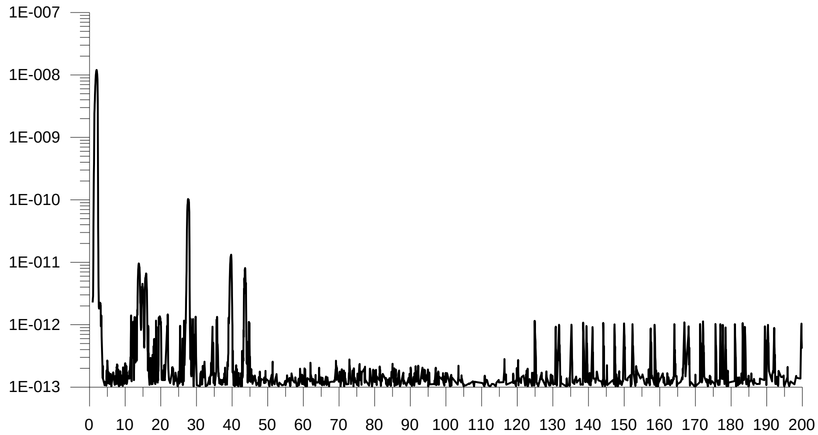

Figure 2. Mass spectrum of gasses measured with a quadrupole mass spectrometer for first delivery batch Virial-sintered boron carbide ceramics at 100 °C. On the vertical axis: the partial pressure in Torr; on the horizontal axis: the atomic mass. Masses (a.u.m.) and components of the six highest peaks: 2 H_2, 14 N, 16 O, 28 CO, 40 Ar, 44 CO_2.

REFERENCES

[1] SHOSHIN, A., BURDAKOV, A., IVANTSIVSKIY, M., et al., Integration of ITER diagnostic ports at the Budker Institute, Fusion Engineering and Design **178** (2022) 113114.

[2] SHOSHIN, A., BURDAKOV, A., IVANTSIVSKIY, M., et al., Test results of boron carbide ceramics for ITER port protection, Fusion Engineering and Design **168** (2021) 112426.

[3] SHOSHIN, A., BURDAKOV, A., IVANTSIVSKIY, M., et al., Qualification of boron carbide ceramics for use in ITER ports, IEEE Transactions on Plasma Science **48** 6 (2020) 1474-1478.

[4] BURDAKOV, A., VARAND, A., KRASNOV, A., et al., The Thermal Outgassing Rate of Materials Used in High-Vacuum Systems, Instruments and Experimental Techniques **65** 3 (2022) 519–523.

[5] SHOSHIN, A., BURDAKOV, A., IVANTSIVSKIY, M., et al., Properties of boron carbide ceramics made by various methods for use in ITER, Fusion Engineering and Design, **146 B** (2019) 2007-2010.

[6] TASKAEV, S., BERENDEEV, E., BIKCHURINA, M., et al., Neutron source based on vacuum insulated tandem accelerator and lithium target, Biology **10** (2021) 350.