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BORON CARBIDE CERAMICS AS NEUTRON SHIELDING FOR ITER PORT-PLUGS

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ABSTRACT

- The possibility of using large amounts of boron carbide ceramics in ITER diagnostic ports has been demonstrated.
- Long-term reliable vacuum tests of boron carbide ceramics have been performed. Thermal properties and chemical composition, including neutron activation, have been investigated.
- A total of almost 54 thousand ceramic blocks for ITER have already been manufactured.

INTRODUCTION

One of the main tasks of the diagnostic ports of the ITER is to ensure neutron 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). It was proposed to use boron carbide for neutron shielding. This material has a low density and high neutron interaction cross-section.

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 [2]. 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 $1\cdot10^{-8}$ Pa·m^3·s^{-1}·m^{-2} for hydrogen at 100 °C and below $1\cdot10^{-10}$ Pa·m^3·s^{-1}·m^{-2} for impurities.

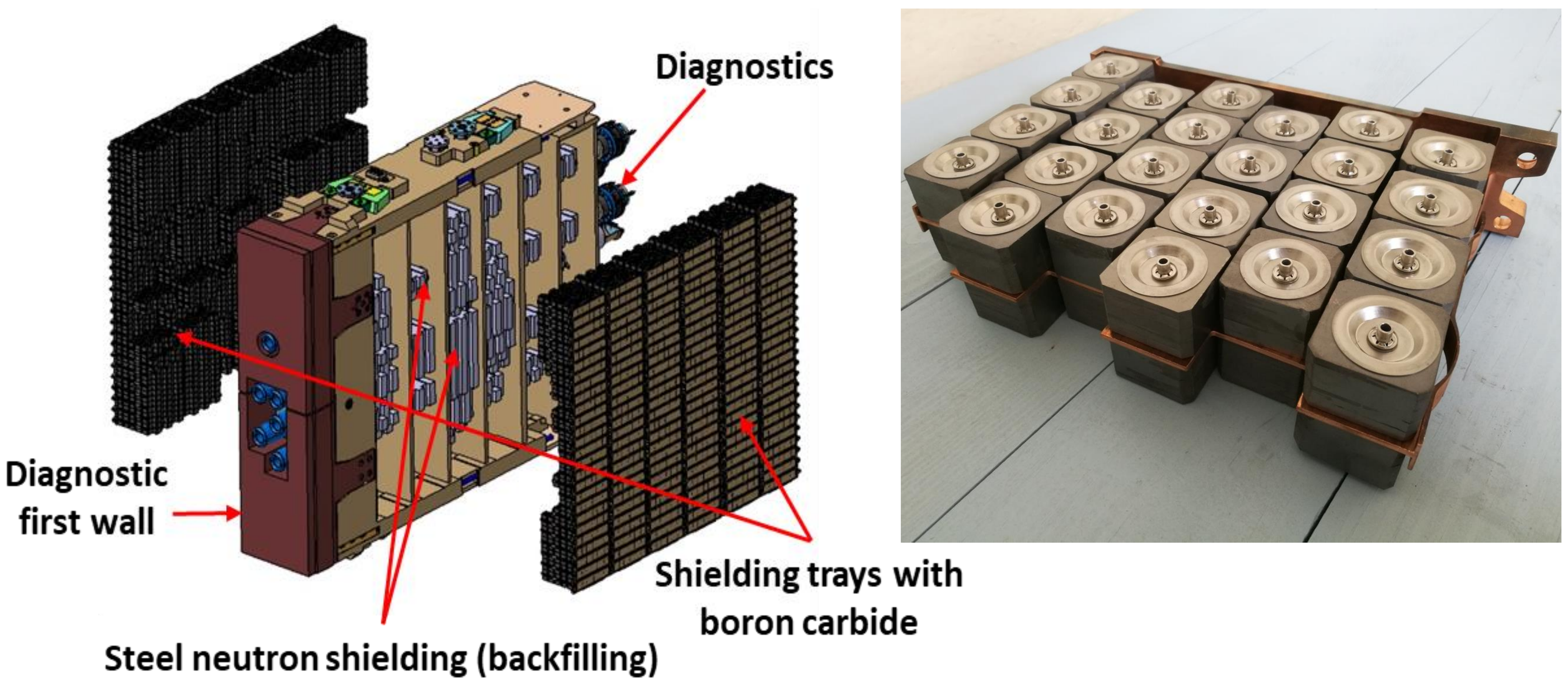

Fig.1 ITER Equatorial Port #11 Diagnostic Shield Module with trays (left), Full scale mock-up of tray with B_4C ceramics (right)

STUDIES OF CHEMICAL COMPOSITION, NEUTRON ACTIVATION AND THERMAL PROPERTIES

The thermal properties and chemical composition of ceramics have been investigated [1]. 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. 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. 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·kg^{-1}·K^{-1}, and thermal conductivity 30,81 W·m^{-1}·K^{-1}.

The VITA facility in BINP was used for experiments on the activation of ceramics by slow neutrons. The gamma-ray spectra after irradiation of ceramics with slow neutrons contained mainly manganese lines.

The activation of ceramics after irradiation with fast neutrons was then measured (Fig. 2). The flux density was $3\cdot10^9$ neutrons/cm^2·s for 20 min and the cumulated fluence was $3.6\cdot10^{12}$ neutrons/cm^2. Which roughly corresponds to the conditions inside the EP11, where the characteristic neutron fluxes are $10^8 \div 10^{11}$ n/cm^2·s [2]. Radioactivity levels have been shown to drop rapidly within three days of activation.

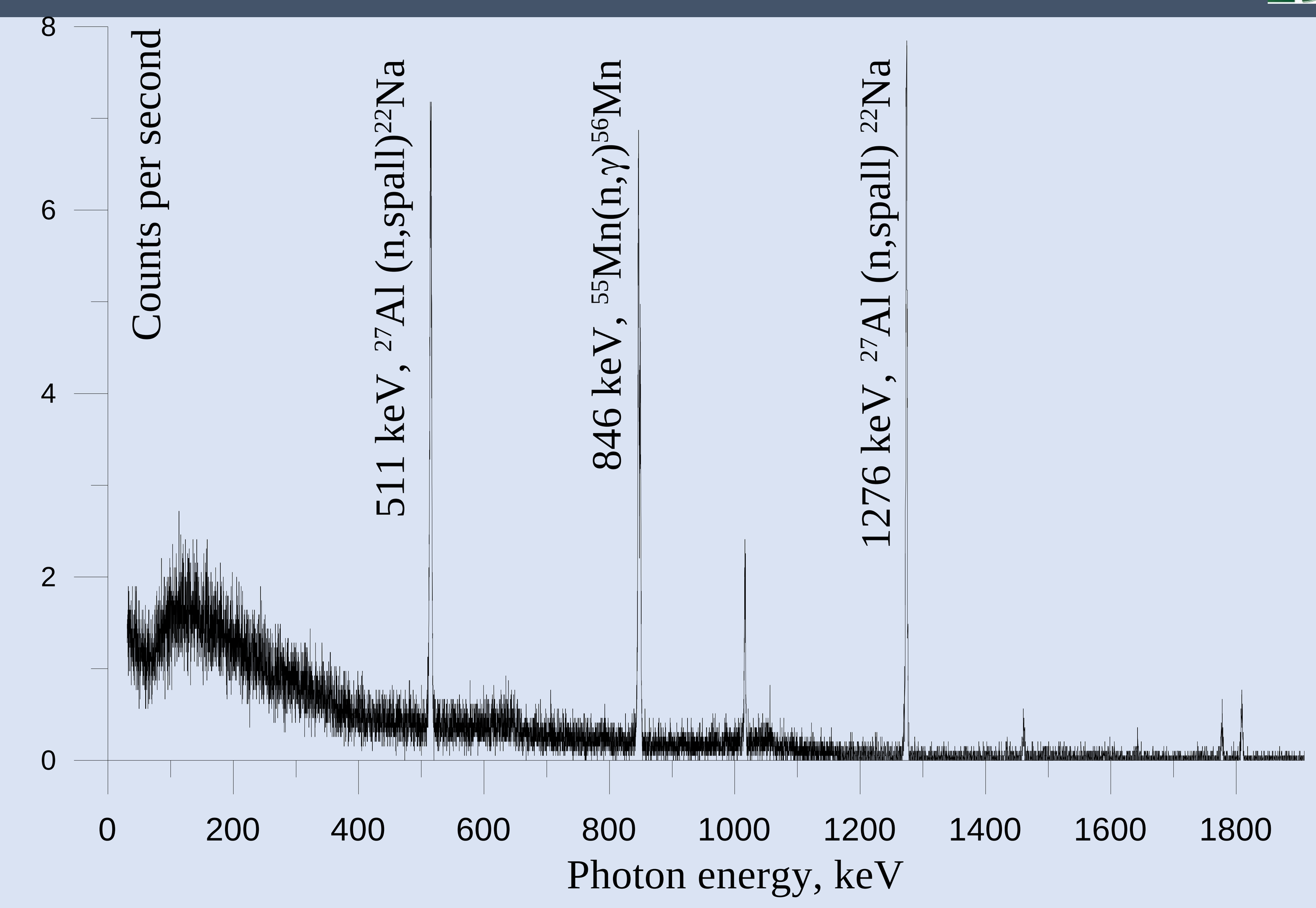

Fig.2 Spectrum of gamma rays emitted by sintered boron carbide ceramics (Virial) after fast neutron irradiation.

DEGRADATION AFTER FAST NEUTRON IRRADIATION

Sintered boron carbide ceramic blocks were irradiated with fast neutrons with an average energy of 5.68 MeV for one month at VITA accelerator. Ceramics was tested with a fluence of 10^{14} n/cm^2 (corresponding to 2-200 ITER shots for Diagnostic Shield Module at EP11). Not one sample cracked. Mechanical strength decreased by 15%:

Properties	After irradiation 10^{14} n/cm^2	Initial ceramics
Density, g/cm^3	2,14±0,01	2,26±0,01
Young's modulus E, GPa	365±14	420±7
Bending strength σ, MPa	190±13	220±11

VACUUM TESTS OF CERAMICS ACCORDING IVH

A program of vacuum tests of ceramics has been agreed with the ITER organization. The test was conducted to confirm that the ceramic meets the requirements of the ITER Vacuum Handbook (ITER_D_2EZ9UM) impurities and 55.QB Material Specification for the supply of Boron Carbide (B_4C) (ITER_D_457TBH). We used first delivery batch of 200 samples of 46*46*28 mm size with a total area of 2.04 m^2.

Vacuum test procedure:

- Ramp up from room temperature to 240 °C: 24 hours,
- Steady temperature at 240 °C for 72 hours,
- Cool down to room T : 48 hours,
- Ramp up to 100 °C : 24 hours,
- Steady Temperature at 100 °Celsius for testing.

Outgassing rate was $8.25\cdot10^{-9}$ Pa·m^3·s^{-1}·m^{-2}. (Fig.3)

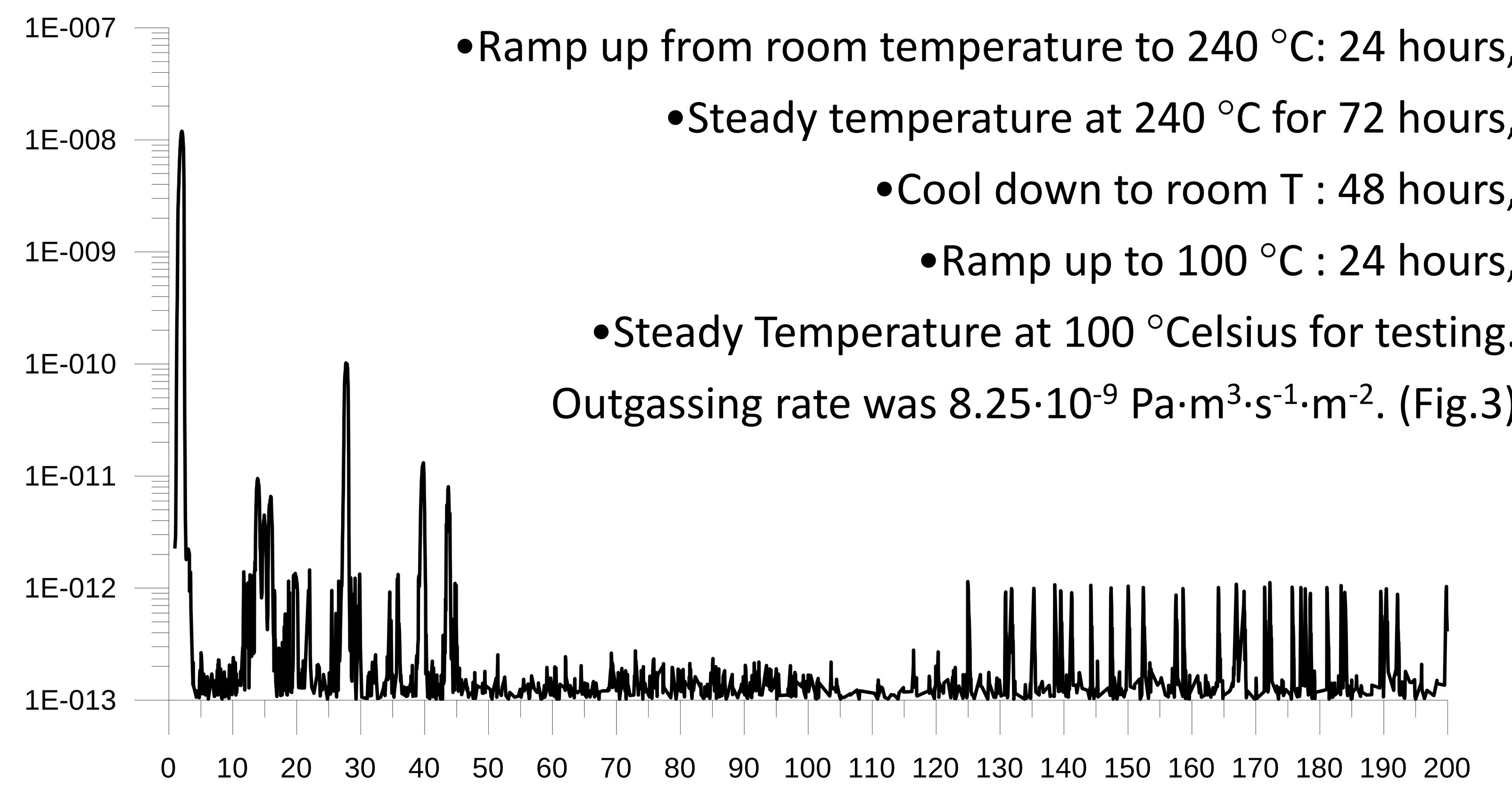

Fig.3 Mass spectrum of gasses for first delivery batch Virial-sintered boron carbide ceramics at 100 °C

CONCLUSION

- A specification for the manufacture of boron carbide ceramic blocks has been agreed with the ITER Organization.
- Serial production of sintered ceramics is deployed by Virial Ltd.
- Based on the Manufacturing and Inspection Plan and test results, an End of manufacturing report on the first delivery batch (ITER_D_DAGDG6) has been prepared and approved by the ITER Organization, allowing the ceramics to be used for delivery as part of the ports to the ITER site.

REFERENCES

[1] A. Shoshin, et al., Test results of boron carbide ceramics for ITER port protection, Fusion Engineering and Design, 168, 112426 (2021).

[2] A. Shoshin, et al., Integration of ITER diagnostic ports at the Budker Institute, Fusion Engineering and Design, 178, 113114 (2022).