TEST OF MATERIALS FOR THE HIGH TEMPERATURE INTENSE NEUTRON TARGET CONVERTER*

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Abstract.

Nowadays in LNL INFN (Italy) the project for gain and study of short-lived radioactive isotopes is in progress [1]. The intense neutron target is required for these goals. In BINP, Russia, the design of high temperature target cooled by radiation is proposed. Presented paper describes the results of preliminary test of materials for the target converter: MPG6-brand graphite, graphite material on the basis of ^{13}C, boron carbide, glassy carbon. Test included the distributed heating over volume of samples with the electron beam up to conditions, simulating the converter working regime (heating power density up to 1300 W/cm2, temperature up to 2000^0 C, temperature gradient up to 100^0 C/mm). Graphite materials show its adaptability under conditions specified.

INTRODUCTION

The proposed target design [2] comprises the converter assembled with plates, which are fastened to the rotating metal disk. Plates are cooled by radiation. The most strained part of this target is the converter, which should have the temperature around 1700-2000^0C for effective cooling. High temperature gradients up to 100^0C/mm, which lead to high thermo-mechanical stress in material, are also appeared to be the critical points of the converter. The main goal of the present work is the test of materials which can be used as basic materials for the target converter, in the conditions close to operating ones.

5 different materials were tested:

- MPG6-brand graphite;
- SU2000-brand glassy carbon;
- High density boron carbide manufactured by "Pure Tech";
- High density boron carbide manufactured by "Good Fellow";
- Graphite-like material on the basis of ^{13}C isotope.

All the materials, except the graphite of ^{13}C, are industrially manufactured. Samples are disks of various thickness (2-3 mm) and diameter (15-45 mm). ^{13}C graphite was manufactured in NIIGrafit by the original technology from the raw material delivered by customer. Experimental samples were the pills 2.5 – 3.5 mm in thickness, 14 mm in diameter, 0.7-0.8 g/cm^3 in density, and the content of ^{13}C isotope 75-80%.

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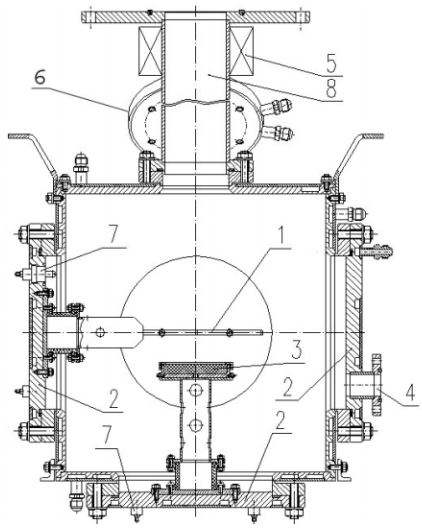

Figure 1: Experimental device. 1 – sample support. 2 – flanges, 3 – beam dump, 4 – pumping flange. 5 – magnetic correctors. 6 – optical windows, 7 – current outlets, 8 – beam channel.

SCHEME OF THE EXPERIMENT

During the experiment the samples under test were disposed in the originally manufactured vacuum chamber (see Fig.1) on the heat resistance support (1). The support design let the sample to be freely placed on the 4 thin tungsten rods and to be centered by the special tantalum cowling. It helps to minimize the thermal contact between the sample and the support and to avoid the additional mechanical stress in the sample caused by the rigid fastening.

The sample was heated by the electron beam of ELV-6 accelerator [3]. The beam was passed through the beam channel (8) equipped with magnetic correctors. The linear scanning of the beam over the selected coordinate (X axis) was realized, the beam profile over X coordinate is shown in Fig.2.

At the beam energy lower than 660 keV (which is equal to the electron free path in the most of the tested materials) the beam profile is essentially irregular and can be very approximately described with the Gauss distribution with σ = 2 mm and amplitude P_0 = 2.1 kW/(mA·cm).

The following parameters were measured during the experiment:

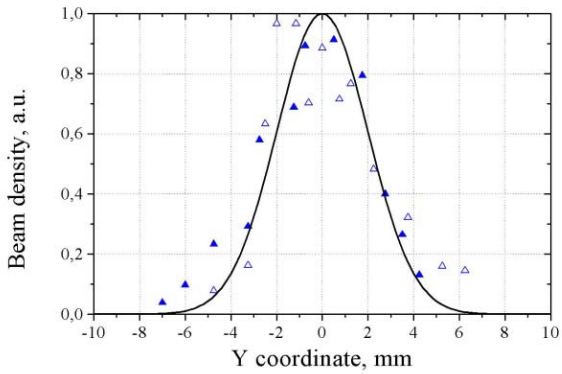

Figure 2: Beam linear density distribution over Y coordinate. Triangles are the measured values; line is the superimposed Gauss distribution.

- balance of currents – the accelerator current, the current deposition in the sample, and the current deposition in the beam dump – to control the heating power;
- electron beam energy;
- temperature distribution over the sample surface across the beam scanning.

Optical measurements were done to determine the samples' temperature. The method of measurement is based on the comparison of the signals from a certain photodetector with the use of different optical filters. This method assumes that the radiating surface is that one of the "gray body" model, i.e., its spectral heat radiation ratio does not depend on the surface temperature and the wavelength (radiation spectrum is similar to that one of the "black body"). Graphite-like materials with the rough surfaces are satisfied to these conditions. In this case, the signals ratio from a certain photodetector depends on the radiation surface temperature only. So, if the spectral parameters of the optical elements are known, one can determine the temperature of the radiating surface.

This is important to note, that:

- there is no need to know the value of the integral thermal radiation ratio;
- there is no need to know the absolute value of signals from photodetectors.

Fig. 3 shows the experimental device assembled on the ELV-6 accelerator. The vacuum chamber, the accelerator output assembly and the heat diagnostics are clearly seen. The weighing and the microscopy of tested samples were done.

TEST OF THE SAMPLES

"Pure Tech" and "Good Fellow" B_4C .

Two samples of "Pure Tech" boron carbide were tested. Both samples were cracked at 220 – 250 μA (not more than 60 W/cm^2, see Fig.4). Temperature measurements were failed at such a low temperature. Both "Good Fellow" boron carbide tested samples were destroyed when attempted to increase the beam current higher than 1.2 mA (350 W/cm^2).

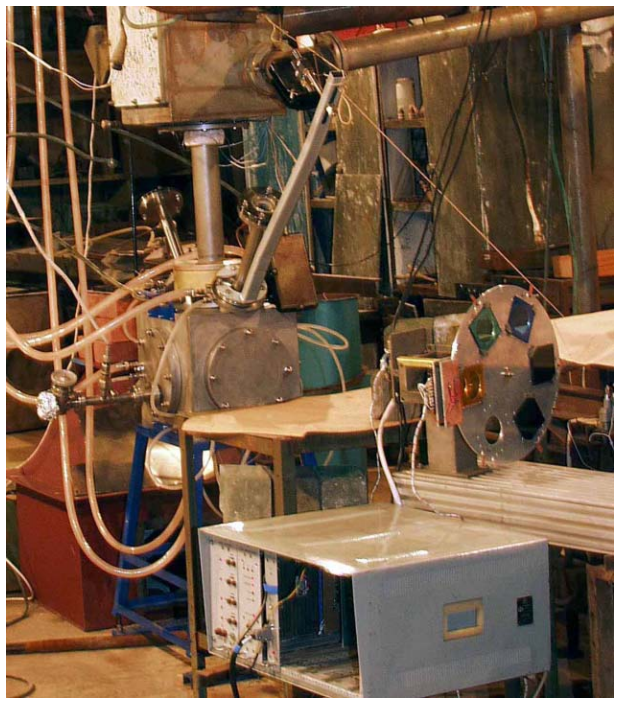

Figure 3: The experimental device in assembly.

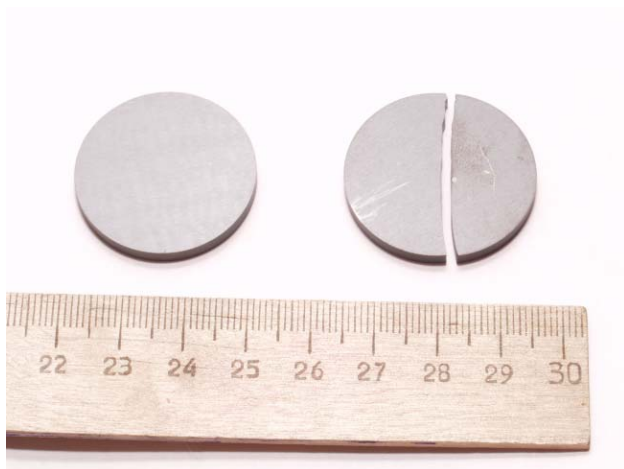

Figure 4: Picture of the boron carbide "Pure Tech" samples. Right – cracked sample after the test.

Glassy Carbon SU-2000.

Two samples were tested. The first one was destructed at less than 700 W/cm^2 heating power. The second one stood the heating up to 900 W/cm^2 and 28 thermocycles. However, both visual and microscope analysis showed the etching of the sample surface (see Fig.5).

MPG-6 Graphite.

A series of samples were tested both under continuous heating and the thermocycling. No any difference was detected between these two types of samples. The heating power reached 1300 W/cm^2, while the surface

temperature was up to 2000^0C. The maximum temperature gradient was up to 100^0C/mm. A few small cracks were observed on just 2 of the 12 tested samples.

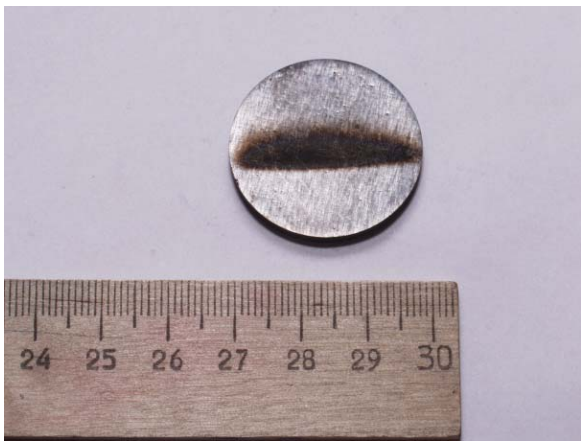

Figure 5: Picture of the glassy carbon sample after experiment.

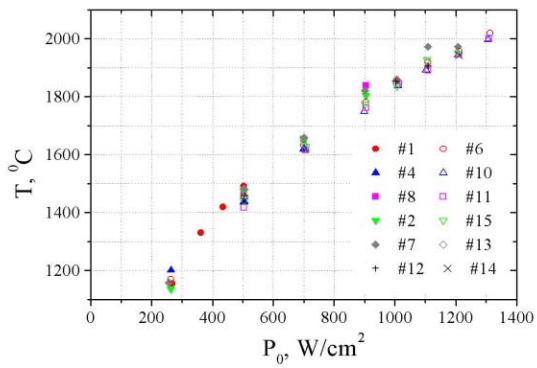

Figure 6: Maximum temperature of MPG6 graphite samples vs. the peak heating power density.

^{13}C Isotope-based Graphite.

The heating power were up to 1000 W/cm^2, the maximum temperature reached 2000^0C, and the maximum temperature gradient reached 100^0C/mm. All 6 samples stood the test without any crash.

COMPARISON OF MPG-6 AND ^{13}C-BASED GRAPHITES

Fig.6-7 show the maximum measured temperature vs. heating power for ^{13}C and MPG-6 graphite. MPG-6 samples had equal size and were manufactured of the same billet, while the technology of ^{13}C graphite samples productions had some differences from sample to sample. Nevertheless, in both cases the measured temperature values for different samples are quite similar at a given power. So one can assume that ^{13}C samples tested, though manufactured following somewhat different technologies, demonstrated the similarities in material properties.

CONCLUSION

Main results of the present work are:

- boron carbide and glassy carbon are not suitable to be the materials for the hot neutron target converter. They either are destroyed at the lowest heat load, or experience high thermal erosion;
- both MPG-6 and ^{13}C graphite showed their serviceability at the operation conditions;
- all ^{13}C tested samples showed the identity in properties, despite ^{13}C material was produced following the unique technology.

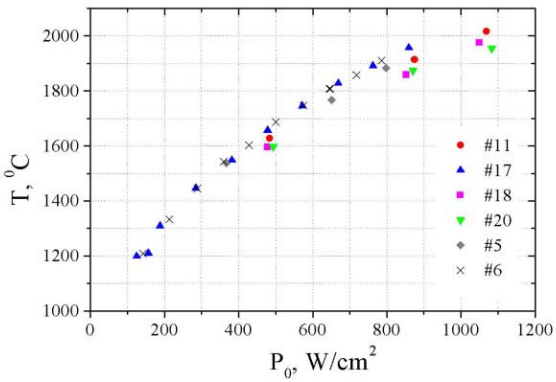

Figure 7: Maximum temperature of ^{13}C graphite vs the peak heating power density.

The results of the preliminary tests obtained allow to continue the works on the creation of the hot neutron target on the basis of the graphite materials.

The investigation of irradiated samples shows that MPG-6 graphite does not experience any visible changes. ^{13}C material turned to be more graphitized (following the X-ray analysis data). Another effect is the appearance of sp^3 (diamond) phase of carbon (according to the Raman spectra). These effects are well-known for reactor graphite and one can suppose that ^{13}C material does not experience any degradation, but its properties are improved under irradiating beam.

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