

# PROJECT OF DEUTERON ACCELERATOR BASED NEUTRON SOURCE FOR RIB PRODUCTION

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The project of a high-intense neutron source for the SPES project in LNL, Legnaro, Italy [1] is developed. The source is based on the rotating carbon target. The target is bombarded by the deuteron beam with energy 20 MeV, diameter 1 cm, average power 100 kW. The target is cooled by its thermal radiation, and its temperature can reach 1800°C. It is shown that high density graphite can be used as a material for neutron production. The source can produce up to  $10^{14}$  neutrons per second with energy within few MeV - few dozens MeV range, its lifetime is around few thousand hours.

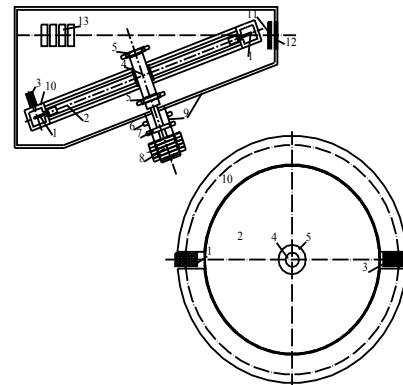
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## 1 INTRODUCTION

To perform experiments with radioactive nuclides, high-intensity (up to  $10^{14}$  particles per second) source of fast neutrons with a small transverse primary beam size (around 1 cm) is required. This source can be based on the target made of light materials (Li, Be, C) bombarded by *d* beam. High beam power (100 kW) imposes essential restrictions on the selection of both materials and target design. First, to increase the effective target area for beam energy deposition, the target design with a mobile operational area is required. Second, the design with an operational area cooled by thermal radiation essentially simplifies the target and makes it inexpensive, reliable, and safe. High-density graphite seems to be the most suitable material for this type of the target. At the deuteron energy 10 - 20 MeV the main channel of neutron production is the strip reaction. Spectral and angular distribution of neutrons can be evaluated by the model proposed by R. Serber [2]. Results of these evaluations, taking into account the deceleration of deuterons in thick graphite full-stop target [3, 4] are well matched with the experimental data for various deuteron energies [5]. This suggests that it is possible to obtain up to  $10^{14}$  neutrons per second in the deuteron beam direction within the angle 40-50°, when the thick graphite target is bombarded by deuteron beam with 20 MeV energy and 5 mA mean current. Maximum of energy spectrum is located near 6-7 MeV, its width (FWHM) is around 10 MeV.

## 2 TARGET DESIGN

The proposed design of a neutron target represents (Fig. 1) the ring assembled of graphite plates 3 cm in width and 2 mm in thickness. Plates are set on the titanium disk 60 cm in diameter and 1 cm in thickness.



*Fig. 1. Layout of the neutron target. 1 - graphite plates; 2 - titanium disk; 3 - bolometer; 4 - shaft; 5 - bearings; 6 - vibration pick-up; 7 - magnetic sensor of rotation; 8 - magnetic clutch; 9 - vacuum chamber walls; 10 - cooling channels; 11 - capacitance-type sensor; 12 - neutron beam output window; 13 - collimator.*

The disk is set on the shaft 5 cm in diameter and rotated with a frequency of 50 Hz. Input of rotation into the vacuum volume is carried out by a magnetic clutch. In order to increase the operational area, the deuteron beam hits the graphite plate to the angle 20°. Cooling of the vacuum chamber walls is carried out by water, circulating inside the cooling channels that are rigidly attached to the chamber and performed as two semicircles. Operational (beam) and diagnostic (bolometer) areas are placed in gaps of semicircles. Collimator, which also acts as a deuteron beam position monitor, is placed before the target. A window for the neutron beam output is located behind the operational area. Graphite plate, that is positioned opposite to the window, serves as an indicator of target damages, and, at the same time, protects the vacuum chamber from the deuteron beam. For target control and protection, sensors of rotation and vibration pick-up are provided as well as flow meters and manometers in the hydraulic system.

## 3 TARGET THERMAL AND MECHANICAL OPERATIONAL CONDITIONS

Numeric simulation was performed in order to define target thermal operational conditions and to estimate thermomechanical stress in its most strained elements.

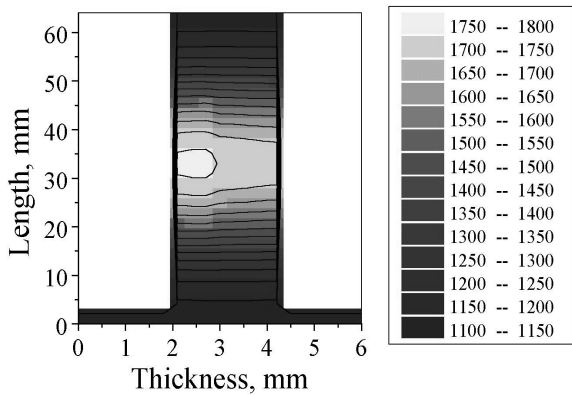


Fig. 2. Temperature distribution over the section of graphite target in °C for the graphite length 64 mm and disk thickness 1 cm.

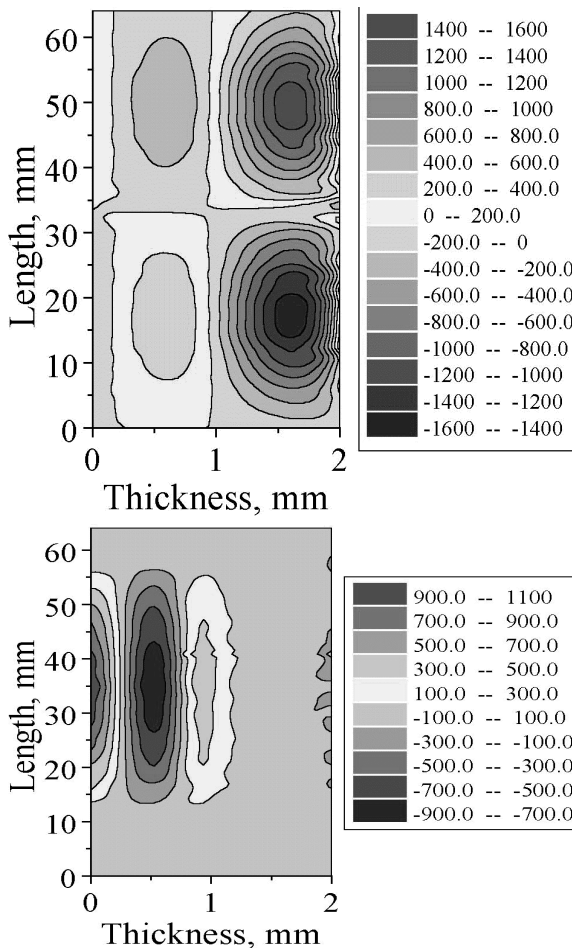


Fig. 3. Distribution of the tangential (above) and longitudinal (below) thermal stress (kPa) over the radial section of graphite for temperature distribution, presented in Fig. 2.

Following this simulation, the non-steady-state equation was solved, taking into account heat radiation from the target surface. It is important to note, that the

non-steady-state task solution is necessary not only for steady-state solution gain, but also for determination of the thermomechanical stress appeared in target elements during the target heating-up, since in this process the stress reaches its maximum.

Computation of temperature fields in graphite area of the target was performed for the heat flux from graphite to titanium, taking into account the measured heat resistance of graphite mount. Fig. 2 shows the result of the computation for one of the given target designs.

To calculate the stress field in the target, the equation of elasticity was solved taking into account the target rotation and temperature field for a given geometry [6]. It was discovered that the stress appeared in the graphite area of the target and caused mainly by the temperature field, is the most close to ultimate stress (see Fig. 3), though still far from the critical value ( $2.5 \cdot 10^7$  Pa for graphite).

#### 4 THERMAL EXPERIMENTS

To verify the reliability of the graphite target at given thermal conditions, series of experiments were performed, aimed:

- to define the admissible number of thermocycles (fast heating up to operational temperature and fast cooling down to room temperature);
- to define the admissible temperature gradient;

During experiments graphite samples with cross-section  $1.5 \times 1.5$  mm and length 15 - 20 mm were heated up in the vacuum volume by pulsed current (half-sinusoid) with  $96 \mu\text{s}$  width and 50 Hz repetition rate. Such conditions correspond to operational conditions of the target, rotating with the frequency 50 Hz. Current and voltage were registered, then radiated power, average temperature, and temperature jump were calculated. Control of temperature distribution over the sample surface was realized by pirometer through the window in the vacuum volume.

Thermocycle test was carried out as follow: the sample was fed by the packet of heating current pulses of 30 sec duration. It was heated up to the temperature  $2000^\circ\text{C}$ . Then the next 30 sec the sample was got cold down to the room temperature. As a result, the sample stood over 500 cycles without destruction. Note that for the first 200 cycles the sample resistance was risen up for 7% and then stabilized at a new level. One can suppose the stabilization of the sample material structure in a new state after its partial destruction, and success to stand the thermal stress of such a kind. This means the target does not require preliminary heating-up before deuteron beam release.

Measurements of the temperature distribution over the sample surface at temperature  $2000^\circ\text{C}$  by pirometer showed that the temperature reached its maximum in the centre of the sample of 16 mm length, and was  $80^\circ$  lower at sample edges. Thus, graphite stable stands the temperature gradient up to  $100^\circ\text{C}/\text{cm}$ .

To define the target lifetime, the sample was stood at constant temperature within the range  $2200 - 2500^\circ\text{C}$ . Change of graphite physical properties was proved by

change of sample electrical resistance. It was increased in time with the rising speed, and after 20 - 25% resistance growth the sample was destroyed. The lifetime curve was plotted by the experimental data (see Fig. 4). The time before the sample destruction was accepted as the sample lifetime, that appeared to be 300 - 400 hours at 2100°C, about 2000 hours at 2000°C, and about 10000 hours at 1800°C to define the target lifetime at temperature 2200 - 2500°C.

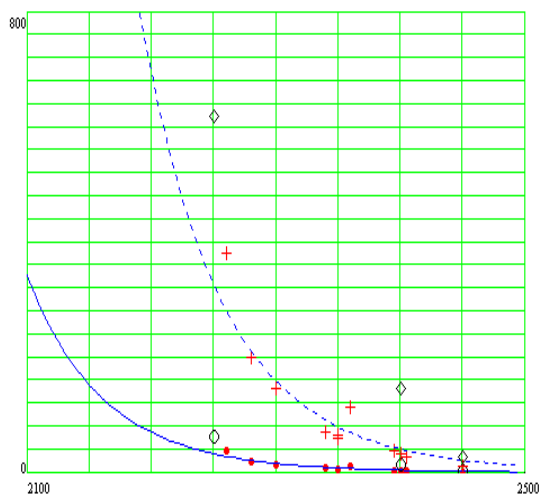


Fig. 4. Lifetime (hours) of samples versus temperature (°C). ● and ○ - measured values, + and ◇ - same values multiplied by a factor of 10, solid line - approximation, dashed line - approximate values multiplied by a factor of 10.

## 5 CONCLUSION

Main goal of the present work is to demonstrate the possibility of production of a high-intense neutron source for high-power primary deuteron beam, on the basis of the carbon target, cooled by radiation. The conceptual design of this source is developed.

## REFERENCES

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