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Research

FEASIBILITY STUDY OF CREATING ADDITIONAL EXPERIMENTAL CHANNELS FOR SILICON DOPING IN IRT-T REACTOR

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ABSTRACT

This paper describes results of exploring the possibilities of creating additional experimental channels for irradiation of silicon in IRT-T reactor. Alternative ways of location of additional experimental channels in horizontal and vertical orientation are shown. Results of research show that new irradiation facility for NTD can be created instead of exist channel HEC-1. In this case characteristics of irradiation ability is few worse that same parameter in HEC-4. Furthermore, possibility of creating new experimental volume consist of tank with heavy water and vertical channel in empty space of the reactor pool. Calculation results show practicability of installation of new irradiation facilities because theoretical parameters of irradiation area are acceptable for NTD-technology.

INTRODUCTION

IRT-T is pool-type Research Reactor used for scientific research in solid-state physics, radionuclide production, neutron activation analysis of determination the concentration of elements in different materials, neutron transmutation doping of silicon, neutron radiography. Moderator, coolant and upper biological shield is distillated light water.

For nearly 50 years (since 1967) IRT-T reactor is successfully used for conducting scientific and technical research and experiments. In June 1977 reactor was shut down for reconstruction following a corrosive damage of aluminium sheath of reactor's tank and aluminium heat exchanger. In 1985 a partial modernization of the reactor core was carried out (transition to new IRT-3M fuel assemblies) and the reactor power was raised from 2 MW to 6 MW. The reactor control and protection system was modernized in 2005. Over the period of operation time nuclear and radiation accident, with radioactivity discharge was not happen (Varlachev *et al.*, 2011).

Currently, neutron transmutation doping (NTD) of silicon mainly takes place in the reactor experimental channels as well as obtaining radionuclide isotopes for medicine. No more than 2-3 out of 10 horizontal and 14 vertical experimental channels are used for these purposes. For NTD of silicon is used only one horizontal experimental channel – HEC-4 see Fig. 1.

The main research purpose is feasibility study for creation of additional irradiation channel in pool-type research reactor IRT-T for neutron transmutation doping of silicon.

The distinction in kind between NTD and other doping technology is produced by the conversion of the Si-30 isotope, which consists of 3.12% in natural silicon, into a phosphorus atom using neutron absorption reaction as follows (Munkhbat and Obara, 2012; Li *et al.*, 2009):

$$^{30}Si(n,\gamma)^{31}Si \rightarrow {}^{31}P + \beta^{+} \qquad (1)$$

Increasing the number of the experimental channels in IRT-T reactor is of interest due to growing global consumption of high-quality doped silicon.

Unfortunately, only two out of 10 HECs (HEC-4 and HEC-1) have desired location in the reactor pool – they are tangent to the reactor core. The rest of the channels are situated in radial direction to the reactor core and it is not possible to use them for NTD of silicon.

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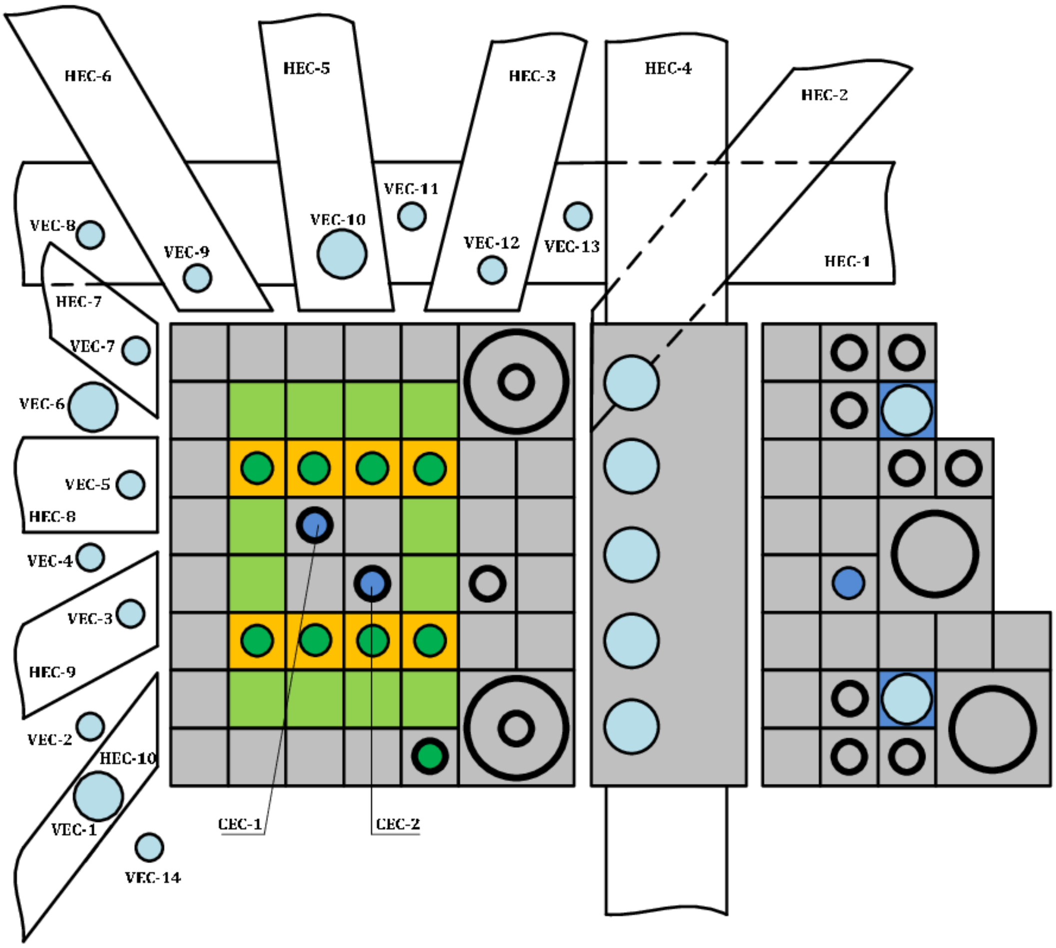

Fig. 1 Cartogram of reactor core and reflector with location of the experimental channels: HEC-i – horizontal experimental channel (HEC) with number i; VEC-j – vertical experimental channel (VEC) with number j.

To carry out NTD in the area of HEC certain conditions must be met. The following conditions allow providing irradiation of silicon ingots with high degree of uniformity using existing irradiation technology:

- Fast neutron flux density should be 20–50 times less than thermal neutron flux density;
- Gamma-radiation flux density in the area of experimental channel should not be high so that irradiated sample does not overheat;
- Radial unevenness of NTD is mainly defined by irregularity of distribution of thermal neutron fluence (for the time of irradation) which should not exceed 3–5%.

RESULTS

Additional Horizontal Channel

These conditions are met during irradiation of cylindrical ingots of silicon with diameter up to 128 mm (5 in) and length up to 700 mm in HEC-4 channel.

The simplest way to create additional channel is to use HEC-1. It has the same diameter as the HEC-4, which is tangent to the reactor core. But HEC-1 is located much closer to the core. If there are 2 rows of beryllium blocks between the reactor core and HEC-4 channel, there is only one row between the core and HEC-1.

On the one hand, this is an advantage – thermal neutron flux density in this channel is higher than in HEC-4. Nevertheless, fast neutron flux density in this channel is much more – with respect to thermal neutrons, there are almost 3 times more of fast neutrons than there are in HEC-4 channel. It is not advisable having large amounts of fast neutrons during NTD process of silicon, since it can lead to formation of unnecessary lattice defects. However, even having all this should have negligible effect on product quality.

Besides that, gamma-radiation flux density in this channel would be about 3 times as high, which would lead to excessive radiative heating of the irradiated silicon. To avoid this, it would be necessary to surround the HEC-1 channel with a layer of lead and increase cooling of the silicon by airflow.

While HEC-4 channel is almost completely surrounded with beryllium blocks, HEC-1 channel is surrounded with pool water of the reactor. This would lead to higher irregularity of thermal neutron flux density distribution in the volume if the channel.

Figs 2 and 3 show distributions of fast and thermal neutron flux densities along the axes of HEC-1 and HEC-4 experimental channels obtained by neutron-physical calculations in TIGRIS software (Alferov *et al.*, 2011; Naymushin *et al.*, 2012).

Flux density of fast neutrons in HEC-1 is three times as much than flux density in HEC-4. That is a permissible limit; flux of fast neutrons is 25 times as much flux of thermal neutrons.

The obtained distributions allow assuming that NTD of silicon is possible in this channel:

- thermal neutron flux density in the channel is almost the same as in the current HEC-4 channel;
- fast neutron flux density in the channel is 3 times higher than in HEC-4 which practically does not hinder silicon doping;
- the only difficulty would be gamma-radiation flux density which, like $\Phi_{f.n.}$, would be about 3 times higher than in HEC-4 channel; this would lead to higher degree of radiative energy release in irradiated ingots but the problem solves by creating additional cooling system and gamma radiation protect system for silicon ingot.

Additional Vertical Changes

The lower part of Fig. 1 shows free volume filled with light water of the reactor pool. If there is a tank with heavy water, thermal neutron flux density ($\Phi_{t.n.}$) will significantly increase in it. This tank allows locating

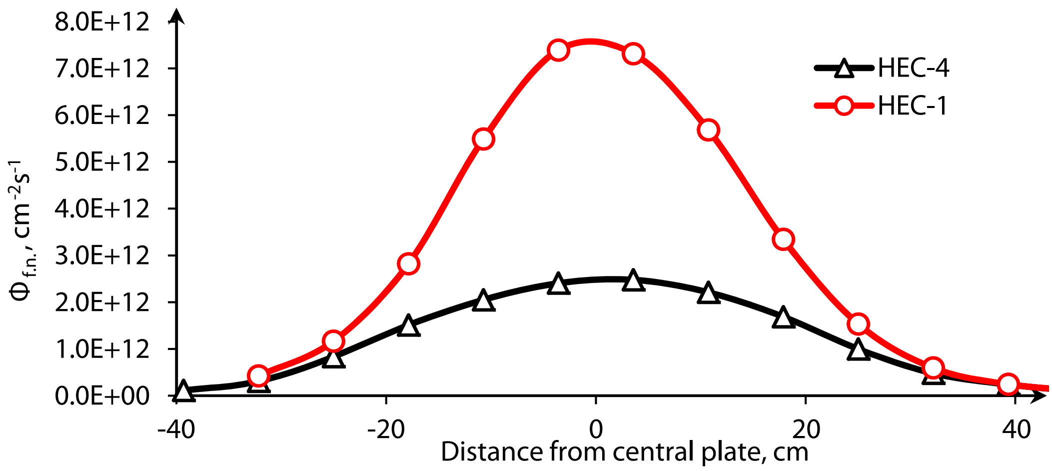

Fig. 2 Distribution of fast neutron flux density along the axes of HEC-1 and HEC-4 experimental channels at reactor power 6 MW.

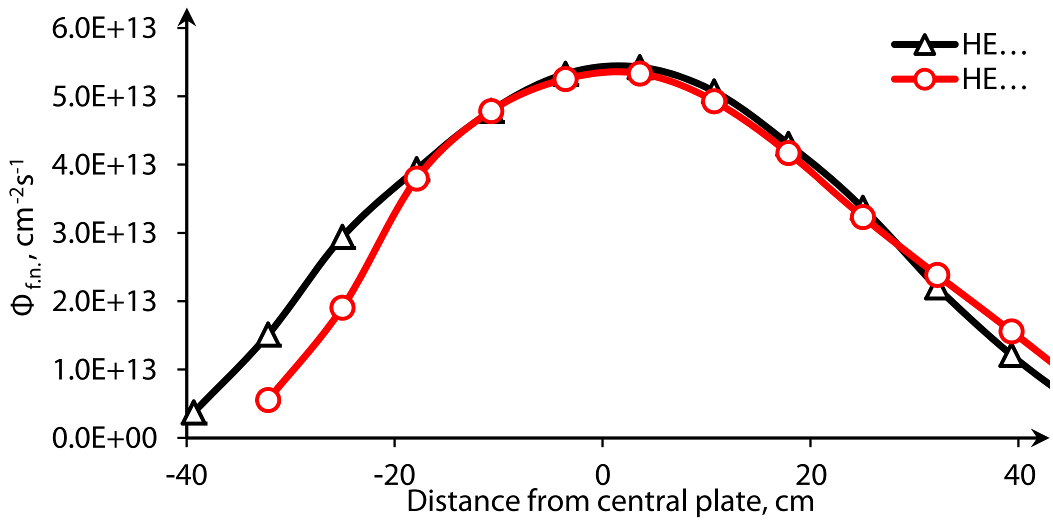

Fig. 3 Distribution of thermal neutron flux density along the axes of HEC-1 and HEC-4 experimental channels at reactor power 6 MW.

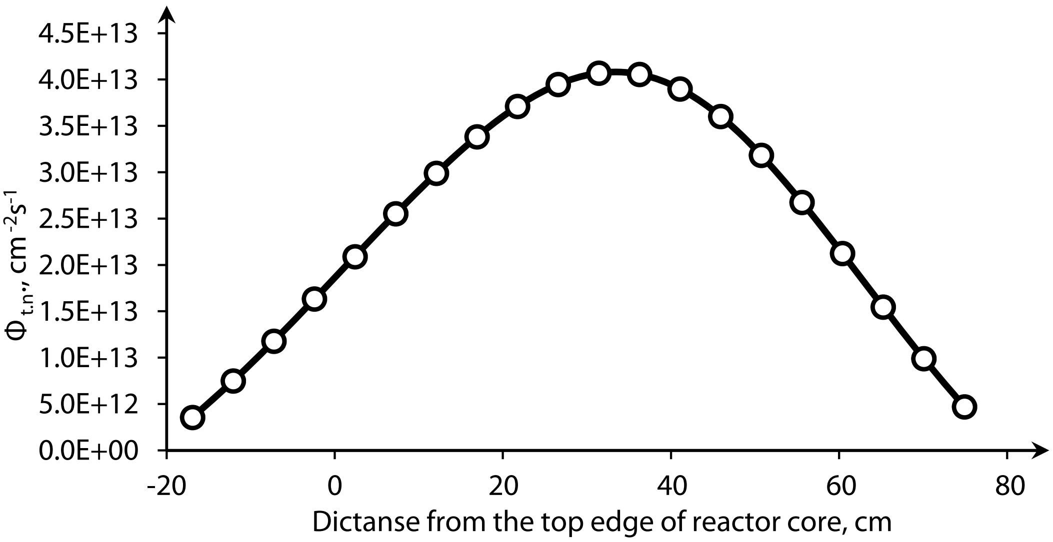

Fig. 4 Distribution of thermal neutron flux density along the axes additional vertical channel in tank with heavy water.

vertical experimental channel inside with 150-250 mm diameter. $\Phi_{t.n.}$ in this channel would be as high as it is in the current HEC-4 channel, however, using heavy water would cause spatial distribution of this flux to be more regular. Manufacturing such tank will allow slightly releasing reactivity margin of the reactor and help to form thermal neutron flux density necessary for NTD of silicon as well as lower background gamma-radiation.

Fig. 4 shown Distribution of thermal neutron flux density along the axes additional vertical channel in tank with heavy water.

Flux density of thermal neutrons in vertical channel approximately 25% less than flux density in HEC. Wight of irradiation area and uniformity of this distribution are equal the same distribution in HEC-4.

Maximum value of thermal neutrons flux in this channel ~20% less than same parameter in HEC-4. Moreover, fast neutrons flux in this channel significantly less than same parameter in HEC-4.

CONCLUSION

Preliminary calculations shows that creating additional experimental channels for irradiation of silicon in IRT-T reactor is possible. First opportunity to create additional NDT-facility is formation of irradiation conditions in HEC-1. Another way is installation of heavy water tanks near reactor core instead of "activity generator".

Additional three-dimensional calculations of neutron flux density distribution and uniformity of silicon ingot irradiation are required for development of this channel.

Silicon production can be increased by 2–3 times in case of creating both additional channel.

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