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Analysis of Wigner energy release process in graphite stack of shut-down uranium-graphite reactor

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Abstract. Data, which finding during thermal differential analysis of sampled irradiated graphite are presented. Results of computational modeling of Winger energy release process from irradiated graphite staking are demonstrated. It’s shown, that spontaneous combustion of graphite possible only in adiabatic case.

1. Introduction

The problem of irradiated graphite shutdown reactors is essential in justifying the safety of operations in preparation to decommissioning and decommissioning of nuclear graphite-moderated reactors [1]. One of the most important steps to solve this problem is a detailed analysis of the issues associated with the effect of the accumulation and release of stored energy (Wigner) in irradiated graphite [2,3]. The parameters that characterize the accumulation and release of stored energy in graphite, determine the conditions and the possible consequences of its release (thermal effects) in the graphite stack [4].

2. Computation of heat effects

During researches [5] took samples of graphite by volume of graphite stack (figure 1) of shut-down the reactor with water cooling, which is operated in a flow mode. At the same time covering the entire range of damaging neutron fluence and temperature of irradiation. These factors determine the parameters of accumulation and release of stored energy. Coring of graphite sleeves was made using hollow cutters after removing them from the graphite stack. Tackling cross-cutting core samples from the walls of graphite blocks was carried out directly from the graphite stack using a special device UGB-3. The direction of coring is horizontal. Selected core length of 57 mm and a diameter of 8 mm was cut into four pieces evenly along the length. Next, from the obtained core pieces were manufactured the same form samples as for the sleeves.

The most critical in terms of values of the possible thermal effects due to self-sustained release of stored energy are the most "cold" (irradiation temperature 50–80^{o}C) graphite sleeves from the top of the graphite stack (figure 2, curve 2). For them the following conditions (1) of the possibility of self-sustaining release of stored energy for adiabatic conditions is realized:

$$\frac{dH(T)}{dT} > C(T) \tag{1}$$

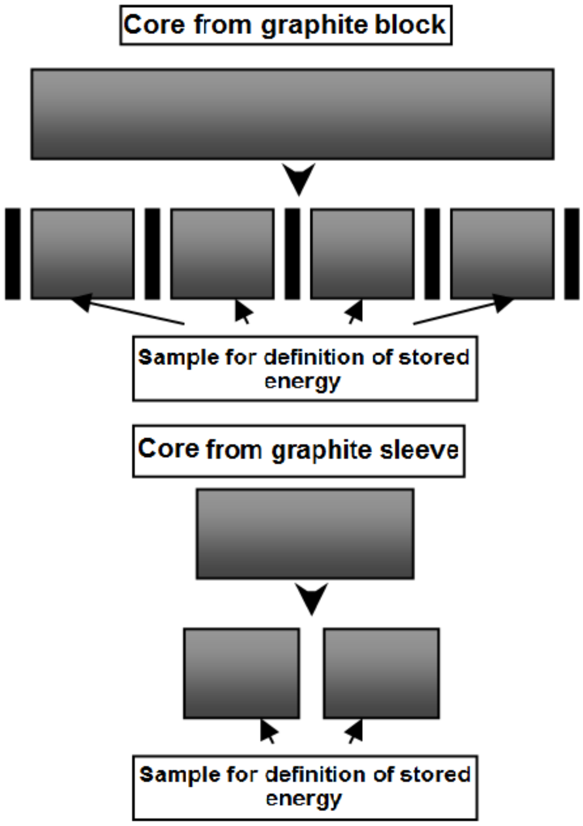

Figure 1. Scheme of manufacture of core samples that were extracted from the blocks and sleeves of shutdown reactor graphite stack.

The graphite block in the entire volume of the graphite stack contents stored energy is substantially lower than in the sleeves. Therefore, self-sustaining release of energy is impossible (figure 3, curves 2 and 3). This is because the block was irradiated at a higher temperature. It can only be forced annealing.

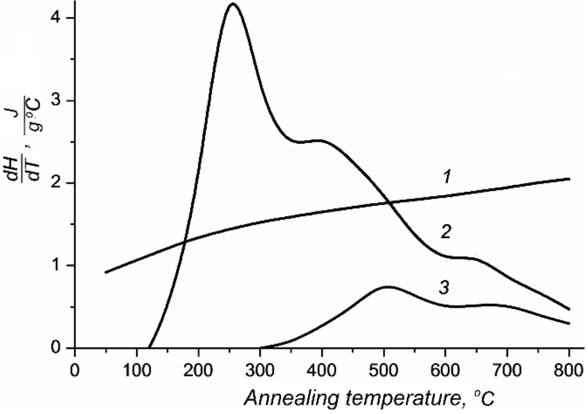

Figure 2. The spectrum of energy Wigner release in sleeve: 1 – the specific heat capacity of graphite; 2 – the intensity of energy Wigner release for sleeve from the top of the graphite stack; 3 – the intensity of energy Wigner release for sleeve from central part of the graphite stack.

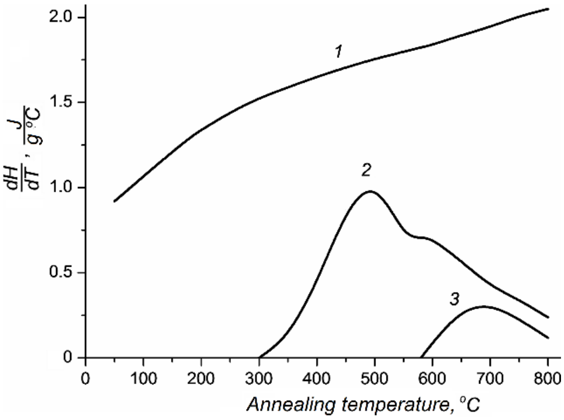

Figure 3. The spectrum of energy Wigner release in graphite block: 1 – the specific heat capacity of graphite; 2 – the intensity of energy Wigner release for sleeve from the top of the graphite stack; 3 – the intensity of energy Wigner release for sleeve from central part of the graphite stack.

It can only be forced annealing. Typical distribution curves of the integral value of the stored energy adjustment sleeves for the graphite stack and blocks shown in figure 4 and 5.

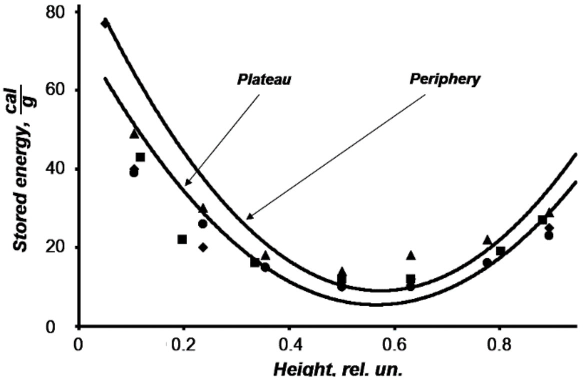

Figure 4. Distribution of the integral value of the stored energy adjustment graphite stack shutdown reactor for block.

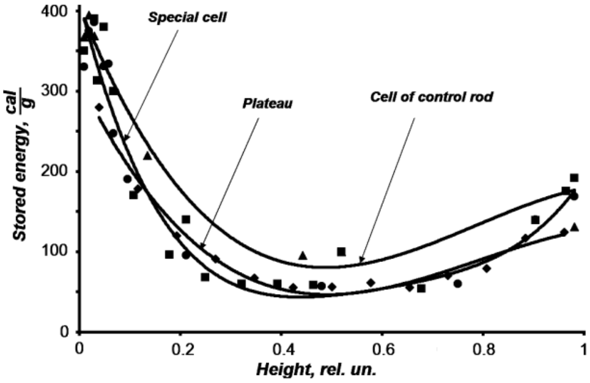

Figure 5. Distribution of the integral value of the stored energy adjustment graphite stack shutdown reactor for sleeve.

Compare the results of the experimental determination of the parameters of energy Wigner (figure 2 and 3) and its integral value (figure 4 and 5). It can be concluded that the most critical area in terms of a possible warming of graphite due to release the stored energy is the upper part of the graphite stack.

Analysis of the magnitude and dynamics of thermal effects for the most critical areas of the graphite stack is made by solving the non-stationary heat equation by methods described in [6]. The parameters characterizing the release of stored energy in the simulated processes are defined on the basis of its release spectra obtained experimentally (figure 2 and figure 3).

Calculations have shown that as a result of energy Wigner growth temperature of graphite to a value higher than the temperature at which it is possible burning of graphite (T_b~700°C), is observed only in the case adiabatic heating most «cold» graphite sleeves (figure 6). This requires the graphite heat up due to external sources of heat to a temperature $T_{initial}>150^{o}C$.

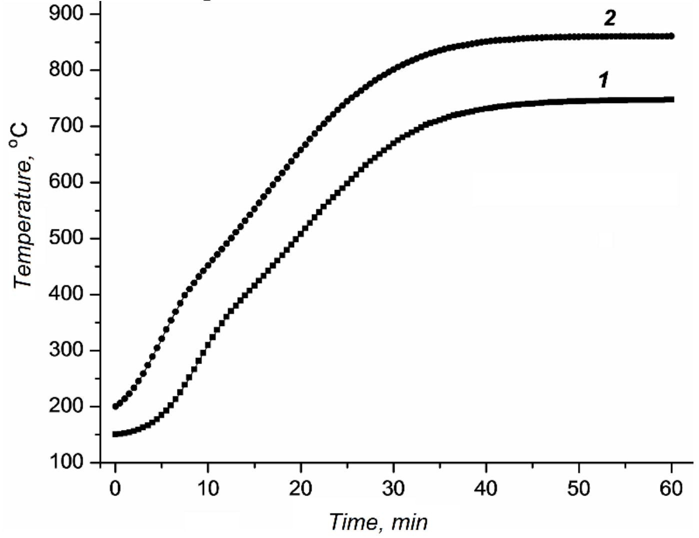

Figure 6. The dynamics of growth temperature of the "cold" graphite sleeve during release of the Wigner energy under adiabatic conditions: 1 – $T_{initial}=150^{o}C$; 2 – $T_{initial}=200^{o}C$.

Obviously, in practice, to arrange a complete absence of heat exchange of graphite sleeve with environment is practically impossible. In particular, the sleeves, located in the graphite stack have thermal contact with the graphite block. The content of the stored energy in the blocks is significantly lower than in the sleeves. Therefore, self-sustaining release of stored energy is impossible. Heat dissipation is also due to convective heat exchange with air on the surface of the sleeve hole. Therefore, in real conditions due to the thermal effects of energy Wigner will be lower.

When calculating the thermal effects in the graphite stack was used by a number of conservative assumptions. The problem was formulated for the equivalent radially symmetric cell (figure 7), of the infinite layers of graphite stack with a grid spacing of 200 mm.

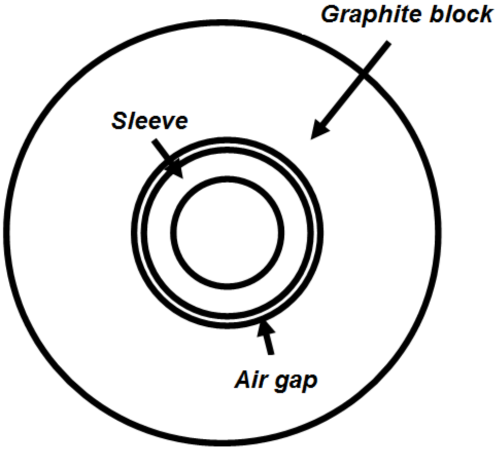

Figure 7. Scheme of equivalent radially symmetric cell graphite stack.

Stack has been preheated to a temperature $T_{initial}$ by external heat sources. This temperature is higher than the temperature of the beginning of a self-sustaining release of stored energy in the sleeves (~150°C). The value and parameters of energy Wigner release for sleeves were selected the most critical (the respective sleeves of the top of the stack). The heat sink through holes of cells graphite stack was set to zero. The air gap between the sleeve and the block has been set as conservatively assumed to be 0.5 mm (0.1–0.4 mm really). The result of the calculation of the dynamics of the temperature field for the equivalent cell graphite stack is shown in figure 8.

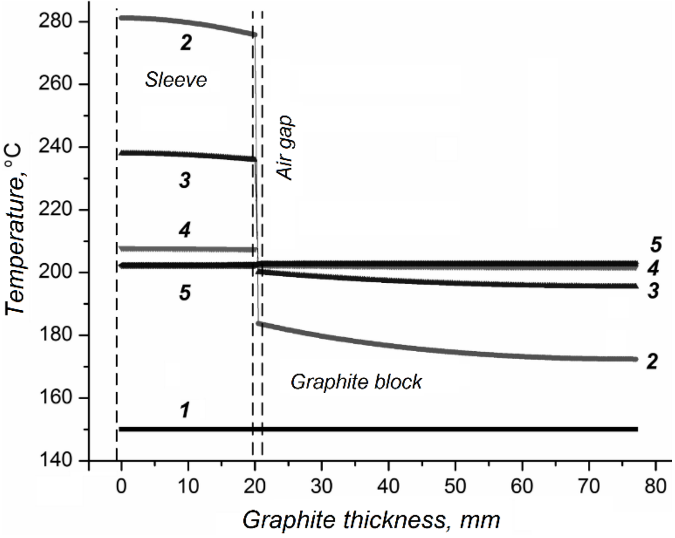

Figure 8. The dynamics of the temperature field in the cell of graphite stack during Wigner energy release: 1 – t = 0 min; 2 – t = 20 min; 3 – t = 40 min; 4 – t = 60 min; 5 – t = 80 min

The results show (figure 8), the maximum heat effect due to release of Wigner energy in the sleeves observed after about 20 minutes after the start of warm-up and amounts not exceeding ~130°C (respectively, the temperature of sleeve is no higher than 280°C). Heat effect the steady after 80 minutes for the entire system is about 50°C, and thus the temperature of all graphite (sleeves and blocks) is set equal to 200°C. The stored energy of the graphite block does not contribute to heat generation. Because steady-state temperature of the graphite block is about 200°C, and the temperature began to release Wigner energy in the graphite blocks with the lowest temperature of the radiation is $T_{initial}$ 250–280°C. Moreover, even in case of achievement block temperature $T_{initial}$ above, heat effect will be negligible. Because self-sustaining release of stored energy in graphite blocks is impossible. It will wear quickly of damped character.

3. Conclusion

Thus, release of stored energy for the most critical areas of the graphite stack of shut-down reactor even in several conservative assumptions will not result in heating of the graphite to a temperature exceeding T_b~700°C. Thus, excess temperature graphite to possible ignition of a substantial amount - at least 420°C at the moment of maximum heat effect due to release of Wigner energy.

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