A Heat Conductive Problem of the Wigner Energy Release in the Irradiated Graphite Block

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Labile Wigner energy, known as the discomposition effect which comes from the displacement of atoms in a solid, especially a graphite carbon in our respects, caused by neutron radiation, has been focused on one of major considerations for nuclear graphite waste management. Because of the unstable behavior of the irradiated graphite including an emissive nuclides and relating radioactive contents as well as a thermal shock at a sudden heat exposure through the irradiated graphite body, the dissipation of the Wigner energy in a controlled manner has to be studied.

In our previous studies, the kinetics of a Wigner energy release have shown very complicated forms such that the overall reaction rates has been considered as first-order rate equations with varialbe activation energy contents like the following general equation[1].

$$\frac{dS(E,t)}{dt} = -\nu \cdot S(E,t) e^{-\frac{E}{kT}} \tag{1}$$

where S is the energy released or the ramaining energy, t is the time, E is the activation energy which is a variable function to the system temperature, ν is a constant frequency factor, k is the Boltzmann constant, and T is the temperature. This means that the Wigner energy release behavior in the graphite carbon matrix rearrangement during annealing might be considered as an consecutive irreversible reaction ($A \rightarrow B \rightarrow C \rightarrow R \rightarrow S \rightarrow \ldots$). A typical values of the variants in Wigner energy release equation of the irradiated graphite from KRR-2 have been shown the following results: $E = (33.7 - 1.83 \log a)\, T \times 10^{-4} - 0.037$ [eV], $\nu = 4.66 \times 10^{14}$ [-], $a = 10$ [℃/min].

In the following study, an analytical thermal neutron diffusion model has been used to evaluate the characteristics of the irradiated graphite due to the accumulated neutron energy doses in thermal column graphite[2]. The equation representing the conservation of the neutron, coming from Fick's law ($J_x = -D\frac{d\phi}{dx}$ in x-coordinate) is shown as following form.

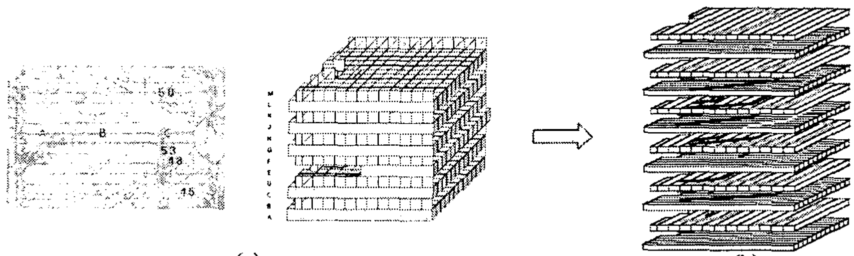
$$D\nabla^2\phi - \sum_a \phi + F = \frac{\partial n}{\partial t} \tag{2}$$

where $D\nabla^2\phi$ is the neutron leakage per unit volume per second, $-\sum_a \phi$ is a number of neutrons absorbed in unit volume per second, F is the source strength(= the rate of neutron density in time), and $-\frac{\partial n}{\partial t}$ is the variation rate of the neutron density in unit volume. When there is no source, $F=0$: Assuming an infinite source in xy- plane, the general solution of Eq. (2) becomes

$$\phi(z) = A\exp(-Kz) + B\exp(Kz), \quad K^2 = \sum_a / D \tag{3}$$

where constants A and B are determined by the boundary conditions, as . $B=0$ and $A = \frac{1}{2}KD$.

As a result of a neutron diffusion in the graphite in the thermal column of the KRR-2 research reactor, the Wigner energy and various nuclide contents show a feature of the distribution contour map along with a dependency on the distance from reactor core. Therefore, the applied energy release model is supposed to be the function of the distance from the reactor core (refer to Fig. 1).



(a) (b)

Fig. 1. (a) Schematic drawing of graphite stocks in thermal column and (b) an imaginary expanded graphite structure.

In an investigation for an annealing characteristics of the irradiated graphite block to evaluate the realistic scale-up problems, the temperature difference profile outbreaks - that is between an inside and an outside temperatures of the graphite lump during annealing - of an irradiated fresh-graphite and an annealed-graphite were revealed in a some degree of transient state temperature gradient that depends on the depth in the irradiated graphite block[3], but there was no hot spot generation in KRR-2. Nonetheless, since geometric models for Wigner energy content maps can help to calculate the overall rate of release of Wigner energy in conduction problems, it will be necessary to estimate a kind of transient heat release model for an adiabatic annealing process using the following model equations[4]. Basic heat conduction problem (rectangular bar):

$$\rho C_p \frac{\partial T}{\partial \tau} + \chi \nabla^2 T = Q, \quad \nabla^2 = \frac{\partial}{\partial x^2} + \frac{\partial}{\partial y^2} + \frac{\partial}{\partial z^2} \qquad (4)$$

where ρ is the density of graphite, C_p is the specific heat capacity of the graphite, T is temperature distribution in conduction, τ is time, χ is thermal conductivity of graphite and Q is heat generation or total heat flux. Boundary & initial conditions:

$$\chi \frac{\partial T}{\partial x} + hT_{x=x_0} = 0. \qquad (5)$$

References

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