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Thermal Instability in Solid under Irradiation

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Abstract : Construction materials for nuclear facilities are operated under extreme thermal and radiation conditions. First of all, they are nuclear fuel, fuel assemblies, and reactor vessel. It places high demands on the control of their state, stability of their state, and their operating conditions. An irradiated material is a typical example of an open non-equilibrium system with nonlinear feedbacks between its elements. Fluxes of energy, matter and entropy maintain states which are far away from thermal equilibrium. The links that arise under irradiation are inherently nonlinear. They form the mechanisms of feed-backs that can lead to instability. Due to this instability the temperature of the sample, heat transfer, and the defect density can exceed the steady-state value in several times. This can lead to change of typical operation and an accident. Therefore, it is necessary to take into account the thermal instability to avoid the emergency situation. The point is that non-thermal energy can be accumulated in materials because irradiation produces defects (first of all these are vacancies and interstitial atoms), which are metastable. The stored energy is about energy of defect formation. Thus, an annealing of the defects is accompanied by releasing of non-thermal stored energy into thermal one. Temperature of the material grows. Increase of temperature results in acceleration of defect annealing. Density of the defects drops and temperature grows more and more quickly. The positive feed-back is formed and self-reinforcing annealing of radiation defects develops. To describe these phenomena a theoretical approach to thermal instability is developed via formalism of complex systems. We consider system of nonlinear differential equations for different components of microstructure and temperature. The qualitative analysis of this non-linear dynamical system is carried out. Conditions for development of instability have been obtained. Points of bifurcation have been found. Convenient way to represent obtained results is a set of phase portraits. It has been shown that different regimes of material state under irradiation can develop. Thus degradation of irradiated material can be limited by means of choice appropriate kind of evolution of materials under irradiation.

Keywords : irradiation, material, non-equilibrium state, nonlinear feed-back, thermal instability
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