Influence of Dose Rate and Temperature on Radiation-Induced Segregation

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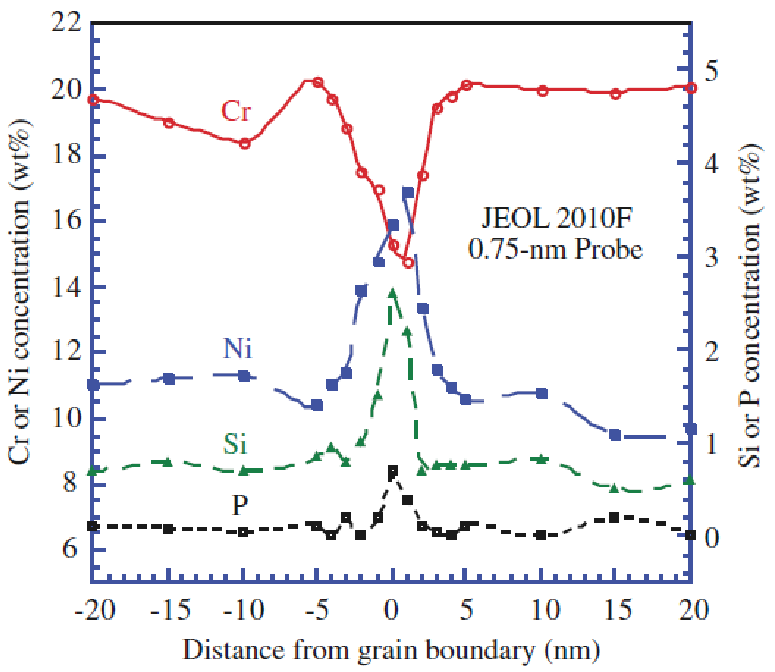
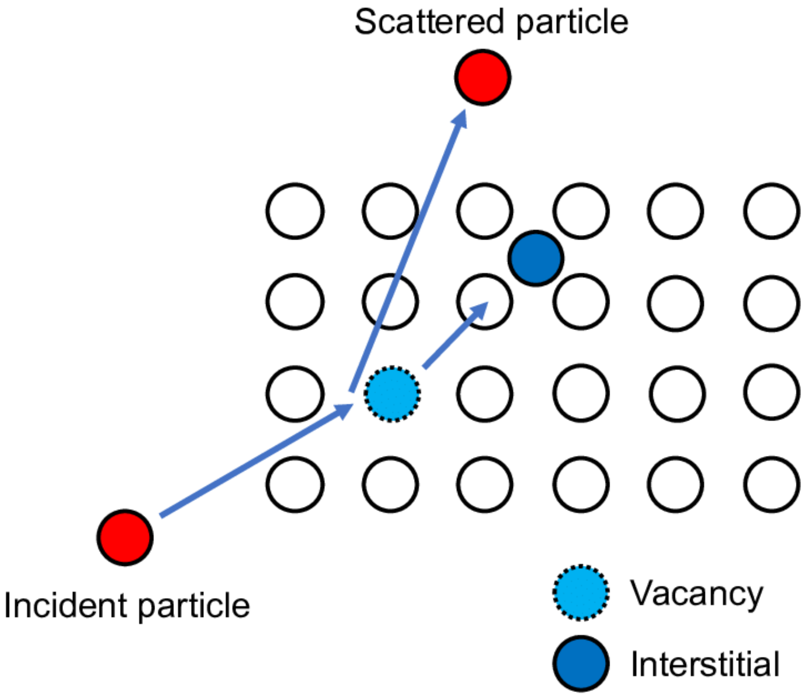
Motivation

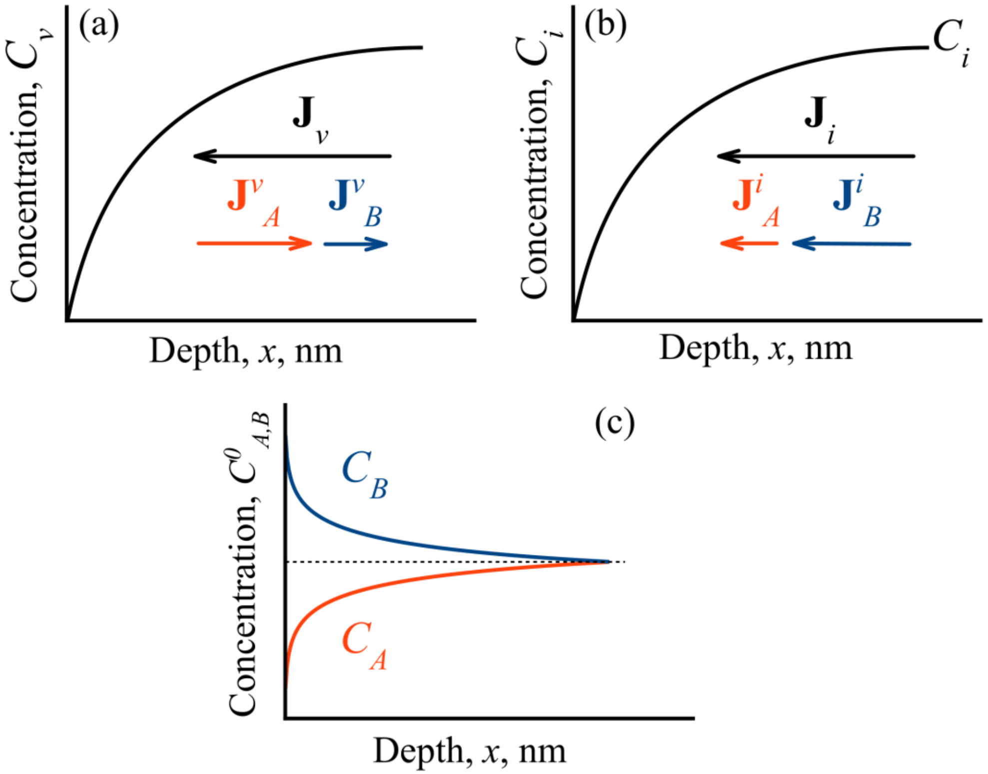
- **Radiation-induced segregation** (RIS) is spatial redistribution atoms various types metal alloy under irradiation.
- Induced **enrichment** or **depletion** of main, solute and impurity **components of alloy near defect sinks (grain boundary, surface)**
- Consequences of RIS are the deterioration of :
  - mechanical strength
  - corrosion resistance of the material
  - acceleration of the formation of precipitation of a new phase
  - etc.
- The **precipitation of a new phase inhibits the movement of dislocations**, and the plastic metal alloy becomes harder and can even become embrittle through the formation and growth of cracks.
- **Important in particular for nuclear reactors.**



Concentration profiles of Cr, Ni, Si and P at the grain boundary of a 300 series stainless steel irradiated in a light water reactor core to several dpa at T=300°C.



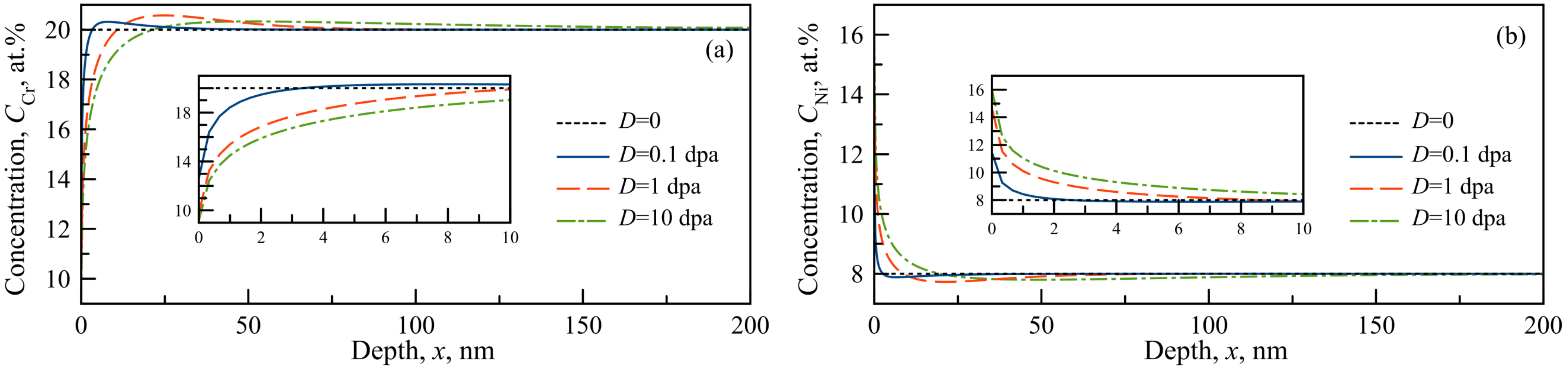
<u>Frenkel pair: vacancy and interstitial.</u>



<u>Schematic representation of the RIS in a two-component alloy 50%A–50%B.</u>

C_v – concentration of vacancies,
C_v – concentration of interstitials,
$\mathbf{J}_v$ – flow of vacancies,
$\mathbf{J}_i$ – flow of interstitials,
$\mathbf{J}_{A,B}$ – flow of component A and B.

Cr and Ni Concentration Profiles at Different Doses

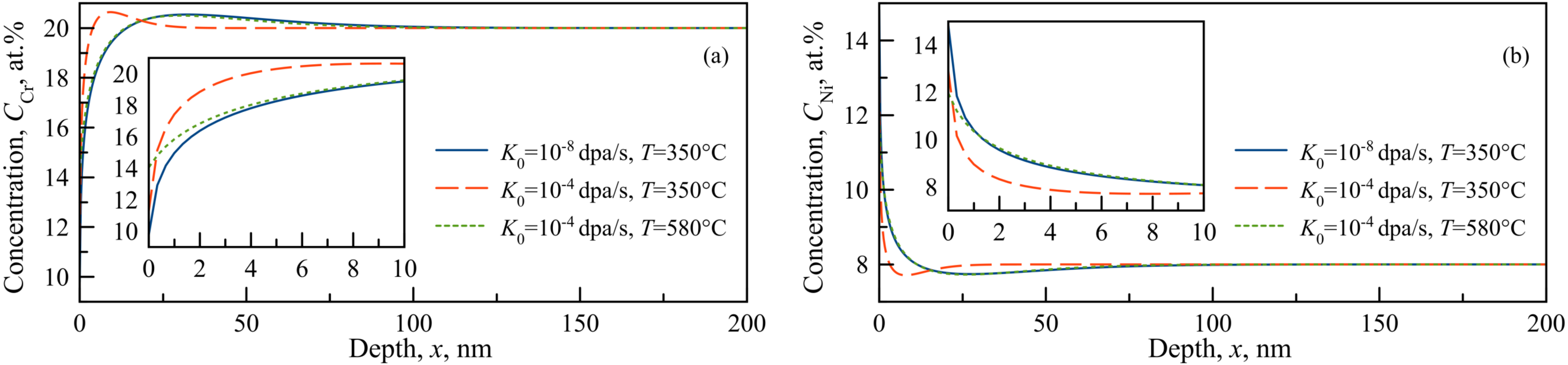


Concentration profiles of Cr and Ni in the Fe-20Cr-8Ni at different doses

($K_0=10^{-6}$ dpa/s, T=350°C).

Cr and Ni Concentration Profiles

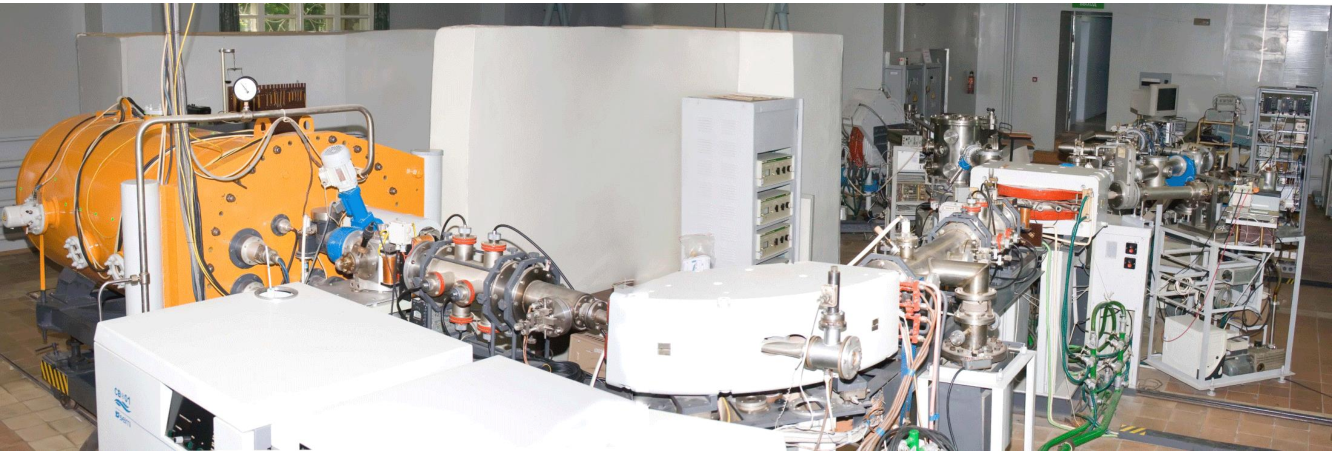
- **Conditions close to the reactor:** $K_0=10^{-8}$ dpa/s, T=350°C
- **Conditions in model experiments:** $K_0=10^{-4}$ dpa/s, T-?



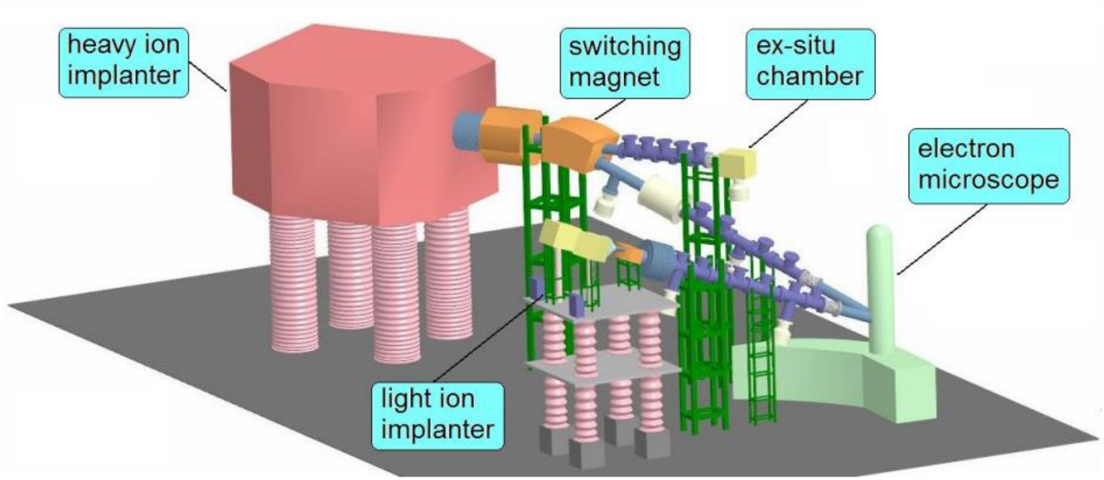
Concentration profiles of Cr and Ni in the Fe-20Cr-8Ni alloy under irradiation.
Calculations were performed at dose D=10 dpa.

Perspectives

Comparison with experimental data obtained at the leading **triple-beam facility** in the Institute of Applied Physics of the National Academy of Sciences of Ukraine, Sumy.

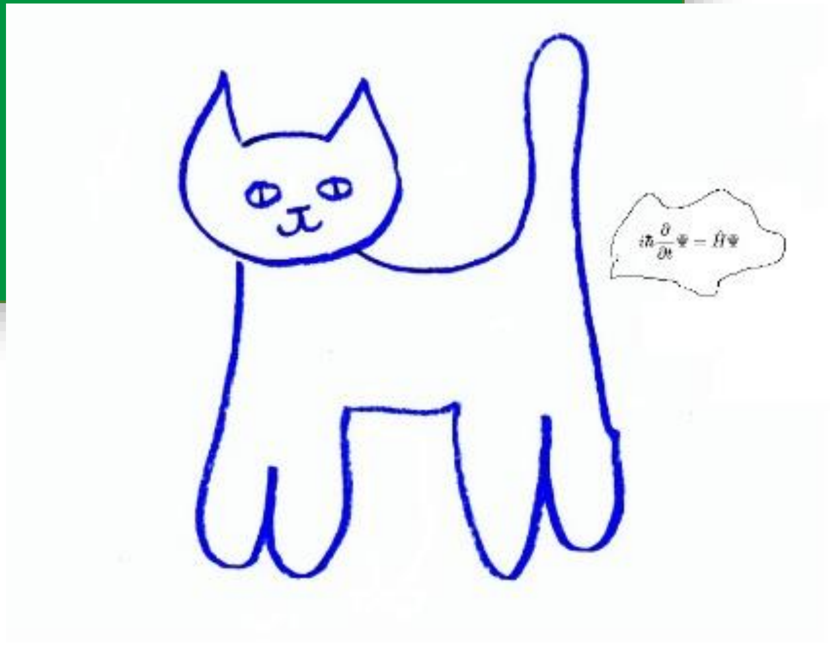


Analytical accelerator complex of the Institute of Applied Physics of the National Academy of Sciences of Ukraine, Sumy.
http://iap.sumy.org/



Layout of Institute of Applied Physics of the National Academy of Sciences of Ukraine triple-beam facility.

Thank you for your attention!



System of RIS equations

$$\begin{cases} \dfrac{\partial C_k}{\partial t} = -\nabla \mathbf{J}_k \qquad (k = \mathrm{Fe}, \mathrm{Cr}, \mathrm{Ni}), \\ \dfrac{\partial C_v}{\partial t} = -\nabla \mathbf{J}_v + K_0 - R_{iv} C_v C_i - k_v^2 D_v C_v, \\ \dfrac{\partial C_i}{\partial t} = -\nabla \mathbf{J}_i + K_0 - R_{iv} C_v C_i - k_i^2 D_i C_i. \end{cases} \tag{1}$$

$$\mathbf{J}_k = -\left(\sum_{d=v,i} d_{k,d} C_d \right) \nabla C_k + C_k \left(d_{k,v} \nabla C_v - d_{k,i} \nabla C_i \right), \tag{2}$$

$$\mathbf{J}_v = -\sum_{k=\mathrm{Fe},\mathrm{Cr},\mathrm{Ni}} d_{k,v} C_k \nabla C_v + \alpha C_v \left(\sum_{k=\mathrm{Fe},\mathrm{Cr},\mathrm{Ni}} d_{k,v} \nabla C_k \right), \tag{3}$$

$$\mathbf{J}_i = -\sum_{k=\mathrm{Fe},\mathrm{Cr},\mathrm{Ni}} d_{k,i} C_k \nabla C_i - \alpha C_i \left(\sum_{k=\mathrm{Fe},\mathrm{Cr},\mathrm{Ni}} d_{k,i} \nabla C_k \right). \tag{4}$$

Initial conditions

$$C_k(x,t)\big|_{t=0} = C_k^0, \tag{5}$$

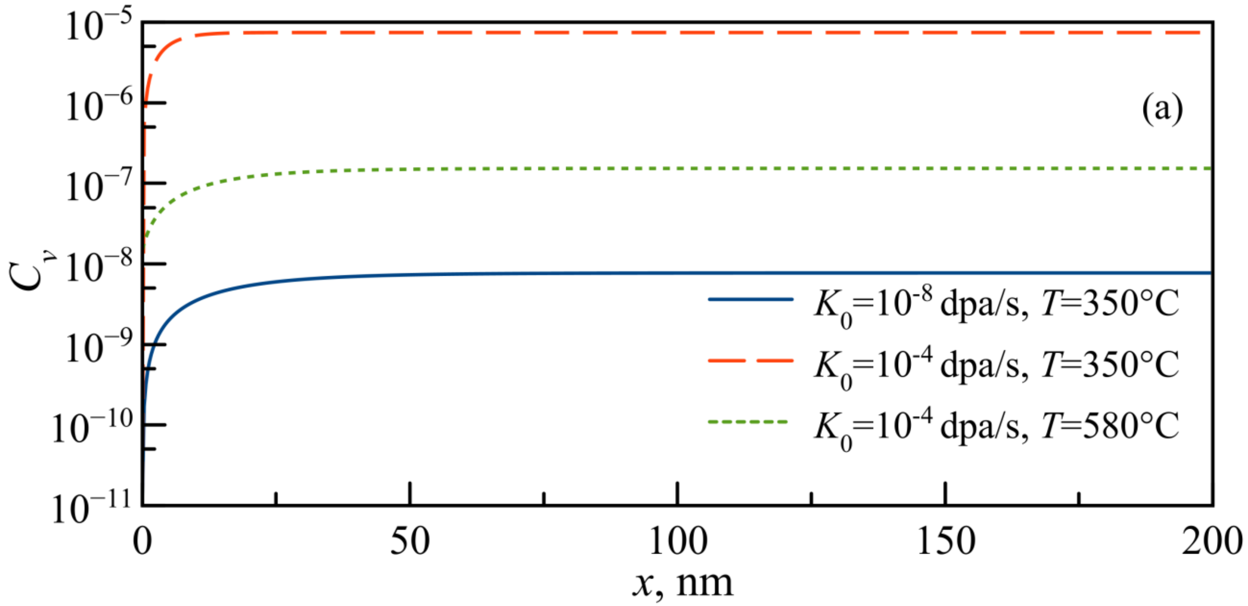
$$C_v(x,t)\big|_{t=0} = C_v^{eq}, \qquad C_i(x,t)\big|_{t=0} = C_i^{eq}, \tag{6}$$

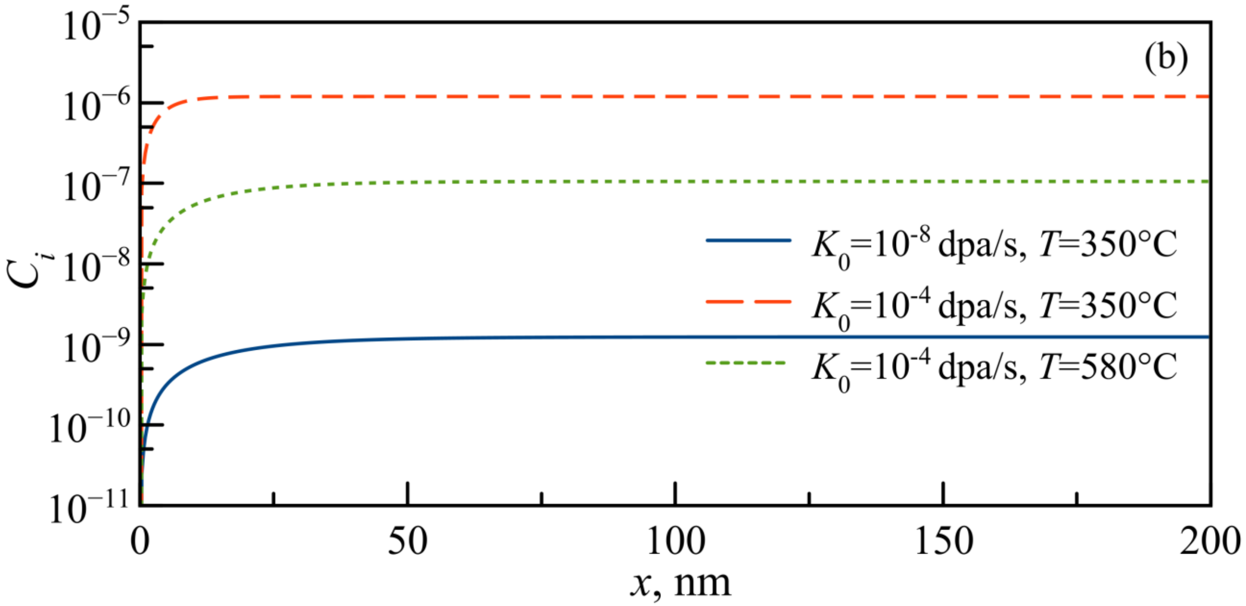
Boundary conditions

$$\left.\frac{\partial C_k(x,t)}{\partial x}\right|_{x=\ell/2} = \left.\frac{\partial C_v(x,t)}{\partial x}\right|_{x=\ell/2} = \left.\frac{\partial C_i(x,t)}{\partial x}\right|_{x=\ell/2} = 0, \tag{7}$$

$$\int_0^{\ell/2} C_k(x,t)\,dx = \frac{\ell}{2} C_k(x,t)\big|_{t=0}, \tag{8}$$

$$C_v(x,t)\big|_{x\to+0} = C_v^{eq}, \qquad C_i(x,t)\big|_{x\to+0} = C_i^{eq}. \tag{9}$$





Concentration profiles of point defects in the Fe-20Cr-8Ni alloy under irradiation.
Calculations were performed at dose *D*=10 dpa.